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A collaboration network model proposal to drive the development of Industry 4.0

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ABSTRACT
Manufacturing industry is facing the emerging of Industry 4.0 through the implementation of various IT. Mexican SMEs have begun to face the challenges that this transformation implies. As a first stage in conducting a research on collaboration strategy as a drive to development of Industry 4.0 in automotive cluster in Mexico, this paper aims to propose a collaboration network model as an explorative tool to represent and describe the structure of the cluster relationships. The model will serve as a basis for a later analysis on the role of each enterprise participating on diverse IT implementation and uses in the Industry 4.0.

KEYWORDS: Industry 4.0 cluster, Information technologies, collaboration, networks.

INTRODUCTION

Nowadays companies faced globalization, intensified competitions, dynamic markets, dynamic demands, shortened product life cycles, forcing manufacturing industries to be more agile and efficient. The emerging of Industry 4.0 allows enterprises to implement a combination of physical operations and information technology which enables to develop a flexible production and logistic systems, planning processes and add more values to their products (Hamzeh, Zhong & Xu, 2018).

Successful adoption of Industry 4.0 requires high level of knowledge regarding digitization within manufacturing industry. Industry 4.0 is emerging in Mexico so small and medium-sized enterprises (SMEs) just begin to face the challenges that its implementation poses. SMEs have some specific managerial features such as, lack of enough knowledge and expertise, local management, experience and shortage of available resources, short-term strategy and lack of methods and procedures. Therefore, to their possible success in the transformation into Industry 4.0, SMEs need to adopt diverse strategies based on collaboration.

In order to understand how companies behave in the automotive cluster located in the state of San Luis Potosi, México in their pursue to begin the Industry 4.0 implementation process, in the first stage of the research, this paper aims to propose a network collaboration model as an explorative tool to represent and describe the structure of the cluster relationships as a basis for the later analysis of the role of each enterprises associated with the diverse IT implementation and uses in the Industry 4.0.

An introduction of Industry 4.0 is provided in section one. Section two describes collaboration theory. The following section gives some insight into the automotive cluster in San Luis Potosi, Mexico. Finally, a collaboration network model is proposed.

LITERATURE REVIEW

Industry 4.0

The concept of Industry 4.0 was started in Germany in 2011 and actually its development has impacted the whole industries changing the way of designing, manufacturing, delivery and payment methods (Młody & Weinert, 2020). Industry 4.0 represents the trend of automation technologies in de manufacturing industry and it uses three main IT concepts for production and automation: digitization, networking and data analysis (Hamzeh, Zhong & Xu, 2018). Its development and technological advances provide a variety of solutions to the needs of information in manufacturing industry (Xu, Xu & Li, 2018). Nowadays enterprises all around the world have explored the benefits of digitizing their horizontal and vertical chains and adopted Industry 4.0 in their processes (Xu, Xu & Li, 2018).

Industry 4.0 is defined as a set of improvements related to processes, products and services through decentralized decision making and based on real time data acquisition, which aims to create smart factories by facing challenges in current manufacturing systems (Brodeur, Pellerin & Deschamps, 2022; Hamzeh, Zhong & Xu, 2018).

Industry 4.0 is a concept related to the use of automation in industry basically using a wide different kind on IT in order to digitalize the production process, mixing the digital world and the physical world. Industry 4.0 involves the use of robotics and automated machinery, artificial intelligence, information systems, cloud computing, 3d printing, Internet of things (IoT), industrial internet of things, internet of services, cybersecurity solutions, big data and analytics, mobile services, social media, simulation, cyber-physical systems, machine-to-machine communication (M2M), vertical/horizontal software integration, additive manufacturing, augmented reality, virtual reality, digital twin, neural networks, and mass customization (Adamik & Nowicki, 2020; Mouef, et al., 2020; Niemczyk & Trzaska, 2020; Xu, Xu & Li, 2018).

All of those technologies work interconnected within and outside of the organizations creating a “network of holistically interpenetrating spaces” (Moeuf, et al., 2018). Based on the interconnexion through internet, it is possible to control machines, productions process and data exchange. The implementation of Industry 4.0 increases the overall level of industrialization, informatization and manufacturing digitization to achieve greater efficiency, competency and competitiveness (Xu, Xu & Li, 2018).

However, Industry 4.0 encompasses many complex components, and has an extensive application in numerous industrial sectors, which implies organizational changes in strategies, planning, investment involving new technology, and processes implementation (Brodeur, Pellerin & Deschamps, 2022). The transformation into Industry 4.0 can affect manufacturing companies because of the transformation business models and the production value chain through connecting embedded systems and smart production processes (Hamzeh, Zhong & Xu, 2018).

Organizations need to be able to effectively implement and use new concepts and methods to support the use of new technology, they also have to acquire appropriate strategies to develop the business and to compete in this new environment, to promote new skills for employees and managers, to take advantages of their relationships for the purpose of build competitive advantages associated with Industry 4.0 (Adamik & Nowicki, 2020).

According to Adamik and Nowicki (2020), seven strategic factors are needed in Industry 4.0: development of management competitions and support for young talents, creating and implementing effective training and incentive systems, development of issues related to Industry 4.0 such as attitudes among the management and the staff, implement tools for effective management in the reality of Industry 4.0, conducting effective network cooperation within the organization and with partners from outside of it, developing the skills to design, obtain and implement new technologies and taking up actions related to digitization.

The impact of Industry 4.0 in organizations reflects in different areas, in particular generates changes within the existing value chains transforming the traditional supply chain by using real-time communications of individual elements of the value chain including dynamic fulfillment, synchronized planning, connected customer, smart factory, intelligent supply and digital development to become a digital supply network (Niemczyk & Trzaska, 2020). There are significant benefits of Industry 4.0 for the enterprises such as reduction in manufacturing costs, increasing agility in operations, improving service offer to customer, developing a new business model, achieving higher product innovation (Hamzeh, Zhong & Xu, 2018). The transformation to a smart manufacturing and cognitive manufacturing offers also new opportunities to manufacturing enterprises to analyze and use design, production, sourcing and invention data to analyze them in real-time from multiples machines, processes and systems. But companies have also to consider some challenges and obstacles related to Industry 4.0 implementation, for example a lack of internal digital culture and training, insufficient talent for implementing new business models that allow them to take advantage of the digital opportunities, a lack of additional investment fund, availability of equipment and software (Hamzeh, Zhong & Xu, 2018). Niemczyk and Trzaska, (2020) point out the importance of preparation of companies for Industry 4.0 because they have to deal with a dynamic growth of industry sectors, they need to develop knowledge and competence to face Industry 4.0 and they need to economic resources and government support to enhance Industry 4.0 solutions. Enterprises face the urgency to enter to the Industry 4.0 and create strategies to take advantages of it as fast as possible, therefore they have also to compete each but at the same time they might have to collaborate with competitors. The enterprises transformation into Industry 4.0 represents an innovation process, which involves actors with different complementary resources, knowledge and competencies and different economic motivations. Even though these processes could be difficult, an alternative way to face it is using local interactions between actors in a collaboration network (Kuehnle & Wagenhaus, 2007).

For example, the automotive industry “employed some application from the Industry 4.0 by using cognitive technologies to optimize the configuration of its production line to balance the workload between stations, use labor more efficiently, and increase the rate of production while also adhering to its design for manufacturing (DFM) practices.“ (Xu, Xu & Li, 2018:2949). This industry has also “used cognitive planning tools to optimize its use of available plant capacity to bring a new model of cars into production.” (Xu, Xu & Li, 2018:2949).

Collaboration

As a consequence of these innovations the management of organizations face new challenges due to the increasing vertical and horizontal integration of value chain, which requires also a wide collaboration of enterprises based on cooperation and coopetition (Brandenburger & Nalebuff, 1997; Lewicka & Zakrzewska-Bielawska, 2020).

Interfirm collaboration in dyads and networks allows firms to achieve something in common that otherwise would not achieve (Axelrod 1984; Hamel, Doz & Prahalad 1989; Harrigan, 1988; Ohmae 1989). Gray (1989:5) considers collaboration as “a process through which parties who see different aspects of a problem can constructively explore their differences and search solutions that go beyond their own limited vision of what is possible”. Some of the reason for establishing collaboration exposed by organizations relate to access to new technologies or new market, to fortify their position in the market, to achieve economies of scale, risk sharing, access to knowledge, complement skills, specialize in core businesses, to outsource value-chain stage (Powell, 1987). “Cooperation is a kind of collaboration with non-competitive partners, while coopetition is a kind of collaboration with competitive partners by which simultaneous cooperation and competition between enterprises are implied” (Lewicka & Zakrzewska-Bielawska, 2020:156).

In general, the need for cooperation and coopetition is explained by rapid changes in technology, the competitive environment, globalization, shortening life cycles of technologies and products (Lewicka & Zakrzewska-Bielawska, 2020; Ring & Van de Ven, 1992).
One of the most important factors for collaboration, cooperation and coopetition is trust in order to avoid opportunistic behavior (Lewicka & Zakrzewska-Bielawska, 2020; Simon 1947). Participants must trust in other participants to reduce conflict and risk and should work for the common interest, not the individual. It is not completely or blind trust but a minimum level of trust is required for organization to collaborate (Lewicka & Zakrzewska-Bielawska, 2020; Porras, Clegg & Crawford 2004).

Another key resource for enterprises is relations, used as the the basis for its market performance, reducing uncertainty and stabilizing its market position. As a member of the network enterprises be able to access to technology information, faster learning, risk sharing, and cost-sharing. Integration of own resources with partners’ resources makes them more unique, which makes it possible, among other things, to generate a greater relational rent (Lewicka & Zakrzewska-Bielawska, 2020).

It is possible to find different forms of collaboration such as strategic alliances (Harrigan, 1987), joint ventures (Harrigan, 1987), networks (Alter & Hage, 1993; Ebers, 1997; Ebers & Grandori, 1997; Ebers & Jarillo, 1997; Jarillo, 1988; Miles & Snow, 1986; Powell, 1987, 1991; Snow, Miles & Coleman, 1992; Thorelli, 1986), cooperatives (Cornforth et al., 1988) and clusters (Porter, 1998).

According to Porter (1998:78), “clusters are geographic concentrations of interconnected companies and institutions in a particular field. Clusters encompass an array of linked industries and other entities important to competition.” In this perspective, geographic location is an important element in defining clusters. Porter considers that establishing clusters generates knowledge and could generate innovations for creating a competitive advantage, although some discontinuities can also emerge between participants due to the different levels of development, resources and capacities are different in each case.

Roelandt y Hertog (1999) consider that clusters focus on linkages and interdependencies between organizations in a value chain. Organizations in clusters have complementarities in horizontal or vertical activities, both needed for innovation. Mayer (2005: 41) understands industry clusters as a “group of firms that, a through their interactions with each other and with their customers and suppliers, develop innovative, cutting-edge products and processes that distinguish them in the market place from firms in the same industry found in other places”.

Clusters allow SMEs to take advantage of the name or activities of larger organizations that otherwise could not make allowing them to have a better market image, to have access to better market opportunities and better contracts also; it allows them to take advantage of the synergies created by participants in clusters. Clusters may include competitors, suppliers, government institutions, universities, research centers, trade associations, etc.

Various studies in the literature review the inter-enterprise collaboration for manufacturing industry in the context of IT use and Industry 4.0. For example, Brodeur, Pellerin and Deschamps (2022) propose a model of collaborative approach for digital transformation for manufacturing SMEs toward Industry 4.0. Mouef, et al. (2020), suggest that collaborative projects will be effective for manufacturing small and medium-sized enterprises Industry 4.0 transformation, indicated that training and management role are important for the success of this transformation. Some authors point out the importance of IT collaboration relationships for the supply chain management, for example a cooperative behavior and IT use could enhance a supply chain integration and performance through collaborative practices such as joint improvement and planning information (Van der Vaart, et al., 2012); the implementation of IT analytic capability enhances demand chain collaboration (Iyer, 2011; Hamzeh, Zhong & Xu, 2018). Camarinha-Matos, et al. (2019) analyze the role of collaborative networks in digital business transformation towards Industry 4.0, which implementation relies on new technology, new organizational forms, mechanisms, and processes with a collaborative nature.

There are several examples of networks for the creation of knowledge and its diffusion in the field of Industry 4.0: in France (Alliance pour l'Industrie du Futur), Germany (Plattform Industrie 4.0), Netherlands (Smart Industry), Sweden (Produktion 2030), Italy (Intelligent Factory Cluster (CFI), Spain (Connected Industry 4.0), United Kingdom (HVM Catapult (HVMC)), Czech Republic (Prumysl 4.0), Poland (Platform for Industry 4.0) (Niemczyk & Trzaska, 2020).

MODEL

The automotive industry cluster in San Luis Potosi, Mexico.

Located in the center East of Mexico, the state of San Luis Potosi together with the states of Aguascalientes, Guanajuato and Queretaro forms part of the region known as "El Bajio", which, according to John Tutino (2016) [Professor at School of Foreign Service Department of History, University of Georgetown], is one of the most dynamic regions worldwide. Some of the reasons include: best aeronautical cluster in Latin America; leading automotive exporter in Latin America, 4th. worldwide, more that 10 assemblers and 800 suppliers; foreign direct investment from 80 countries; pharmaceutical leader in Latin America; more than 100 research centers, 200 universities and leader in industry 4.0; more than 146 specialized industrial parks, largest industrial corridor in Latin America; wine corridor, 76 vineyards.

In 2016 the World Bank ranked the city of San Luis Potosí as the eighth-best city to do business throughout the whole of Mexico; in 2015 KPMG nominated it as the fourth-best city for investment in the country. The area has become a hub for Mexico's manufacturing industry, and in particular a center for automotive manufacturing. The state receives an important amount of FDI. Exports have witnessed consistent growth since early 2009. Where there are different industries located along the state like food and home appliances, the automotive industry has seen a boom with the arrival of various assembly plants including GM in 2006 and BMW in 2016 (OBG, 2017).

According to official data, in the state of San Luis Potosi, there are 6 industrial parks registered, three clusters (automotive, logistics and medical), more than 229 automotive companies which represent more than 25% of manufacturing state GDP employing 82,000 persons (OBG, 2017).

The automotive cluster was formed in 2015 in a triple helix scheme where public sector, industry and academia participate. Currently it is conformed in total by 42 enterprises including GM, BMW and 40 automotive companies, universities and research centers (CASLP, 2022).

The companies of the automotive cluster are embedded in networks of actors such as, producers, suppliers, research centers, governmental organizations that have local interactions between them. As part of the cluster it is assumed that cooperation and coordination of activities between buyers and suppliers include information sharing, joint planning, joint demand management, joint inventory management, and sharing of goals and objectives. Some of the interaction could be collaborative agreements, cooperation agreements or coopetition relationships.

Some of the enterprises participating in the cluster include: General Motors, BMW, Cummins motors, BrogWarner, ABB, Bosh, Goodyear, and medium and small automotive enterprises (CASLP, 2022).

One the automotive companies established in the cluster is BMW, which was formally opened in June 2019 producing the BMW Series 3. In August 2020 BMW produced the first 330e hybrid connectable at the time it celebrated the production of the unit 50,000 assembled in the plant, unitis that are exported to 36 countries. BMW uses Industry 4.0 in its production. According to official data, this is the most innovating plant of the group. In May 2021 the group officially announced the production of the Series 2 Coupé in San Luis Potosi starting summer 2021. 90% of the production process is automatized, using 500 robots. The plant makes use of the Smart Maintenance Assistant software assisting in the planning for equipment maintenance (BMW, 2022).

BMW as global company that uses Industry 4.0 has the possibility to offer excellent conditions for innovation by agreements on collaborative interrelated innovation processes, with suppliers and partners linked tightly together by information flows to facilitate integration of knowledge, design, production and overall logistics (BMW, 2022).

Mouef, et al. (2020) point out that Industry 4.0 requires a project leader to have multidisciplinary knowledge, openness and curiosity, and a good understanding of the operational professions in order to make a link between technological solutions and industrial needs. Based on these ideas, our hypothesis is that through a collaboration network strategy, BMW will be able to enhance the transformation to the Industry 4.0 in the SMEs participating in the cluster.

To probe that collaboration strategy could be as a drive to the development of Industry 4.0 in automotive cluster in SLP, in the first stage of the research we propose a collaboration network model to represent and describe the structure of the cluster relationships as an explorative tool that will be used to analyze the role of each enterprise associated with IT implementation and uses in the Industry 4.0.

According to Camarinha-Matos, Afsarmanesh, and Ollus (2008) a network is defined as a diversity of autonomous members, geographically distributed and heterogenous in operational terms and objectives, which collaborate to achieve common or compatible goals. The members' network can achieve goals that would not be possible o more expensive if the organizations work by themselves. It is possible to find in the literature different generic topology which involves most of the problems associated with the establishment collaborative processes in the SMEs, but Andres and Poler (2016) propose two: hierarchical network (HN) and not hierarchical network (NHN).

Because the characteristics of the automotive cluster the members may work in collaborative process, which involves multiple partners that play different role. The processes are defined based on business interactions agreements, and diverse organizations could collaboratively participate in the processes (Andres & Poler, 2016). There are multiple collaborative processes based on the decision making level to which they belong: strategic, tactical and operational (Andres & Poler, 2016). Andres and Poler (2016) also defined a hierarchical network (HN) which have an “X” structure with a central node that separates the network in two, in one side are the suppliers and in the other side the customers, usually the decision making is done in a centralized way, having a single decision unit within the network determined by the minority of dominant /central firms. This is similar to the proposal of internal network made by Miles and Snow (1994).

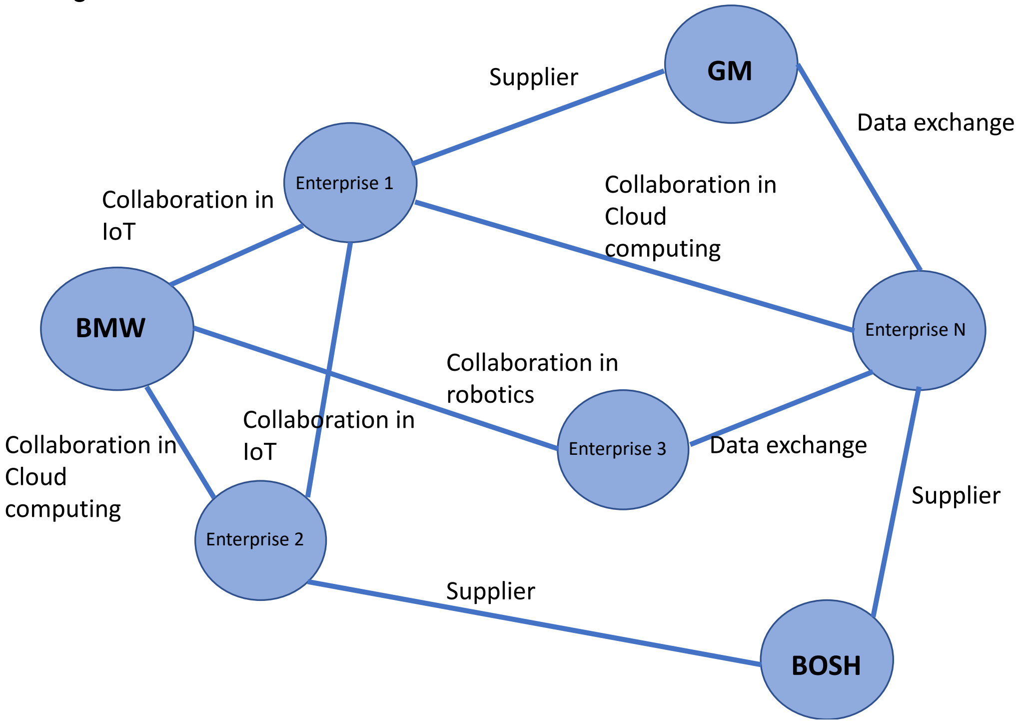
The model was developed considering the advantages of the network where organizing activities of the entities are involved. Cluster members’ are moderated by a cooperation framework established by themselves where each company has the possibility to establish different relationships to cooperate, compete, or both within the cluster.

In a second stage of the research we will analyze the collaboration relationships found in the cluster related to Industry 4.0 technologies to probe if participating in the cluster is an advantage for the transformation of the SMEs into Industry 4.0, to find out the benefits and costs of such participation.

The nodes in the developed collaboration network model are the global automotive enterprises (BMW, GM, Cummins, BrogWarner, Bosch, Goodyear), the SMEs, government organizations and research centers participating in the cluster.

The elements that links the network are the different relations among the nodes such as suppliers, buyers, collaborations agreements to implement specific areas of IT for the Industry 4.0 that BMW has already implemented in the area of robotic, IoT, cloud computing and manufacturing assisted systems (see Fig. 1.). Relations that can be more or less structured according to the intensity of the established relationship.

Figure 1. Collaboration Network Model for the automotive cluster in S.L.P.



METHODS

The unit of analysis for this research is the group of organizations members of the automotive cluster in SLP (42) in a cross sectional study. The database of the automotive cluster of San Luis Potosi will be used as a general data source for contact firms. Based on the proposed collaboration network model for the automotive cluster in SLP, a survey instrument will be used for an exploratory study to determine the role of each enterprise within the cluster performance. For collecting data, a questionnaire is going to be established including organization of SMEs data, cluster's enterprises relationships, their way and intensity of collaboration and the Industry 4.0 implemented technologies. We will include in the questionnaire specific technologies from Industry 4.0 that BMW in SLP has already implemented such as robotic, cloud computing, smart maintenance assistant software, IA, IoT. The survey results will be analyzed to determine the appropriate network model for the cluster relationships study.

CONCLUSION

The main subject of this paper is to contribute to the understanding of the complex and diverse problems of the enterprise transformation into Industry 4.0, analyzing the impact and consequences that occur when enterprises create a network collaboration between them. The conditions generated by Industry 4.0 represent opportunities and challenges for SMEs in the automotive cluster in San Luis Potosi. For this, enterprises will have to develop strategies that allow them to implement and use multiple information technologies focused on the transformation of Industry 4.0. Participate in the automotive cluster can mean an advantage for this transition through being able to establish also a network with the members of the cluster.

In the second stage of this research, using a questionnaire, data will be collected through a survey applied to the members of the cluster in order to test the possibility to implement and use all information technology linked to smart factories through a network of participants collaborating within them.

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A Decision Rule for Selecting Optimum Forecasting Methodology: Applied to Australian Fire Forecasting

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ABSTRACT

Managing wildfires is a challenge in many parts of the world. The ability to forecast the average number of outbreaks is important for first responders, health care workers and the general public. The ability to adapt the forecasting procedure and change forecasting methodology based on a proposed switching rule is important for fire managers as well as minimizing environmental, societal and economic threats from wildfires. A hybrid methodological approach will be applied to forecasting average outbreak of wildfires using data from the Global Fire Emissions Database from 2002 to 2018.

KEYWORDS: Forecasting, Fires, Croston's method, simulation, Single Exponential Smoothing

INTRODUCTION

High temperatures and low rainfall fueled heavy bushfire seasons in Australia from 2019 and 2020 and are known as the Black Summer Fires (Filkov, Ngo, Matthews, Telfer and Penman 2020). Worldwide wildfires have resulted in tremendous loss of life with a costly economic impact. Jolly, Cochrane, Freeborn, Holden, Brown, Williamson and Bowman (2015) identify an alarming trend that shows that the number of severe fire seasons have increased globally. These fires result in increased deterioration to the ecosystems, society, economies, and climate and are creating a burgeoning crisis to many parts of the world. Interestingly, the number of fires were considerably higher a century ago. However, society in general has initiated policies of fire suppression that contribute to the creation of more severe fires, albeit, fewer fires. Wildfires are a natural part of the global ecosystem and are essential in forest health. However, when they infringe on human developments suppression is required, risking human health and wellbeing. The impact of wildfires on government budgets was found by Liao and Kousky (2020) to be substantial and negative in California. It can be assumed that similar negative effects are likely for other municipalities and regions. This paper's research contribution is a proposed approach to estimating average daily fires to assist management in planning logistically for better utilization of resources.

LITERATURE REVIEW

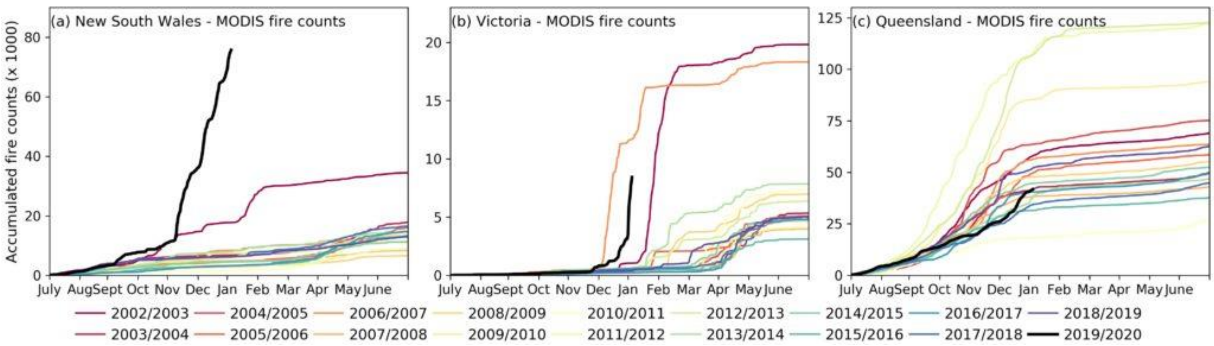
Filkov, et al. (2020) provide a succinct summary of the impact of Austrailia's recent 2019/2020 bushfire season, known as the "Black Summer", on the environment and impacted communities. The "Black Summer" fires killed 33 people and burned almost 46 million acres and 3,000 homes which was the most of any fire season in 20 years. They also demonstrated the negative impact of smoke, vegetation biodiversity and animals from the 2019/2020 season. The economic impact is not fully known. However, the similar 2005 season fires in Australia are estimated to have resulted in losses to the GDP of over 1% (Jolly, et al. 2015).

It is interesting, that the impact of wildfires on recreation is not decidedly negative. However, Nobel, Lizin, Witters, Rineau, and Malina (2020) suggest that the recreational value alone of some ecosystems exceed the costs of wildfire prevention measures by a factor of 6 to 10 in areas of Europe. What is not known, however, is the impact on the global community of smoke and ash from recent megafires as it travels in the atmosphere around the world or the impact of these mega fires on the economy, infrastructure, vegetation and animals (Filkov, et al. 2020). Yu, Xu, Abramson, Li and Guo (2020) identify many of the serious health impacts of the bushfires in Australia. One is the indirect effects of the air pollution from the fires resulting in premature deaths and morbidity as well as increased risks of hospitalization and doctor visits due to respiratory issues. These indirect costs are much more difficult to estimate than the billions in loss due to injuries, death, loss of habitat and burned structures.

Fire Data

The Global Fire Emissions Database provides global fire activity information gathered from satellite information The database estimates monthly burned area and fire emissions. The dataset is cumulative active fire detections from the Moderate Resolution Imaging Spectroradiometer or MODIS aboard the Terra (EOS AM-1) and Aqua (EOS PM-1) satellites operated by NASA. The satellites view the Earth's surface daily. The datasets are cumulative MODIS active fire detections in Australia and split into three areas covering New South Wales, Victoria and Queensland. The cumulative data goes from July 1st to June 30th for a "fire year". Detections of fires from the satellites were considerably higher for the 2019/2020 fire year for New South Wales and are near record levels for Victoria. Queensland, while high, regularly sees many natural savanna fires in the north.

Figure 1: https://globalfiredata.org/pages/category/australia/



Motivation for the Model

The authors have developed a model that automatically shifts forecasting models based on a triggering event. The original intent of the model was for demand of inventoried items. Businesses that stock goods often spend excessively on holding costs in order to maintain a desired service level. When the products are slow-moving, namely the demand for them is intermittent; it is even more likely that holding costs will not be minimized. SAP's ERP package, Oracle's Retail Auto ES, Forecast Pro XE and Pro Basic and MaxQ Technologies Demand Planning employ Croston's (1972) method and other techniques to provide forecasts for low volume slow-moving items. Croston's method is generally regarded as one of the principal procedures for estimating slow-moving demand. A condition that has only been investigated to a certain extent is how to account for shifts in mean demand, a common case in inventory management. In many circumstances the item would have to be identified as slow moving and utilize methodology for intermittent demand during the slow period and then return to the original technique Most businesses utilize refined mathematical methods that routinely provide demand forecasts (Larrain, 2007) but, situations similar to the one just described requires a managerial input to distinguish when a shift occurs. This research examines cutoff values to decide if the occurrence is at a generally recognized “regular/fast” rate or a “slow-moving” rate. The choice of the “cutoff” value needed to utilize this “hybrid” approach of switching between SES models in forecasting average demand is examined in this study.

Single Exponential Smoothing

SES is a moving average technique traditionally used to forecast demand for stocked items. The method is favored due to its ease of use and minimal data requirements. The process is noted as follows:

X_t = binary indicator of demand at time t

Z_t =size of demand

$Y_t = X_t Z_t$ = demand for an item at time t

α = smoothing parameter

Y_t” = exponential smoothing estimate of demand for period

The formula for SES is: $Y_t" = Y_{t-1}" + \alpha(Y_t - Y_{t-1}")$ (1)

The $Y_{t's}$ can be some demand or zero. It utilizes the previous period’s smoothed value of Y_{t-1} to determine the demand for the future. When current data is more important to the forecasted item a larger alpha value is typically used. The presence of trend and seasonality is problematic for SES. Double Exponential Smoothing is appropriate when a trend is present. In the presence of a trend and seasonality, Winter’s Method is applicable. Winter’s method smooth’s the seasonal element for each estimate, essentially triple exponential smoothing. The goal in selecting an appropriate alpha is to pick a value that minimizes error on most data. Trigg and Pitts (1962) provided guidelines for alpha selection. Ekern (1981) cautions against “adaptive” methods that automatically adjust alpha in response to the forecast performance and identifies the case of the nonstationary demand rate as being difficult. Saygin (2007) considers the ability to maximize service level and minimize inventory cost in alpha selection.

METHODS

In this section the proposed hybrid model is developed and described. The simulation process is then described, including the different parameters that are examined and the variations of Croston’s method that are investigated in this study and utilized in the hybrid model. When no period with zero occurrences exists, the model reduces to simply the SES methodology. The proposed modification of Croston’s method uses the notation similar to Croston. The idea is that the level of demand may be different during “fast” moving sales periods and “slow” moving sales periods. A superscript of “S” and “F” are used to identify “slow” and “fast” periods of demand.

If $X_{t-1} = 0$ and $X_{t-2} = 0$,

Then If $X_t = 0$, $Z^S_t = Z^S_{t-1}$

$P^S_t = P^S_{t-1}$
$q = q + 1$ (2)
Else $X_t = 1$ $Z^S_t = Z^S_{t-1} + \alpha(y_t - Z^S_{t-1})$
$P^S_t = P^S_{t-1} + \alpha (q - P^S_{t-1})$
$q = 1.$
Count_Slow = Count_Slow + 1 (3)

If $X_{t-1} = 1$ or $X_{t-2} = 1$,

Then If $X_t = 0$, $Z^F_t = Z^F_{t-1}$
$P^F_t = P^F_{t-1}$
$q = q + 1$ (4)
Else $X_t = 1$ $Z^F_t = Z^F_{t-1} + \alpha (y_t - Z^F_{t-1})$
$P^F_t = P^F_{t-1} + \alpha (q - P^F_{t-1})$
$q = 1.$
Count_Fast = Count_Fast + 1 (5)

The mean demand per period is then

(Count_Slow * Z^S_t / P^S_t + Count_Fast * Z^F_t / P^S_t)/(Count_Slow + Count_Fast) (6)

Daily data from the Global Fire Emissions Database for Queensland Australia was collected for the period from 2002 to 2019. The Data was examined to determine a cutoff point for "fast" or high values and "slow" or low values. An average was computed for each year shown in the Table 1 below. The average for all years was 80 and thus this value was selected for the cutoff between high values and low values for fires in the time frame.

Table 1: Yearly fire count averages from 2002 to 2018

Y2002	**Y2003**	**Y2004**	**Y2005**	**Y2006**	**Y2007**	**Y2008**	**Y2009**	**Y2010**
93	64	88	77	67	49	69	90	42
Y2011	**Y2012**	**Y2013**	**Y2014**	**Y2015**	**Y2016**	**Y2017**	**Y2018**	**Overall**
130	142	76	80	54	63	80	95	80

For the High values, the average median value was 300 and for the low values, the median value was 33. Few periods actually had zero occurrences The maximum was 4095. This does not mean 4095 new fires started in a day, but that 4095 fires were occurring on that day. One approach to determining the classification of the data as being "fast" or "slow" is to consider Bernoulli likelihood functions of occurrences. Historical probabilities of an occurrence occurring during periods of intermittent data and during periods of regular demand are used for determining "optimal" cutoff values for classification purposes.

Four different smoothing constants or alpha values were selected for the model. Consistent with alpha values for inventory models, values of 0.05, 0.1, 0.2 and 0.3 were selected. In one set of simulations the probability of a slow occurrence was set at 0.7 and at 0.3 for fast. For the second set it was reversed. It resulted in a mean of 446 for fast and 55 for slow with a standard deviation of 446 and 44 respectively. For the second set the average for the fast group was 236 and 16 for the slow. Standard deviations were 290 and 10. A cutoff value of 166 was used for the first group and 33 for the second group. As a baseline for showing improvement, a forecast was also computed for the entire data set at the four alpha values and is shown in the "SES RMSE" (root mean squared error) column in Table 2. The daily data from 2002 to 2018 was conducted for 6391 time periods for each set of conditions. A total of 12 conditions were investigated with four smoothing constants and three sets of probabilities and cutoff values for fast and slow rates.

RESULTS

The Hybrid Croston forecast improved over SES as smoothing constant decreased. The RMSE is the square root of the Mean Squared Error and was computed for each forecasting method. The RMSE was determined for the improvement in the modified method over SES in Table 2.

Alpha	SES RMSE	Hybrid Croston RMSE	Probability of Slow	Probability of Fast	Slow Stand Dev	Slow Mean	Fast Stand Dev	Fast Mean	Cutoff Value
0.05	193.23	**52.63**	0.7	0.3	44	55	347	446	166
0.1	211.06	62.51	0.7	0.3	44	55	347	446	166
0.2	225.02	73.15	0.7	0.3	44	55	347	446	166
0.3	233.18	78.60	0.7	0.3	44	55	347	446	166
0.05	193.23	**83.08**	0.5	0.5	22	33	300	320	80
0.1	211.06	97.80	0.5	0.5	22	33	300	320	80
0.2	225.02	110.14	0.5	0.5	22	33	300	320	80
0.3	233.18	116.42	0.5	0.5	22	33	300	320	80
0.05	193.23	**135.85**	0.3	0.7	10	16	290	236	33
0.1	211.06	152.7	0.3	0.7	10	16	290	236	33
0.2	225.02	164.88	0.3	0.7	10	16	290	236	33
0.3	233.18	171.54	0.3	0.7	10	16	290	236	33

Table 2 shows the improvement in the modified method over SES. Improvements in the forecast were found all three probability levels and cutoff values and all smoothing constant values.

DISCUSSION AND CONCLUSIONS

The ability to adapt the forecasting model based on a certain "cutoff" value yields a decrease in the Root Mean Squared Error when matched against SES. Table 2 illustrates the "Hybrid Croston" approach produces from 136% up to a 367% reduction in error. The practitioner should note two things. First employing more information in the forecasting procedure is advantageous and that knowing when to reclassify a model based on additional information to determine an optimal forecasting procedure is important. Second, with occurrences of low values the sooner the "slow-moving case" can be identified and an appropriate forecasting technique applied, the better the accuracy. It appears, the "fast" group is heavily skewed. As the probability of the fast group increases the accuracy decreases. Making the "fast" group a smaller proportion of the total values improves the accuracy of the model.

The Hybrid Croston method provided a wide reduction in RMSE when compared to SES no matter which variation was utilized. As the probability of demand for slow moving data increases, the cutoff value increases. These results should guide the practitioner in two ways. It is clear that utilizing more information in a forecasting procedure is beneficial and that knowing when to reclassify based on occurrences to determine an optimal forecasting procedure is important. Second, the sooner the slow-moving case can be recognized and an appropriate forecasting technique applied, the better, for forecasting accuracy.

This model predicts the average number of fire occurrences per day. Managers can benefit from this information by being able to anticipate when resources will need to be shifted to address heavy outbreaks. Assuming that more fires mean more ash and smoke the public can also be warned in advance of the likelihood of poor air quality days due to heavy outbreaks. This knowledge would allow front-line workers to be more prepared as well.

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A Digitalization Roadmap for Cross-border Logistics in Non-automated Environments

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ABSTRACT

Cross-border logistics, where cargo movement is facilitated by the involvement of a multitude of diverse and dispersed stakeholders that requires close coordination and exchange of information, is a prime candidate for a host of available and emerging digital solutions. However, some facets of digitalization carry a substantial price tag, which may not be feasible in all environments. This paper postulates that significant gains in performance are possible by leveraging existing investments in digitalization and via incremental investments within high-impact segments. Identification of such opportunities is demonstrated through a systematic analysis of the underlying processes.

KEYWORDS: Cross-border logistics, Digitalization roadmap, Process analysis, Role Activity Diagrams

INTRODUCTION

Digitization enables the generation, transmission, processing and analysis of information, that were traditionally considered cumbersome tasks involving human intervention, to be performed autonomously using technology with substantial gains in speed, accuracy and efficiency. Digitalization encompasses the methods in which digitized information is used to enable new ways of accomplishing tasks affecting various aspects of business operations and human life in general (Brennen & Kreiss, 2016; Stolterman & Fors, 2004). In the extant literature, the term digitalization is used to imply both the aspects of digitization and the applications that make use of digitized information. One area where digitalisation has particularly proven to have significant potential is logistics and supply chain management (Fruth & Teuteberg, 2017).

Supply chain performance parameters of speed, efficiency and responsiveness come under severe strain when cargo crosses international borders. Cross-border logistics (CBL) involves an international transport phase, supported by ships, aircraft and cross-border trucks or trains. This international transportation phase is often supplemented by a hinterland transportation system at either end of the chain facilitated by trucks, barges or trains. When the transport mode changes, the cargo must often transit through intermediate storage yards and warehouses, due to the consolidation and break-bulk activities involved. Government agencies led by customs who aim to deter undesirable flows and collect taxes have also set up facilities through which the cargo must transit in their journey. As each facility and each link of the chain is operated by a different stakeholder, coordination among them becomes critical for ensuring the swift and smooth flow of cargo (Hintsa & Hameri, 2009). While the containerization drive has simplified many aspects of handling and storage with dramatic increases in efficiency, digitalization offers the potential to further improve many of the problems that are still prevalent within CBL systems.

Logistics has a unique blend of characteristics representing both manufacturing and service delivery systems, requiring the adoption of concepts from both domains for analysis. Handling, moving, storage and retrieval of cargo, the physical operations in logistics, may lead to the build-up of inventory or idling cargo adding costs and hiding inefficiencies analogous to the typical problems faced in manufacturing (Womack et al., 2007). Handling of financing and information processing along with associated service provision adds the characteristics of value co-creation, simultaneous production and consumption without storage that are commonly found in the services domain (Vargo & Lusch, 2004). Therefore, the associated problems such as service variability and matching demand and supply in real-time are also challenges in logistics. Digitalization-based solutions have been advocated and adopted in both sectors as solutions to these persistent problems. While mechanization and automation have been used in manufacturing to reduce variability and achieve the smooth flow of parts and sub-assemblies through the production line, information solutions have been used to exchange information, enable coordination, empower, interface and engage with customers in the service sector (Field et al., 2018; Zakoldaev et al., 2019).

Having considered the above developments, the study reported in this paper undertook to identify the opportunities for the digitalisation of CBL systems in environments with minimal automation. While there are several forms of CBL operations, this paper focuses on maritime cross-border logistics for containerized cargo. To this end, the study captured and analysed the CBL processes of a globally significant container port, albeit in a developing country, to identify the most impactful areas for digitalization with limited investments. The analysis of the processes, which were modelled using an appropriate notation capturing alternative perspectives, revealed opportunities for digitalization with respect to multiple dimensions of cross-border logistics processes.

The next section of this paper explores the relevant literature on digitalization in cross-border logistics, followed by an outline of the methodology adopted in the study. The results and analysis section presents the analysis of a segment of CBL processes for identifying potential improvement opportunities. The discussion section proposes an investment roadmap for the digitalization of CBL systems based on the dimensions of underlying processes, followed by the conclusions.

LITERATURE REVIEW

Differences can be observed in the degree of digitalization in many segments of the maritime CBL network. This section explores different forms of digitalization that have been deployed in the CBL systems, including the circumstances leading to their adoption.

On the seaside where the CBL industry is relatively advanced and expensive assets have been deployed, driven by the need to maximise their utilization, significant investments in digitalization can be observed (Fransoo & Lee, 2013). For example, terminal operators who generally have operations in multiple major ports around the world have deployed sophisticated information systems known as Terminal Operating Systems (TOS) (Min et al., 2017). Such systems are primarily used for planning the stowage of containers in vessels and in the yard considering the balancing of the vessel, reducing the number of crane movements and allowing for optimal access

to containers for the next movement. As the knowledge of container positions is critical for terminal management, some of these systems may have capabilities to automatically acquire their positions through technologies such as Radio Frequency Identification (RFID), Wireless Sensor Networks or digital imaging (Fruth & Teuteberg, 2017; Heilig & Voß, 2017). Further evolution of these tracking and visualization systems may result in 'digital twins' even though their deployment is still in the early stages (W. Hofmann & Branding, 2019). A digital twin replicates its physical counterpart in a digital environment and provides visualizations for human counterparts aiding decision-making through various levels of analytic capabilities. Through built-in simulations and optimization algorithms, a digital twin can not only aid in the operations of a container port but also assist in the designing stage of new terminals (Li et al., 2020). Li et. al. (2020) also illustrate how the fidelity of digital twins could span from conceptual stage of an entire port down to a rack location within a warehouse.
Containers were introduced to CBL to eliminate the need to handle heterogeneous types of cargo and replace them with homogeneous packages enabling uniformity in handling, transport and storage (Levinson, 2016). With the standardization of containers, it was possible to have standardized handling equipment as well, making mechanization an advantage from the inception of container terminals. These mechanized systems are now being increasingly automated with the introduction of automated guided vehicles (AGV) and automated cranes to further enhance their efficiencies, especially in locations with high labour costs (Steenken et al., 2004). Such automated operations bring efficiencies and lower dependence on human labour, which have proven to be a historically contentious issue in the maritime industry (Levinson, 2016). Such large-scale physical automation requires significant investments, which may not be feasible for all locations and may even be undesirable where low-cost human labour is widely available unless safety requirements demand otherwise.

In the hinterland, where the industry is fragmented with a large number of smaller-scale operators ranging from consignees, shippers, truckers, customs brokers and freight forwarders, digitalization has been comparatively lower and slower (Lam & Van De Voorde, 2011). The involvement of government agencies, perceived to be conservative (Costa et al., 2019), hasn't helped in progressing the digitalization agenda either. However, the need for having centralized information systems accessible to multiple stakeholders is acutely felt in the hinterland segment, where the stakeholders need to share information for facilitating efficient operations and are required to submit the same information multiple times (Choi, 2011).

Customs and border protection agencies are arguably the most influential and powerful stakeholder groups in hinterland operations. Traditionally the role of the customs has been to protect the border and collect revenue, with trade facilitation emerging as only a recent phenomenon (Grainger, 2021). The historical roots of customs have prompted them to assume a distrusting view on the side of other stakeholders, leading to a less collaborative stance, especially in developing countries where malpractices tend to be more prevalent. Given such a background, even in cases where customs agencies have implemented extensive information systems, similar to other government agencies, they have exhibited a lower willingness to share the available information with other stakeholders (Ebrahim & Irani, 2005) in a manner that facilitates trade. Even the collaboration of customs with other government stakeholders has been observed to be weak (Grainger, 2003; Villa, 2006). Such an environment has led to the emergence of National Single Windows (NSW) as a solution for the coordination problems which have been promoted as a preferred solution by international agencies who seek to enhance trade facilitation (WTO, 2014). NSWs are inter-organizational information systems that aim to ease the burden on stakeholders by sharing information with all stakeholders who require that information legitimately with a single submission (Choi, 2011). However, the implementation of such systems has proven to be long-term endeavours that could span years, fraught with long negotiation processes (Tsen, 2011). Maintaining such national-level projects on track over extended periods can also be a challenge for most developing countries. Even after the implementation of such systems, the evolution of technology poses significant challenges for such monolithic systems leading to maintenance and obsolescence issues.

While sophisticated systems help terminal operators serve their primary customers, the shipping lines and the other stakeholders operating within the port also require coordination. Their needs have been proposed to be served by Port Community Systems (PCS) (Carlan et al., 2016). While being centred around port operators, PCSs s are more prevalent than NSWs due to their smaller scale of being confined to a single port and the lower involvement of government actors. However, PCSs are also prone to some of the disadvantages of large inter-organizational information systems including user adoption issues (Steenken et al., 2004) posing further challenges to their deployment. Stemming from their divergent roles and interests, challenges in achieving consensus among various stakeholders to implement common IT platforms across CBL systems that benefit everyone while safeguarding their autonomy is well documented in the literature (Serra & Fancello, 2020).

Congestion caused by trucks queuing to drop off and pick up cargo at ports pose problems not only to port community groups but also to those who live or work in metropolitan areas where the ports are located (Islam et al., 2013). Other modes of hinterland operations are also fraught with similar problems with trains and barges experiencing scheduling problems and delays (Almotairi et al., 2011; Van Der Horst & De Langen, 2008). Truck appointment systems, a simple yet effective solution to truck congestion have been proposed and adopted in by some ports with different degrees of success (Baalen et al., 2009). A further step in the truck appointment systems is smart gates, where data from the truck and the container is machine-read and gate functionality is automated. While not as capital-intensive as a fully-fledged PCS, smart gates also employ a host of technologies to reduce processing time at port gates (Yang et al., 2018).

In recent times, block-chains, also known as distributed ledgers, have been proposed for some aspects of CBL, including the digital transmission of documents such as Bills of Lading where the authenticity can be verified without having to rely on a single party (Ganne, 2018). While some initial adoption has been witnessed (Macedo, 2018) their widespread deployment is yet to be seen as it requires substantial international cooperation and adoption. The high resource intensity in terms of computing equipment and power consumption, for at least some blockchain implementations, has been cited as a drawback of the technology (Sedlmeir et al., 2020). Some studies (Tsiulin et al., 2020) have highlighted the similarities of objectives being pursued by blockchains and PCS in terms of sharing information with built-in authentication capabilities.

Considering applications such as machine learning requires substantial amounts of data not only for the applications but also for research into advanced applications Filom et.al (2022) have highlighted the need for data governance, ownership, privacy and security. They also emphasize the difficulty of obtaining data from port operations due to privacy and confidentiality concerns.

The gap between the required and existing knowledge and skills of the workforce in maritime CBL in implementing emerging technologies has been well recognized (Filom et al., 2022). The challenge of low digital literacy in the workforce is understandably pronounced in developing countries (Sabbagh et al., 2012). In addition to the challenge of recruiting workers, organisations in such environments tend to question the value of digitalization and its ability to replace human judgement as well. Therefore, there is a need for a measured and coordinated approach to digitalization focusing on high-impact priorities that are acceptable to all stakeholders, while maximizing impact from the limited funds available for investment.

While the literature on cutting-edge and emerging solutions for the CBL sector is abundant, there is a gap in identifying methods to prioritise investments when capital is limited and digital literacy is low. The proposed solutions while promising to deliver highly efficient CBL systems, also create risks with multi-year deployments and high investments in an uncertain and ever-changing global environment. Therefore, exploring low-investment, high-impact solutions which allow quick and incremental deployments would be more pragmatic in the digitalization journey.

METHODOLOGY

The empirical data for the study reported in this paper was collected based on a case study of cross-border logistics operations at a leading container port in South Asia. The Port of Colombo is ranked among the top 30 container ports of the world with 3 operational container terminals and 2 more in the planning phase. The port is also home to the only deep-water container terminal in South Asia where vessels with capacities of over 18,000 Twenty-foot Equivalent Units (TEUs) can be accommodated (UNCTAD, 2018). The port has seen sustained growth in container volumes over the years.

The case study approach is a useful methodology to study CBL operations. Being transactions among stakeholders across the world, there are dimensions of CBL that are inherently global. For example, financial transactions must comply with international norms and trade terms are usually defined using INCOTERMS. Container vessels that ply global routes get similar treatment at each port they visit, as well. However, aspects such as customs regimes and hinterland logistics operations tend to be unique to each location. Therefore, case studies in CBL at any location hold the potential to provide insights into both global practices as well as local adaptations.

Process analysis and improvement, a powerful tool that lies at the core of operations improvement frameworks such as Total Quality Management, Lean and Six Sigma (Hammer & Champy, 1993; Womack et al., 2007), was selected to explore CBL operations through the selected port. Also, there is ample evidence to suggest that the digitalization journey should be looked at from the perspective of processes rather than from technology (Martinez, 2019). The first step in any process analysis effort is capturing the “as-is” processes, which is also known as process discovery. The operations in the selected port were captured mainly through in-depth interviews and observations. Due to the multi-stakeholder nature of CBL, the process knowledge is highly fragmented requiring a multitude of interviews to capture and validate the processes comprehensively.

Capturing the process in rich detail is a prerequisite for the subsequent analysis requiring the selection of an appropriate modelling notation. Following a comprehensive evaluation of existing modelling formalisms, a Role Activity Diagram (RAD) (Ould, 2005)-based framework was developed to capture the processes (Bandaranayake et al., 2022). RADs while capturing the essential functional, control, organizational and informational aspects of the processes also capture the interactional dimension in the same diagram. Since RADs do not have an excessive amount of syntax elements, the resultant diagrams are intuitive and easily understood by a novice user, enabling model validation by process participants themselves. RADs were supplemented with addendums to include the temporal and spatial dimensions to graphically depict physical flows further easing comprehension. The resultant modelling framework inclusive of the manifestation of these addendums can be seen in the process model shown in Figure 3. Process models discovered through interviews were also supplemented with partial temporal data acquired from the related information systems, where applicable.

As the constituent elements of a process model, the temporal, spatial, control, functional, informational, organizational and interactional perspectives provide a useful frame of reference for analysis of the underlying process. These dimensions are graphically illustrated using the process model in Figure 1. The value-adding steps (activities) of the process are captured by the functional dimension and the movement of goods/transporters is captured in the spatial dimension. The control perspective captures the sequencing of activities as well as the decision-making. The information required and acquired in executing functional activities, decision making and those captured from spatial movements are represented by the informational perspective.

The organizational dimension shows the roles that are involved in executing the process, which may be organizations, units or individuals depending upon the granularity of the process model. As such, the organizational dimension can be seen as an enabler of the processes which is dependent upon the knowledge, skills and attitudes of those who represent the roles. The interactional perspective captures how the organizational units interact and share information, a critical aspect considering the multi-stakeholder nature of CBL operations. The temporal dimension, which captures the execution times and waiting times of the processes can also be treated as an output parameter that is often linked to various performance parameters of the processes and serves as a useful starting point for process analysis.

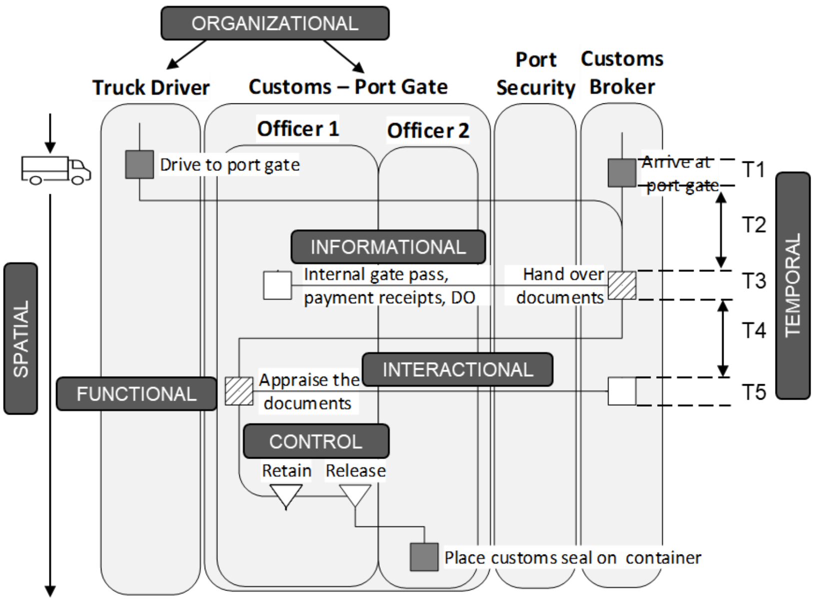

Figure 1 Process Dimensions Captured and Analysed

The framework used to analyse the digitalization potential and the path for each process dimension are illustrated in Figure 2. Digitized information is the common thread that links and holds all other dimensions together. Once converted or captured in digital mode, information can be analysed and used with a relatively low effort not only to aid execution but also to analyse and improve processes. Therefore, the level of digitalization depends upon the degree to which digitized information is captured, processed and used in various other process dimensions.

Digitized data can be captured from functional activities and spatial movements of objects, while processed information can be provided to enable and ease functional activities and decision-making. At high levels of digitalization, functional activities, whether it is information processing or movement of cargo, can be automated. From a control perspective, the captured data can be analysed, and insights can be generated to various degrees to assist or automate decision-making and routing. From an interactional point of view, inter-organizational communication can be enhanced through offline (such as email) or online interconnected systems. The digital literacy of the organizations and human resources will determine the level of digitalization potential and the temporal dimension will measure the associated process performance.

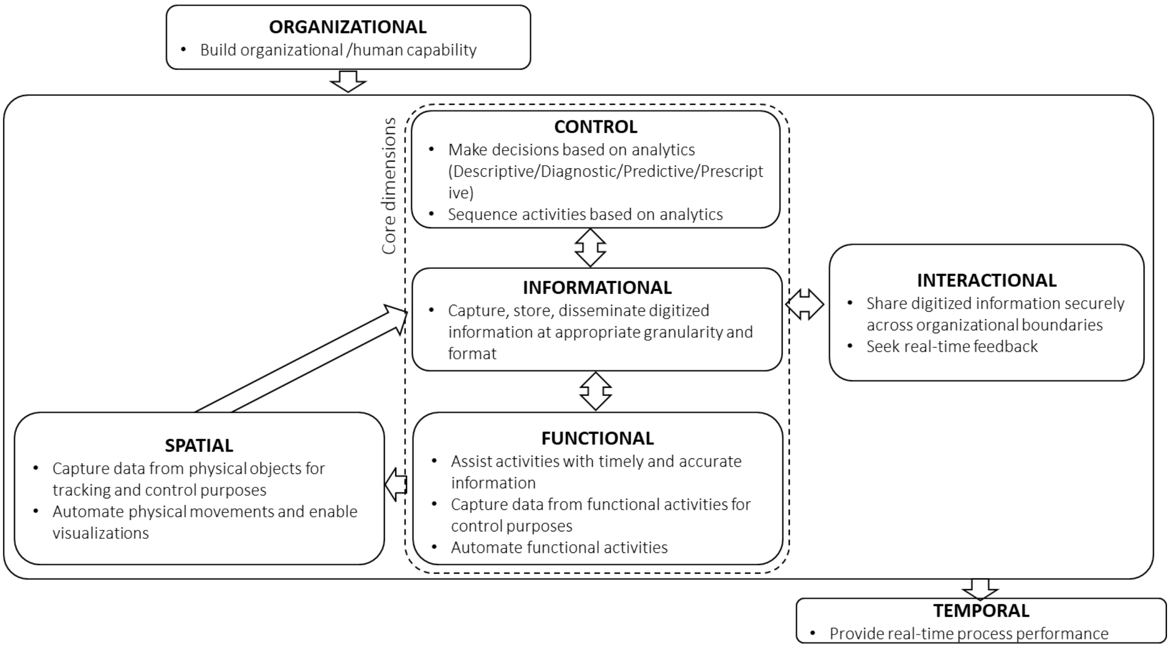

Figure 2 Framework for Analysing Digitalisation Potential

While control, informational and functional dimensions are inherent in any process, each process tends to have several salient dimensions. The analysis first identifies these dominant dimensions by examining the process structure. Thereafter the current level and further potential of digitalization of those dimensions are explored in line with the guidance provided by the framework presented in Figure 2.

This section described the methodology followed in the collection and documentation of empirical and the tools and methods used for process analysis by delving into the constituent dimensions of the processes. The following section explains the results of the process discovery and delves into the analysis of the captured processes.

RESULTS AND ANALYSIS

This section focuses on the results and the analysis of CBL processes in terms of digitalization. The analysis has been confined to the import operations but could be extended to other CBL segments as well.

Captured in close to 100 hours of interviews with different stakeholders, 87 process models of CBL operations were developed at three levels of granularity. Process models were hierarchically structured, to provide a holistic view at the aggregate level while revealing details at the more granular levels. Figure 3 shows the process model at the aggregate level for importing Full Container Loads (FCL) and identifies segments codified as T1 to T6 based on temporal dimension for further analysis.

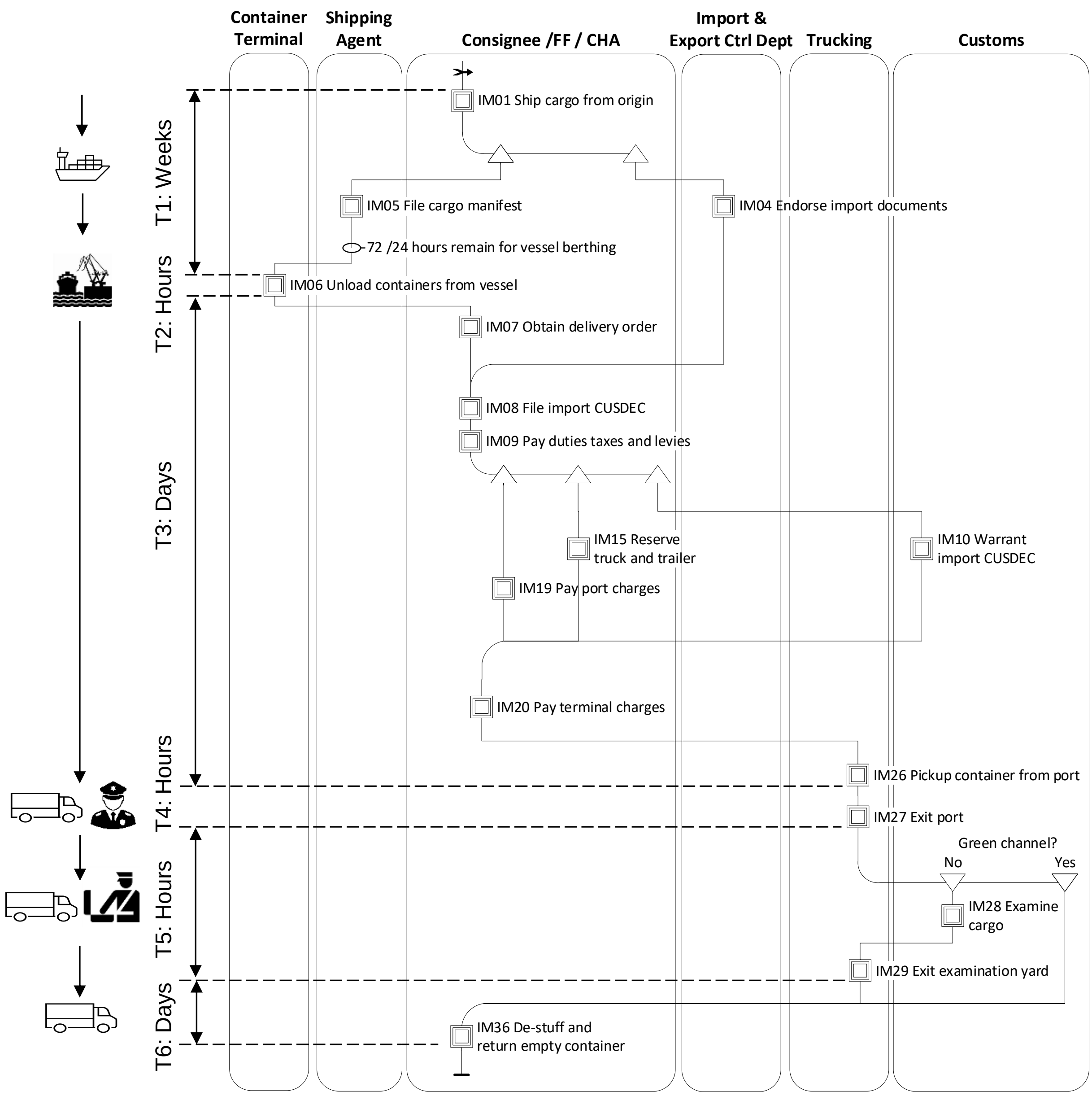

Figure 3. RAD-Based Process Model of Import Processes at Aggregate Level

For each segment identified in Figure 3, the dominant process dimensions were determined based on its characteristics and are tabulated in Table 1.

Table 1 Dominant Process Dimensions for Process Segments

Process Segment/Sub-segment	Description	Dominant Process Dimension					
		Informational	Control	Functional	Spatial	Interactional	Organizational
T1	Ocean shipment			✓	✓		
T2	Unload at port			✓	✓		
T3	Document clearance	✓	✓				
T3/IM08	Submit customs declaration	✓		✓			
T3/IM19/20	Pay port and terminal charges			✓		✓	
T3/IM10	Warrant customs declaration		✓	✓			✓
T4	Exit the port		✓		✓		
T5	Cargo inspection		✓		✓		
T6	Destuff container and return the empty			✓	✓		

The ocean transport process is usually measured in weeks (shown by T1 Figure 3) unless it is between close neighbouring countries. Shippers and consignees around the world have come to accept these long shipment times in return for the efficiencies it delivers. As such, that segment is not further analysed in this study.

The next step in the process, denoted by T2, is the loading and unloading of containers from the vessels and their movement to the container yard. Considering the movement of containers involved, the spatial and functional dimensions are prominent in this step. As such, drawing from the analysis framework, assisting functional activities through the provision of digitized information and capturing digitized information from physical objects are options available with regard to digitalization. Ship-to-shore cranes also known as quay cranes are used for loading and unloading the vessels, trucks and straddle carriers for horizontal movement and yard cranes for staking at the yard are used in these operations. While the case study port has started the journey towards operating these assets remotely, the communication of the next container movement to digital displays in the equipment is the prevalent mode of operation. Significant improvements have been made with this mode of operation compared to providing the operators with a paper-based list of movements. This is evidenced by the fact that the time taken for loading and unloading cargo at the port is among the best in the region (Dappe & Suárez-Alemán, 2016). While automating cranes and horizontal movers are adopted in high labour-cost locations with financial strength for substantial investments, making use of digitized information to visualize physical operations would be a logical next step for the case study port. Such systems, supported by Internet of Things (IoT) technologies (Andersson & Mattsson, 2015), strongly link the spatial dimension to the control dimension enabling timely and well-informed decisions. The necessary data to build such models could be acquired through sensors which are becoming increasingly cheaper (Tu, 2018). However, such a system would not be a true “digital twin” as it lacks the capacity to automatically make changes in the spatial dimension to match changes in the virtual dimension.

Once the cargo has been transferred onshore, idling cargo accrues costs to various stakeholders, in terms of space utilization (container yard) and equipment usage (containers) which are ultimately passed on to the consignee. As such, cargo idling at the case study port for days (T3) can be identified as a key concern, mainly driven by the cargo clearance process. This is a step with significant emphasis on information and control dimensions where the flow of information lags the physical flow causing the physical flow to stall. Considering digitized information could be transmitted at or close to the speed of light, digitalization has significant potential to eliminate this idle time considering customs declarations are already in digital format. This needs to be enabled by changes in the control dimension, where the current sequence of activities is not optimal, by choosing to process customs declarations ahead of the arrival of cargo. Such changes however require legislative and policy changes for implementation. It also has an organizational dimension, requiring a shift in the mindset of the agencies concerned with enhanced trust in digital solutions including the acceptance of digital signatures to realize its full potential. Since investments to convert declarations to the digital format have already been made, the changes proposed require minimal additional investment.

Submitting the customs declaration (IM08 in Figure 3) is an activity with a firm emphasis on the informational and functional dimensions. Submission of information and supporting documents in digital form is an improvement from a paper submission. However, the customs information system being a stand-alone system, the declarant must collect information from a multitude of electronic and paper sources to compile the submission which creates substantial functional activities. Since there are many such instances in CBL, inter-organizational systems such as NSWs and PCSs have been proposed, albeit with significant investments, to enable system-to-system communication alleviating redundant data key-in tasks. Robotic Process Automation (RPA) has been proposed as an interim solution to these problems where routine functions such as copying information from one source to another can be automated using a suite of technologies, including Optical Character Recognition (P. Hofmann et al., 2020). RPA does not require significant changes to information systems in place, instead reduces repetitive functional activities with simple interfacing programs making them ideal candidates in non-automated environments.

There are several other activities within block T3, such as paying the shipping line, the terminal and the port authority their dues and obtaining the approval to remove the cargo and making a reservation with a trucking company to pick up the cargo. These activities, with a strong interactional emphasis, have eliminated the need for real-time interactions through the use of stand-alone information systems. However, each of these activities requires the submission of similar information to each stakeholder’s (stand-alone) system, creating additional functional activities. These low-value-adding data entry activities can be eliminated with inter-organizational systems in the long run. Leveraging existing systems through RPA-based interfaces could again be a lower-cost alternative in the interim, eliminating redundant functional activities, speeding up operations and saving valuable human resources for higher value-adding activities.

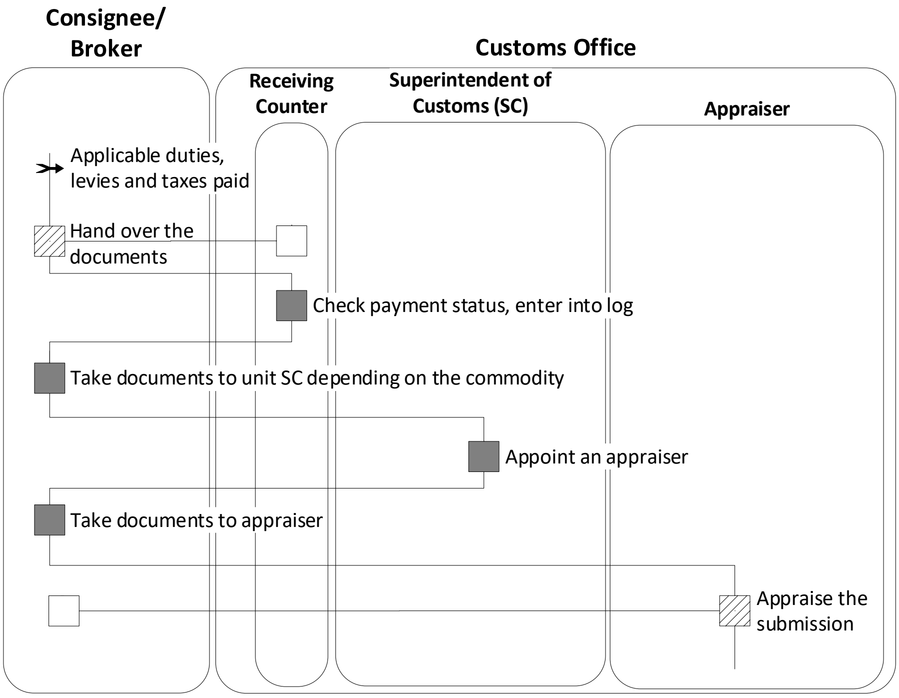

Figure 4. Partial Depiction of Approval of Customs Declaration (Warranting)

Approval of the customs declaration denoted by IM10 in Figure 3 and elaborated partially in Figure 4, requires the declarant to visit the customs office along with the originals of related documents such as Bill of Lading, commercial invoice etc. The objective is to obtain the approval of customs who seek to authenticate the owner and verify the value and classification of cargo and the authenticity of the declaration for revenue collection and border protection. While the process objective is firmly in the control dimension, the objective is operationalized through many (low value-added) functional activities. These functional activities can be eliminated through digitalization. The process model illustrates the physical routing of the declarant to several stations, some with minimal value addition, and each with the potential for forming queues. The activities are based on “witnessing” original documents and “questioning” the declarant. While the human decisions here are already supported by “the risk assessment module” of the customs information system, further adoption seems to be hindered by the digital literacy and discomfort in moving to a virtual approval system featuring “digital signatures” and “authentication”. Thus, further enhancement of this process requires strengthening the organizational dimension towards acceptance of digitalization. The infrastructure for adopting such technologies is largely in place without the need for further significant investments.

Exiting the port which takes hours (T4 in Figure 3) is among the most visible process issues at the Port of Colombo where excessive congestion is observed in the afternoon and early evening. This step has an emphasis on functional and spatial dimensions. The value addition in this activity is the verification that “cleared cargo” is carried by an “authorised stakeholder”. The gatekeepers ensure the cargo is cleared by customs, the shipping line, the terminal and the port authority, where the three latter stakeholders require their dues to be settled for clearance. The current operationalization of the process requires reading the container number, truck number and driver ID, checking the authenticity of the printed gate pass, placing a container seal, and updating the information system. These functional activities take substantial time, leading to queues being formed. From the analysis framework, providing required information for functional execution and acquiring information from physical objects are the avenues for digitalization. Proven technologies, especially those based on IoT, exist to automatically acquire information from containers and trucks which offer substantial savings in time. While it requires moderate levels of investment the costs for associated sensors have been coming down. Most containers are picked up during working hours, especially in the afternoon after completing document processing steps in the morning causing congestion. From a control perspective, considering the port operates around the clock, the pickup times could be pre-allocated to trucks through a scheduling system reducing peak time congestion. Such a scheduling system would require investments in information systems but could be comparatively low compared to investments in infrastructure.

Cargo inspection (T5 in Figure 3), which has an emphasis on spatial and control dimensions is also identified as an area of concern due to the substantial time spent. Physical examination of cargo by regulatory authorities, while burdensome and time-consuming, may always be necessary to ensure compliance. From a control perspective, the number of inspections could be drastically reduced with appropriate risk-based selection methods (Varese & Ronco, 2019). The selection algorithms can be enhanced by establishing feedback loops on inspection outcomes to generate better risk profiles which are currently lacking. Customs organizations have started international collaborations and intelligence sharing in this regard as well (Holloway, 2009). Non-intrusive inspection methods, although capital-intensive, also help in reducing the associated time and operational costs.

This section analysed the import processes for the case study CBL system and proposed improvements based on digitalization options delving into the underlying dimensions of the processes.

DISCUSSION

A number of instances where digitalization can improve the import processes with lower capital intensity were identified in the previous section. Since the patterns recur in other CBL processes as well, this section attempts to generalize the analysis to analogous situations elsewhere in CBL. Three digitalization maturity levels, grouped by process dimensions are identified in Table 2 and an investment roadmap to reach those levels is depicted in Figure 5.

Table 2 CBL Digitalization Maturity Levels for the Process Dimensions

Dimension	Rudimentary Stage	Intermediate Stage	Advanced Stage
Informational	Paper-based data	Digital data along with paper-based data	Digital data
Interactional	Synchronized face-to-face human interactions	Remote interactions through digital interfaces	Autonomous system-to-system interactions
Functional: non-spatial	Paper-based processing. Manual inputs/outputs, paper-based workflows	Information system-assisted processing with semi-automated data entry/retrieval	Automated workflow and data acquisition with minimal user inputs
Functional: spatial	Manual operations assisted by paper	Manual operations assisted by digital communications	Automated cargo movements
Control: activity sequence	Cargo flow stalled by lagging paper-based information flow	Digitized information processed along with cargo flow	Adaptive cargo flow with leading information flow
Control: decision making	Human judgement based on experience	Data-driven decision-making based on analytics	Autonomous decision making
Control: regulatory	Near universal physical examinations.	Data-driven risk assessment with non-intrusive inspection and selective physical examinations.	International and inter-agency intelligence sharing with non-intrusive inspections and highly selective physical examinations
Organizational: capability	Low digital literacy. Unutilized digitized data	Intermediate digital literacy. Limited use of digitized data	High digital literacy. Data fully utilized drawing valuable insights
Organizational: attitude	Change resistant organization	Organizations receptive to moderate changes	Dynamic organization receptive to changes

The rest of this section discusses how digitalization has impacted and can be further leveraged in each of the process dimensions.

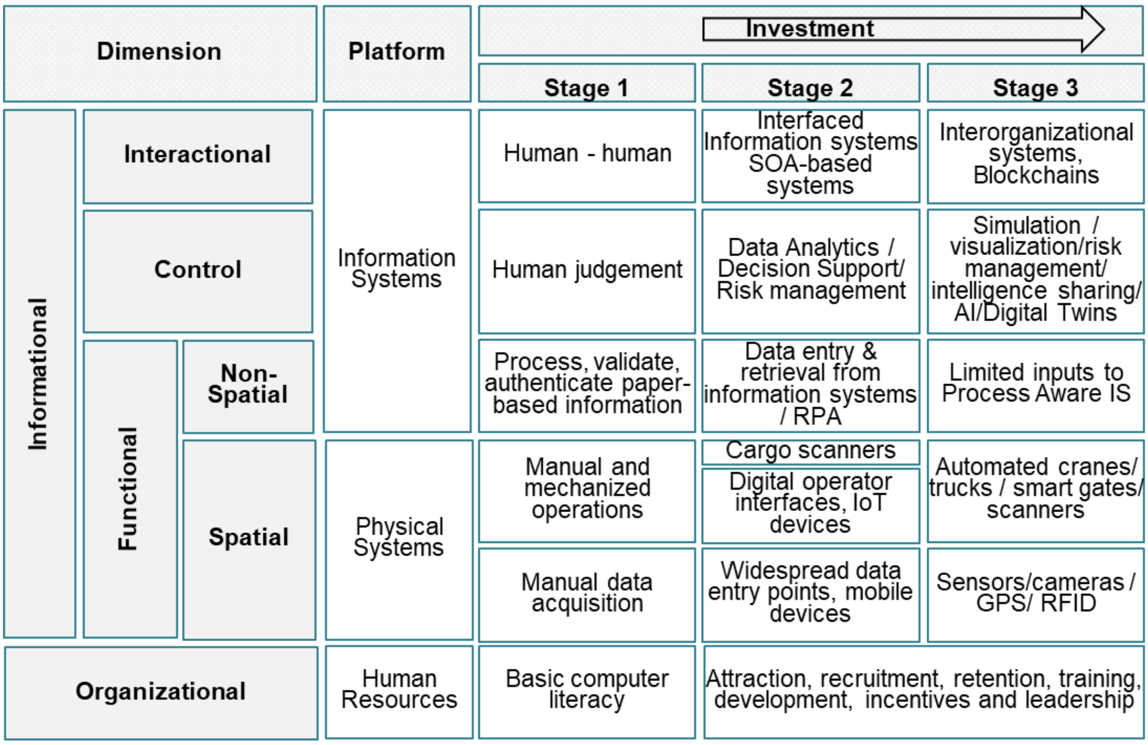

Figure 5. Digitalization Investment Roadmap for CBL

As can be witnessed through process models, substantial resources in CBL operations are spent on functional activities of preparing, submitting, receiving, validating and authenticating data. Considering the real value addition in CBL is derived from the physical movement of cargo, the functional activities pertaining to information processing can be seen as supporting activities with lower value addition against the ultimate goal. Digital solutions have been well accepted as having a significant potential to reduce such burden on organizations since the days of Business Process Re-engineering (BPR) (Hammer & Champy, 1993). Deploying information systems that are highly tailored to each processing step with automated workflows (process-aware information systems) has been a further step in this direction (Dumas et al., 2005).

Legacy information systems in organizations are usually stand-alone systems, requiring manual inputs from users and producing paper-based outputs. These systems do not adequately address the cross-organizational sharing of information, a recurring theme in CBL operations captured by the “interaction” dimension of the processes. The ultimate solution to this problem is the implementation of fully-fledged inter-organizational systems which require high investment and effort. However, opening interfaces to existing systems would be an intermediate step that would reduce functional activities related to data conversion and interfacing with each stakeholder. Such well-designed interfaces could also serve as the first step in developing modular systems, which are more feasible compared to the deployment of inter-organizational systems. When deploying new organizational systems using technologies such as Service Oriented Architecture (SOA) would ease such interfacing as it enables software services to be made available and accessed over networks (Afsarmanesh et al., 2015). Stakeholders submitting information to legacy systems could consider RPA-based solutions, which are simple, comparatively inexpensive, and faster to deploy, to ease their burden of interfacing among multiple systems (P. Hofmann et al., 2020).

In addition to inter-organizational interactions discussed above, the other form of interaction prevalent in CBL is face-to-face human interactions. Such encounters carry the potential for creating waiting lines and service variability, well-recognized service industry problems (Bitner et al., 1990). These are also potential instances for service providers to obtain customer inputs for service co-creation (Lusch & Vargo, 2006). Therefore, replacing such face-to-face interactions with well-defined system interfaces has the potential to save time and costs for both parties involved. The human presence is required by some stakeholders for authentication purposes. Therefore, building digital authentication capabilities into systems is also a requirement in this regard. In most situations when the information is received from the originator through inter-organizational systems, additional steps of verifications could be avoided. In cases where further verifications and authentications are required, distributed ledger solutions (Blockchains) have been proposed as well (Ganne, 2018).

More recent developments in digitalization have had a higher impact on the control dimension of the processes. Human decision-making, while reassuring to the experienced practitioners in the domain, may now be substantially aided or performed equally if not better by information systems through pattern recognition (Davenport & Kirby, 2016). While implementation and adoption of state-of-the-art Artificial Intelligence (AI) systems, maybe still be expensive, existing information systems can be used to assist human decision-making with insights from historical data as an intermediate solution. While such a descriptive level of analysis explains what happened in the past, the diagnostic analysis can provide insights as to why it occurred. Further along, using more advanced analysis techniques, such as machine learning, and predictive analysis can forecast what is likely to happen while prescriptive analysis can recommend what needs to be done (Filom et al., 2022; Lepenioti et al., 2020). In addition to historical data, such higher-order analysis requires real-time inputs as well. It is also possible to achieve decentralized decision-making, moving away from traditional hierarchical control, when such intelligence and processing power are available at the subsystem or device level.

When prescriptive outcomes are obtained from digital systems, as described above, their impact on functional and spatial dimensions can be enhanced, as well. For example, informing the driver of a prime mover, operating at a container terminal, where to pick up the next container and where to deliver it is done through sophisticated back-end systems which not only consider the optimal travel path of the truck but also the stacking order of containers. Such systems lay the groundwork for fully automating such operations as well. While automation of cargo handling and movements is a high investment option, the other dimension of the spatial perspective, the acquisition of data from physical systems, is becoming cheaper, with the cost of necessary sensors and cameras and other IoT devices decreasing substantially (Tu, 2018). Such data acquisition can assist in, simpler automation solutions such as smart gates at the port perimeter which can bring substantial improvements to a CBL system (Baalen et al., 2009). Where deployment of sensors/ cameras is not feasible, computer terminals could be deployed to keep track of the cargo through manual inputs to the systems throughout the journey. Making use of pervasively available mobile devices is another option at the intermediate stage.

Low organizational capability in terms of human resources can be a major impediment to digitalization. While building a highly digitally literate workforce would be an ongoing long-term endeavour, which may require the upskilling of a nation's workforce, providing training and education to the users could be an intermediate step. When the workforce is not conversant with digital technologies even the available systems and digitized information would be under-utilized. There would also be the urge to use paper-based systems in parallel. Similarly enhancing the positive organizational attitude toward digitalization is also a critical step in the journey. While it can be also enhanced through training and workshops it could be fast-tracked with adept leadership at organizational and governmental levels.

While individual process dimensions have a digitalization potential and a path on their own, synergies that arise through multiple dimensions must also be noted. For example, when more functional activities are digitized, it also generates a substantial amount of new data. Such data provide a rich source for further process analysis and improvements through data mining techniques such as process mining (van der Aalst, 2016), which can highlight process issues and non-compliances which in turn could enhance the operations.

It is important to look beyond the process dimensions at the broader environment of CBL systems, as well. In a non-automated CBL system, the required legislation support may be lagging behind digitalization. For example, auditors at the government level may not be satisfied with digitized information and may insist on a paper-based audit trail while trust in digital signatures may be low (Holloway, 2009). Change-resistant government organizations may use such an environment to delay the digitalization journey. On the other hand, digitalization should not be used as a vehicle to dilute the existing policy frameworks which might create further loopholes for corruption in developing countries, which is already a major concern (Hors, 2001). Therefore, digitalization must be accompanied by appropriate legislation and governance frameworks. Another system-level requirement for digitalization is the advancement of society's digital literacy as a whole. This may require changes to the education system and introducing digitalization to other government services as well. When society is embracing digitalization, momentum would be built in all sectors to accelerate the journey.

Through the analysis of process models for import processes at the case study location, this section explored the digitalization opportunities available for CBL performance improvements based on the process dimensions. The roadmap introduced acknowledges the state-of-the-art solutions and also introduces several intermediate solutions with lower investments but with high impact as well.

CONCLUSIONS

Digitalization is a compelling need for improving CBL operations and has seen significant advancements in recent years. While capital and resource-intensive digitalization options have been proposed as solutions to some of the prominent problems in CBL, this paper proposes a methodology to find solutions with lower capital intensity through leveraging existing investments. The approach is well suited for settings where digitalization efforts are at early stages with a limited appetite for capital-intensive investments.

The proposed analysis requires the processes to be captured by an appropriate notation in rich detail, a need fulfilled by a formalism based on RAD in the study reported in this paper. The systematic analysis of control, temporal, informational, organizational, functional, spatial and interactional perspectives captured in the process models can cohesively identify and prioritise the digitalization options towards achieving the swift and smooth flow of cargo. Each perspective has a spectrum of digitalization options, which can be adapted to suit the broader CBL environment and capital availability. The paper illustrates the spectrum of possibilities and the associated investments for each dimension.

The proposed framework for analysing digitalization potential offers opportunities to assess the digitalization opportunities elsewhere, as well. While process parameters play a pivotal role in the digitalization roadmap, they must be supported at the system level not only through legislation and policy but also through the upliftment of the digital literacy of society as well.

This study is based on the analysis of processes of a single case study which could be seen as a limitation. The future research efforts may include the study of CBL processes elsewhere enhancing the universal applicability of the digitalization roadmap presented.

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A Heuristic Master Planning Algorithm for Multiple Sourcing and Demand Considering Fairness

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ABSTRACT

This study proposes the multi-sourcing fairness master planning algorithm (MSFMPA) to produce a multi-sourcing master plan that satisfies the requirements of sourcing from different vendors and allocating supplies fairly. In terms of scale, MSFMPA can produce a multi-sourcing plan within 0.6 seconds that the MINLP model cannot find any feasible solution within an hour for an identical case. As for quality, MSFMPA successfully fulfills the specific sourcing requirements and the average difference of overall costs is 4%, compared with the results obtained by the MINLP model.

KEYWORDS: Supply Chain Management, Multi-Sourcing, Multiple Supplier, Procurement Allocation, Master Plan Fairness

INTRODUCTION

In a multi-sourcing supply chain network, manufacturers or distributors are having difficulty to control multiple sources of supply and various customer demands. The multi-sourcing master planning has to not only determine purchasing quantities of different vendors, but also think over how to match supplies with demands so that orders are able to be satisfied successfully. While devising a master plan, cost minimization is often not the only consideration. As minimizing the overall cost, the multi-sourcing master plan usually purchases low-cost sources of supply that may be low-quality or low-preference. Besides, the plan may allocate supplies from one vendor to a certain demand and fail to meet the customer requirements in contracts as well. Thus, to obtain a more doable and controllable plan, it is important for companies to consider sourcing preference and fair allocation.

Although multi-sourcing strategy brings a lot of advantages, comparing to coordinating with only one vendor, purchasing from multiple vendors gives rise to several issues to be consider. Suppliers usually have different capacity and provide products with some discrepancy, so companies have to pay more attention to maintain consistent quality in their own commodities. Besides, owing to the pursuit of supply chain transparency, customers carefully monitor their upstream operations information such as product quality or delivery performance (Zhu et al., 2018). Instead of providing supplies from single source to only one customer demand, firms have to allocate the supplies to different orders to avoid dissatisfaction of customers due to unfair distribution of products.

Fairness among demands from different sources is hard to define because there are too many factors, i.e., time, capacity, demand quantity, needed to be in the definition of fairness with also a unique standard to consolidate everyone's understanding (Leng, 2019). Apart from the difficulty of defining fairness, Leng (2019) also mentioned that balancing between fairness and fulfillment of all demands is another challenge. If a firm is unable to fulfill demands in accordance with due dates, it will suffer from bad reputation and customer loss. Moreover, in master production planning, manufacturers only need to take own production capacity into consideration, but this is not enough for multi-sourcing master planning. For plans purchasing supplies from more than one supplier, it is essential to evaluate the fairness between multiple sources of supply and various demands. Therefore, the concept of fairness should involve demands with different requirements and integrate all suppliers as well.

In the past master planning or scheduling problems, besides cost minimization or profit maximization, the multiple objectives also involved time, inventory level and customer satisfaction. Decreasing setup time or idle time in the production process helps firms to make good use of limited resources and process more orders (Peidro et al., 2012; Wang et al., 2017). In the supply chain operations, it is sometimes necessary for companies to hold inventories in order to satisfy demands before due dates and thus need to minimize inventories (Sawik, 2007). In addition, if demands are unfulfilled owing to delay or backorder, this will reduce customer satisfaction and even influence future business opportunities. Minimizing backorder quantities or delay penalties is also an important issue in master planning and scheduling (Chern and Hsieh, 2007; Peidro et al., 2012; Sawik, 2007).

To solve multi-objective problems, one way is to combine more than one objective with giving weight to each objective into single objective, and the other is to utilize hierarchical procedure to optimize multiple objectives. Both methods have to take the trade-off relationship between different objectives into account since achieving one objective is possible to conflict with the optimization of other objectives. For the multi-sourcing master planning problem considered in this study, the objective about fairness will not contradict by objectives such as inventories or the requirements of multi-sourcing but may have impact on cost optimization. Thus, it is essential for companies to clarify their primary objectives before solving this kind of multiple objective problem and generating a feasible plan.

As mentioned above, many companies adopt the multi-sourcing strategy and have the requirement for choosing between different sources of supply. There are two methods to possible enable multi-sourcing, one being priority and the second being quota arrangement (Snapp, 2012). First, some companies have priorities over specific suppliers. Only if the supplier with higher priority cannot satisfy demands, will the supplies with lower priority be purchased. On the other hand, adopting the quota arrangement, companies assign each supplier different percentages respectively and procure supplies according to the percentages. Assume assigning percentages of 50%, 30% and 20%, respectively, to three suppliers A, B and C, the total demands will be fulfilled with 50% from Supplier A, 30% from Supplier B and 20% from Supplier C. Although existing optimizers offer the option for multi-sourcing, this requirement fails to be satisfied by optimizers automatically and should be taken into accounts.

Previous researchers have proposed lots of models and solutions which focused on master planning and discussed how to allocate capacities to orders. There are also several studies dealing with problems of demand allocation or order allocation among multiple suppliers. However, literature seldom combines the concept of fairness into supply purchasing and allocation under the condition of multiple suppliers. Furthermore, in the real world, few companies continue to use the optimal or heuristic solutions generated by their APS (Advanced Planning and Scheduling) systems since the plans usually target cost minimization as main objective and it is not doable. Instead, the planners prefer the plans manually formulated by themselves even if the cost of manual plans is higher than the one optimizer produced. Thus, this research intends to develop a method to create a multi-sourcing master plan for multiple demands based on fairness. This plan should be tested by statistical methods and be proved that it is useful for planners as well.

In addition to aforementioned objectives, another significant issue with regard to multi-sourcing planning is the planning horizon, a time interval containing multiple periods for planning. It is not likely to formulate a plan containing only one period or crossing too many periods because demands of each period are distinct and too short or too long planning horizon is not practical for users. Moreover, for different industries, planning horizons differ and are affected by several factors such as environment of industry and flexibility of company. To sum up, the planning model should allow users to choose specific planning horizon or set up appropriate length of periods before executing multi-sourcing planning and providing results for users to decide how to allocate supplies from different vendors.

The rest of the paper is organized as follows. The problem is described in Section 2. Section 3 presents our heuristic algorithm and provides a description of the solution process and the complexity. The results obtained with our heuristic algorithm are compared with those obtained with other methods in Section 4 to evaluate the efficiency and optimality of our heuristic algorithm. Section 5 provides the conclusions of this study.

PROBLEM DESCRIPTION

The aim of this paper is to provide a feasible multi-sourcing master plan which allocates supplies to multiple demands and integrates the concept of fairness. There are three main challenges to be conquered. First, to enable multi-sourcing, the model needs to meet the requirement of choosing among different sources of supply according to methods that users choose. Second, how to quantify fairness considering demand and supplier simultaneously and transform quantified indicators into objective function is another issue to be solved. Last, the proposed model has to be validated by various cases and proved to be applicable for different scenarios.
According to the two methods Snapp (2012) mentioned allowing for multiple sourcing, we divide the first challenge into three cases: priority, quota arrangement and neither of two methods. For priority, the objective is to first allocate supply from the highest priority and then distribute the secondary priority if the capacity of higher priority is exhausted. To satisfy this requirement, we define “priority gap” to measure the extent of following the assigned priority. It is calculated as the proportion of the difference between the allocation quantity of one supplier and the maximum quantity provided by the supplier to total provided quantity of all suppliers and then divided by two. Since distributing one extra quantity from one vendor will decrease one allocation quantity of other sources of supply, the difference should be divided by two to avoid counting it twice.

Moreover, we generate “priority weight” to represent the relative necessity for minimizing the priority gap of each vendor. The weight is transformed from the priority assigned by users to each source of supply and its distribution is associated with Pareto distribution, which is sometimes expressed as the Pareto principle, or “80-20 rule”. This rule states that 80% of the wealth of a society is held by 20% of the population. In the same way, we can infer that 20% of the sources of supply with higher priority receive 80% of the emphasis on reducing priority gap. Following by Pareto distribution, we can produce a more comprehensive weight for each supplier. The index of the fulfillment of priority can then be defined as one minus the product of priority gap and priority weight. Higher priority obtains larger weights and hence the corresponding supply will be allocated to achieve their maximum as far as possible.

As to quota arrangement, we define “quota gap” which is a factor for measuring the achievement of assigned percentages. The quota gap is computed as the half difference between the percentage of supply of one supplier to total allocated supply and the assigned percentage of the same supplier. This gap means the difference between the expected percentage of using one source of supply and the actual usage, but it is influenced by the percentage assigned to each supplier and the amount of quantity one supplier can provide. The supply capacity of the supplier assigned high percentage may be the lowest among all sources of supply and this results in larger quota gap. Therefore, to eliminate the impact of provided quantity on quota gap, “quota weight” is defined to weigh the quota gap of different vendors. The weight is computed as the assigned percentage of a supplier times its maximum provided quantity and then being adjusted so that weights of all vendors are added up to 1. The index of the fulfillment of quota arrangement can be simply defined as one minus the product of quota gap and quota weight. For the third case that planners choose neither priority nor quota arrangement, we assume there is no limitation of sourcing and the model will purchase supplies based on the proportions of suppliers’ capacities.

In addition to the requirement of selecting between different vendors, another challenge is to combine the fairness concept into multi-sourcing master planning. To be concise, not only priority or quota arrangement have to be satisfied, but also fairness has to be taken into consideration. Even if one supplier has been assigned the highest priority or the largest percentage, its supply should be allocated to various demands. Because multi-sourcing master planning considers both demand and supply, we define two kinds of fairness for demand and supply respectively. First, the demand fairness is concerned with the proportions of supply from multiple vendors to a demand. The required quantity of one demand should be fulfilled by different sources of supply according to their percentages of maximum allowed quantity for allocation. Otherwise, demands may be allocated too many supplies from a specific vendor. The “demand fairness gap” is defined as the half difference between the proportional allocation quantity from one supplier and the proportion of maximum quantity allowed for allocation from the same supplier to total amount of supply. Then the index of demand fairness can be generated by one minus the sum of demand fairness gaps of all demands.

On the other hand, the supply fairness is regarding the distribution of sources of supply to multiple demands. Allocating equal amount of supply capacities to different demands is intuitive but results in that the demand requiring larger amount get relative less proportion of sources. To ensure above situation, the more ideal allocation is according to the proportions of each demand required to total demands. Therefore, the “supply fairness gap” is computed as the half difference between the ideal proportion of a source of supply allocated to one demand and the actual proportion of allocation quantity of the supplier to the same demand. Likewise, we define the index of supply fairness as one minus the sum of supply fairness gaps of all suppliers.

Lastly, it is necessary to verify whether our model is effective and feasible to solve the multi-sourcing master planning problem taking the fairness into account. We will construct a mixed integer nonlinear mathematical model starting from small scale problems and continue the validation process to more complicated cases. The results of our model must also be examined if the model is applicable for the planners in real cases or for companies with different scales of sourcing.

Before formulating a basic mathematical model, we need to define variables and parameters for a multi-objective master planning problem.

- **Parameters:**

D: The demand set.
S: The supplier set.
T: The total time period.
d: A specific demand.
s: A specific supplier.
t: A specific time period.
II_s: The initial inventory level from supplier s at the beginning of the first period.
CM_{st}: The maximum supply quantity by supplier s in period t.
PR_{st}: An ordinal number representing priority assigned of supplier s in period t.
R_{dt}: The required supply quantity for demand d in period t.
DD_d: The due date for demand d.
QP_{st}: The quota percentage assigned to supplier s in period t.
$wt_{tc,td}$: The time weight in current period tc for due period td.
wpr_{st}: The priority weight of supplier s in period t.
wq_{st}: The quota weight of supplier s in period t.
IC: The inventory holding cost per unit for a period.
FC_s: The fixed cost of placing an order to supplier s.
VC_s: The unit purchasing cost from supplier s.

The parameter PR_{st} denotes the ordinal number representing priority assigned to each supplier in each period by planners. Highest to lowest priority are set from one to the number of suppliers. Another parameter QP_{st} represents the percentage of quota assigned to each supplier in each period. For two multi-sourcing methods, the parameter wpr_{st} represents the weight for the priority of each supplier in each period. The value of weight is derived from a distribution, which takes the Pareto distribution as primary reference. A supplier assigned higher priority will obtain higher weight while the priority index is calculated. Another parameter wq_{st} represents the weight of each supplier in each period for the case of quota arrangement and it is also produced from our algorithm. The priorities or quotas assigned to vendors may change over time, so the priority index and the quota arrangement index need to be computed for each period. In addition, to take the factor of time into account, the parameter $wt_{tc,td}$ denotes the weight for adjusting the measurement of allocation and multi-sourcing related indices in current period tc for due period td. This weight also generates from a distribution referring to the Pareto distribution. As computing the indices of priority and quota arrangement, periods closed to the start of period weight more than periods far from the start of period. Since it is possible for the plan to improve the achievement of priority and quota arrangement in further periods, the indices of periods having passed cannot be revised.

- **Decision Variables:**

Q_{st}: The supply quantity from supplier s in period t.
SQ_{st}: The surplus supply quantity from supplier s in period t.

MQ_{st}:	The maximum allocation supply quantity from supplier s in period t.
AQ_{sdt}:	The allocation supply quantity from supplier s to demand d in period t.
VTC:	The total purchasing cost of the plan.
ITC:	The total inventory cost of the plan.
FTC:	The total fixed cost of the plan.
BP_{st}:	A binary variable = 1 if priority gap of supplier s is counted in period t; = 0 otherwise.
BQ_{st}:	A binary variable = 1 if quota gap of supplier s is counted in period t; = 0 otherwise.
BS_{st}:	A binary variable = 1 if the plan procures from supplier s in period t; = 0 otherwise.
PRI_t:	The priority index in period t.
QAI_t:	The quota arrangement index in period t.
FD_{dt}:	The demand fairness index for demand d at period t.
FS_{st}:	The supply fairness index for supplier s at period t.
$SPRI$:	The standard priority index.
$SQAI$:	The standard quota arrangement index.
SFI:	The standard fairness index.
STC:	The standard total cost.

The variable PRI_t denotes the priority index in each period, which ensure that the allocation quantities from sources of supply with higher priority are able to meet the maximum quantities for allocation as far as possible. Another variable QAI_t then denotes the quota arrangement index in each period, which ensure that the percentages of allocation quantities of each supplier are not far from the appointed percentages that planners require.

- **The Constraints:**

(1) $Q_{st} \leq CM_{st}\ \forall s \in S$ and $t \in T$

(2) $\sum_{t=1}^{T} \sum_{s \in S} Q_{st} + \sum_{s \in S} II_s \geq \sum_{t=1}^{T} \sum_{d \in D} R_{dt}$

(3) $SQ_{st} = SQ_{s,t-1} + CM_{st} - Q_{st}\ \forall s \in S$ and $t \in T$

(4) $MQ_{s1} = Q_{s1} + II_s\ \forall s \in S$

(5) $MQ_{st} = Q_{st}\ \forall s \in S$ and $t = 2, 3, \ldots,$

(6) $\sum_{d \in D} AQ_{sdt} \leq MQ_{st}\ \forall s \in S$ and $t = 1, 2, \ldots, T$

(7) $\sum_{t=1}^{DD_d} \sum_{s \in S} AQ_{sdt} = \sum_{t=1}^{DD_d} R_d\ \forall d \in D$

(8) $M \times (1 - BP_{st}) \geq \sum_{i=1}^{PR_{st}} CM_{it} - \sum_{l=1}^{s} \sum_{d \in D} AQ_{ldt} \geq -(M \times BP_{st}) + m$
$\forall BP_{st} \in \{0, 1\}, \forall s \in S, \forall t = 1, 2, \ldots, T$, M is a large number, and m is a small number.

(9) $M \times BQ_{st} \geq CM_{st} \geq m \times BP_{st}$
$\forall BQ_{st} \in \{0, 1\}, \forall s \in S, \forall t = 1, 2, \ldots, T$, M is a large number, and m is a small number.

(10) $PRI_t = 1 - \left(\sum_{s \in S} \left| \frac{\sum_{d \in D} AQ_{sdt} - CM_{st}}{\sum_{i=1}^{s} CM_{it}} \right| \right) \times \frac{1}{2} \times wpr_{st} \times BP_{st}\ \forall t \in T$

(11) $QAI_t = 1 - \left(\sum_{s \in S} \left| \frac{\sum_{d \in D} AQ_{sdt}}{\sum_{i=1}^{s} \sum_{d \in D} AQ_{idt}} - Q_{st} \right| \right) \times \frac{1}{2} \times wq_{st} \times BQ_{st}\ \forall t \in T$

(12) $FD_d = 1 - \left(\sum_{s \in S} \left| \frac{\sum_{t=1}^{T} AQ_{sdt}}{\sum_{i=1}^{s} \sum_{t=1}^{T} AQ_{idt}} - \frac{\sum_{t=1}^{T} MQ_{st}}{\sum_{i=1}^{s} \sum_{t=1}^{T} MQ_{it}} \right| \right) \times \frac{1}{2}\ \forall d \in D$

(13) $FS_s = 1 - \left(\sum_{d \in D} \left| \frac{\sum_{t=1}^{T} AQ_{sdt}}{\sum_{j=1}^{d} \sum_{t=1}^{T} AQ_{sjt}} - \frac{\sum_{t=1}^{T} R_{dt}}{\sum_{j=1}^{d} \sum_{t=1}^{T} R_{dt}} \right| \right) \times \frac{1}{2}\ \forall s \in S$

(14) $M \times BS_{st} \geq Q_{st}$ $\forall BS_{st} \in \{0, 1\}$, $s \in S$, and $t = 1, 2, \ldots, T$, M is a large number.

(15) $ITC = IC \times [\sum_{s \in S} II_s + \sum_{t=1}^{T} (\sum_{k=1}^{t} \sum_{s \in S} Q_{sk} - \sum_{d \in D'} R_d)]$ where $D' \in \{d \mid d \in D$ and $DD_d \leq t\}$

(16) $FTC = \sum_{t=1}^{T} \sum_{s \in S} BS_{st} \times FC_s$

(17) $VTC = \sum_{t=1}^{T} \sum_{s \in S} VC_s \times Q_{st}$

- **The Multi-Stage Objective Functions:**

In this study, a three-phase optimization process was used to this study to solve the problem, which are the maximization of multi-sourcing related indices, the maximization of fairness index and the minimization of total costs. For maximizing the multi-sourcing related indices, it can be separated into two objective functions: priority and quota arrangement. Planners can choose to maximize either priority index or quota arrangement index. Three objectives had to be accomplished: (1) Maximize the priority index (*SRPI*) or the quota arrangement index (*SQAI*); (2) Maximize the fairness index (*SFI*); and (3) Minimize the total costs (*TC*). The constraints to be added after each stage of optimization is completed. Constraint (18) limits the following stages of optimization program that the priority index or quota arrangement index should not be less than standard priority index or quota arrangement index after the maximizing priority or quota arrangement stage is completed. Constraint (19) limits the following stages of optimization that the fairness index should not be less than standard fairness index after the maximizing fairness stage is completed.

Objective 1: Maximize the priority index, *SRPI*, or the quota arrangement index, *SQAI*.
Max. $SRPI = \Sigma_{t=1}^{T} (PRI_t) \times w_{tT}$ or $SQAI = \Sigma_{t=1}^{T} (QAI_t) \times w_{tT}$
$s.t.$ Constraints (1) to (17)

Objective 2: Maximize the fairness index, *SFI*.
Max. $SFI = \Sigma_{t=1}^{T} \left(\frac{\sum_{d \in D} FD_{dt} + \sum_{s \in S} FS_{st}}{2} \right) \times \frac{1}{2}$
$s.t.$ Constraints (1) to (17) and

(18) $\Sigma_{t=1}^{T} (PRI_t) \times w_{tT} \geq SRPI$ or $\Sigma_{t=1}^{T} (QAI_t) \times w_{tT} \geq SQAI$

Objective 3: Minimize the total costs, *STC*.
Min. $STC = VTC + ITC + FTC$
$s.t.$ Constraints (1) to (17) and

(18) $\Sigma_{t=1}^{T} (PRI_t) \times w_{tT} \geq SRPI$ or $\Sigma_{t=1}^{T} (QAI_t) \times w_{tT} \geq SQAI$

(19) $\Sigma_{t=1}^{T} \left(\frac{\sum_{d \in D} FD_{dt} + \sum_{s \in S} FS_{st}}{2} \right) \times \frac{1}{2} \geq SFI$

THE HEURISTIC MULTI-SOURCING FAIRNESS MASTER PLANNING ALGORITHM (MSFMPA)

This study has formulated a nonlinear multi-objective mathematical model to solve the multi-sourcing master planning problem considering fairness in Section 2. However, as the problem size increases, the complexity of solving the model grows exponentially. It is impractical to use the mathematical model because the solving process requires considerable time and computer resources and even the solution may not be found. Thus, we propose a heuristic algorithm, called Multi-Sourcing Fairness Master Planning Algorithm (MSFMPA) to effectively solve the multi-sourcing master planning problem considering fairness. By adopting MSFMPA, the available supplies are allocated to different demands in the fairest condition to produce a multi-sourcing master plan. The product quantity of demand or supply is the smallest calculation unit of this algorithm. Demand requests different quantities of supply and the supply capacities of vendors also differ in quantity.

The main process of MSFMPA includes five phases: preliminary works, maximum allocation quantity determination, supplementary measures, fair supply allocation and overall performance calculation. For preliminary works, the algorithm computes the essential weights and constructs an initial table to record the deserved quantities of each demand in each period. For maximum allocation quantity determination, the amount of supply from different vendors are decided according to the multi-sourcing method chosen. For supplementary measures, we handle some additional problems such as the usage of supply from previous periods and the shortage of supply. For fair supply allocation, the determined maximum allocation quantities are allocated to demands according to the table of deserved quantities. For overall performance calculation, the algorithm calculates the multi-sourcing related indices, the fairness index and the overall cost for the plan. Each of the five phases will be discussed in detail in the following subsections.

For company choosing priority as the multi-souring method, supply from vendors with higher priority should be used up as many as possible to the maximum quantities that vendors are able to provide. It is necessary to transform the priority assigned into numerical values so that priority gap of different suppliers can be weighed while computing the priority index. The priority weight (wpr_{st}) is one of the parameters for our mathematical model in Section 2 and is derived from the Pareto distribution. The cumulative distribution function of a Pareto random variable is 1 – $(x_{min} / x)^{\alpha}$ where x is a value in the domain, x_{min} is the minimum value and α is the Pareto index (Pareto, 1906). Taking advantage of the distribution's large curvature to widen the differences among suppliers, we apply the original function, where x denotes the reverse ordinal number representing the priority of a supplier and x_{min} denotes the minimum value of ordinal numbers, namely 1. Besides, the computation of priority weight has to consider previous weights to keep the sum of priority weights of all suppliers as 1 in each period. Thus, the priority weight in a period for a specific supplier can be written as:

$$wpr_{st}=\left(1-\sum_{k=1}^{t-1} wpr_{sk}\right)\times\left[1-\left(\frac{1}{PR_{lowest,t}-PR_{s,t}+1}\right)^{\alpha_p}\right] \quad (1)$$

Likewise, the calculation of the quota arrangement index needs quota weight (wq_{st}) to weigh different suppliers' quota gap. Our algorithm multiplies the assigned percentage of one supplier by its maximum provided quantity to obtain the weighting percentage. Then the quota weight of a supplier in a specific period is computed as the weighting percentage of the supplier divided by the total weighting percentage to ensure the sum of all weights equals 1. We can write the formula of the quota weight as follows:

$$wq_{st}=\frac{QP_{st}\times CM_{st}}{\sum_{i=1}^{S} QP_{it}\times CM_{it}} \quad (2)$$

To avoid delay due to unexpected events, companies often start purchasing from sources of supply earlier and preparing supply for demands in advance. It is necessary to take the factor of time into account to develop a multi-sourcing plan and adjust the measurement of multi-sourcing related indices. The time weight ($wt_{tc,td}$) for each period approximately follows the Pareto distribution as well. According to the weight calculation proposed by Leng (2019), because of large curvature of the Pareto distribution, the weights for further periods are much lower than the more recent periods and even less than 1% if the planning horizon is more than five periods. Thus, the original cumulative distribution function should be adjusted to 1 – $[(x - x_{min}) / x]^{\alpha}$. We apply the adjusted function to compute the time weight for each period, where $\boldsymbol{x}$ denotes the current remaining period before due period of a demand, x_{min} denotes the minimum value of period, namely 1. Similar to the priority weight, the calculation of time weight also needs to consider previous weights so that the sum of weights of different x always equal to 1 for each length of planning horizon before due period. The weight chosen will be also applied to the mathematical model proposed in Section 2 as a parameter. Once time weights are applied, the model are able to be adjusted on the basis of timeline.

After time weights generated from the Pareto distribution are assigned, MSFMPA constructs a deserved quantity table for all demands in each period. The sum of deserved quantities in a specific period may exceed the amount of quantities that companies can purchase from suppliers. This causes deserved quantities unable to be fulfilled in that period will be postponed to the following periods and hence changes the quantity distribution derived from time weights. Therefore, MSFMPA computes the other kind of deserved quantity, which is computed as the total maximum provided quantities in the period is multiplied by the ratio of deserved quantity of the demand to total deserved quantities. After obtaining both deserved quantities generated from the required quantity and provided quantity, the algorithm chooses the smaller one. Moreover, to prevent demands due in the current period from not being satisfied owing to the choice of smaller quantity, the deserved quantity in the due period is the total left required quantity of the demand.

The last problem is regarding the conflict between demands with different due periods. To rationalize the distribution of deserved quantity between demands, that research developed the prioritizing mechanism, which is also adopted in this study, to deal with the conflict. The mechanism prioritizes each demand by dividing the number of periods left before due period when calculating the ratio of deserved quantity of the demand to total deserved quantities

Although the more reasonable distribution of supply to demands across different periods can be created by the prioritizing mechanism, the problem of capacity snatch still exists in some extreme cases. The planning window is designed to prevent demands due in further periods from snatching the supply capacity of more urgent demands soon and it will keep moving until reaching the end period of planning horizon. MSFMPA fix the planning window size set as a constant for all demands and apply the rolling window procedure, during which a demand can be allocated supply only when its due period falls in the current planning window. As the preparation for supply allocation, the initial deserved quantity table should be constructed on the basis of planning window and thus we adjust the calculation of deserved quantity as follows:

$$DQ_{dt} = \begin{cases} \min\left(\begin{array}{c} Dct_d \times R_d \times wt_{DD_d - t+1,\, DD_d}, \\ \sum_{i=1}^{S} CM_{it} \times \frac{Dct_d \times R_d \times wt_{DD_d - t+1,\, DD_d} / pl_d}{\sum_{j=1}^{D} Dct_j \times R_j \times wt_{DD_j - t+1,\, DD_j} / pl_j} \end{array} \right) & t \neq DD_d \\ R_d - \sum_{k=1}^{t-1} DQ_{dk} \quad t = DD_d \end{cases} \quad (3)$$

where pl_d is the number of periods left before due period of demand d and Dct_d represents whether demand d should be counted under the current planning window.

For the phase of maximum allocation quantity determination, MSFMPA handles two additional problems. First, if the total CM_{st} in a specific period is unable to fulfill the total deserved quantity of that period, the difference between CM_{st} and total deserved quantity should be resolved by the quantity saved in the previous period. Second, even though CM_{st} is supplemented by the saved quantity, it may not sufficient for some situations and results in the case of supply shortage. As the case occurs, the algorithm has to overcome this difficulty before proceeding to the phase of fair supply allocation.

Through purchasing extra supply in previous periods, we supplement CM_{st} by the saved quantity before the current period and record the supplementary quantities as CM_{st} of the corresponding periods. In the case of priority, it is intuitive to start supplement from the source of supply with the highest priority until all unallocated quantity of the supplier are used up and then move to the lower priority. To prevent from purchasing supply too early and increasing inventory, for each supplier, we should supplement CM_{st} from the previous period which is the closest to the current period. The supplement procedure will finish when the difference between total CM_{st} and total deserved quantity disappears.

As to the quota arrangement method and the case in neither way, how to supplement is influenced by the percentages assigned or computed. The CM_{st} of a specific supplier is first supplemented by its own saved quantity from the most recent period to the first period. However, if the saved quantity from itself cannot reach the amount of quantity the supplier should provide, the algorithm will begin to supplement CM_{st} by the saved quantity of other suppliers. MSFMPA calculates the proportion of remaining saved quantity of each other vendor and obtains the quantity for supplement via multiplying the difference left by the proportions. Finally, CM_{st} is supplemented by the quantity calculated above. Although this way leads to the deviation from the percentages that we originally hope to follow, satisfying demands is more important and hence the tradeoff is inevitable under the consideration of both percentage and fulfillment.

While the case of supply shortage occurs, MSFMPA checks whether CM_{st} can fulfill the deserved quantity of due demands in the period. Supposing total CM_{st} is greater than or equal to the deserved quantity of due demands, the algorithm will decrease the deserved quantity of undue demands in proportion to their deserved quantities in the period and add the decreased quantity to the next period. After this adjustment finishes, MSFMPA recalculate the deserved quantities in subsequent periods and updates the deserved quantity table.

On the contrary, if CM_{st} is less than the deserved quantities of due demands, it means that there are demands unable to be fulfilled on time and we have to give up some of them. The demands chosen to be fulfilled prior to other demands are called “enforced demand,” which are selected in advance by the user before the algorithm starts. Once CM_{st} can fulfill the enforced due demands, MSFMPA will retrieve all allocated quantities of due demands not selected as enforced, reconstruct the initial deserved quantity table which excludes the unenforced due demands and rerun the phase of maximum allocation quantity determination. After re-determination completes, the user can choose to allocate the remaining supply to unenforced demands according to the proportion of original deserved quantity in each period of the demands or just record the remaining quantity in the next phase of supply allocation. As for the other condition that CM_{st} is not enough for the enforced due demands, the algorithm will terminate and allow the user to reselect the enforced demands.

In this phase, MSFMPA allocates the CM_{st} of each supplier to demands based on the proportion of each demand's deserved quantity to total deserved quantity in the current period. Furthermore, considering the case of supply supplement, the supplementary quantities have been recorded as CM_{st} of the previous periods so the CM_{st} allocation are also performed for all periods before the current period. The following is the formula of allocation quantity (AQ_{sdt}):

$$AQ_{sdt} = CM_{st} \times \frac{DQ_{dt}}{\sum_{j=1}^{D} DQ_{jt}} \quad (8)$$

In the final phase, MSFMPA calculates the multi-sourcing related indices, the fairness index and the total cost based on the plan generated for each window size. The unit inventory cost, the fixed cost and the unit purchasing cost are all given as parameters before the algorithm starts. MSFMPA will produces a detailed report containing the indices for each time, demand or supplier and the three kinds of cost in each period. The computations of multi-sourcing related indices, priority index and quota arrangement index, are listed in the three objective functions, which multiply the index in each period by the corresponding time weight following Formula (3). It is notable that the extra supply of vendors with lower priority and the situation of no supply capacity in some periods lead to the decrease in the priority and quota arrangement index. Thus, like the mathematical model in Section 2, we should not regard the two situations as priority gap and quota gap in the multi-sourcing related indices. In addition, these two indices are relevant to suppliers so their calculation contains the priority weight and the quota arrangement weight to balance the different supply conditions of vendors.

COMPUTATIONAL ANALYSIS

This study developed a prototype based on MSFMPA using R programing language. On the other hand, the MINLP model proposed in Section 2 was solved by Lingo® 17.0. Both the mathematical model and the MSFMPA-based prototype were done on a PC with Intel® Core™ i7-7700 CPU, 32 GB RAM and Microsoft® Windows 10.

To demonstrate the accuracy and ability of the algorithm for achieving the near-optimal solutions, we design 24 scenarios and compare the results of the MSFMPA-based prototype with the MINLP model. These scenarios are relatively smaller in scale due to the limited capacity of Lingo® 17.0. Four factors, including multi-sourcing case, diversity of provided quantities from suppliers, diversity of required quantities of demands and diversity of due dates of demands, are taken into accounts. Apart from three multi-sourcing cases, each factor has two indicators: low and high diversity of provided quantities, low and high diversity of required quantities, and equal and unequal due dates. The planning horizon is set as 6 periods with 3 suppliers and 2 demands for all scenarios. Low diversity of maximum provided quantities is set as [100, 100, 100] while high diversity is [30, 90, 180]. Low diversity of required quantities is set as [500, 500] while high diversity is [100, 900]. All due dates are set as the last period for equal due date while due dates are [2, 6] for unequal due date.

The optimal solutions of the proposed algorithm are the ones with the maximal multi-sourcing related indices and the fairness index. In contrast, we regard the planning results obtained by Lingo® 17.0 as the near-optimal solutions in terms of the minimum total cost. Since the objectives of the prototype and the MINLP model are different, we make comparison from two aspects. One is to compare the priority index, the quota arrangement index and the fairness index of the solutions of the MSFMPA-based prototype with the ones of the MINLP model that only optimizes the overall cost as small as possible. The other aspect is to compare the total cost under the same conditions of multi-sourcing and fairness. Thus, we set the multi-sourcing related indices and the fairness index produced by the MSFMPA-based prototype as the constraints of the MINLP model. The only step for Lingo® 17.0 to solve the MINLP model is to minimize the total cost. Otherwise, when the MINLP model is solved by multi-objective optimization, the constraints tend to be too strict for Lingo® 17.0 to solve at the next stage. Furthermore, we set the upper bound of execution time for Lingo® 17.0 to solve the MINLP model. For the tests minimizing cost regardless of the indices, 30 minutes are given. As for the tests minimizing cost with the indices produced by MSFMPA as constraints, 60 minutes are given. While Lingo® 17.0 cannot find any feasible solution or the feasible solution is unable to be found within the given time, we allow Lingo® 17.0 to continue to search for the solution with double or more execution time.

Table 1: Test Results of 24 Scenarios

Scenario ID	MSFMPA			MINLP				Difference	
	PRI_t / QAI_t	Fairness	Exec. Time	PRI_t / QAI_t	Fairness	Exec. Time	State	PRI_t / QAI_t	Fairness
1 (PLLE)	1	1	0.68	0.96938	0.8914	>1800	LFS	-3.06%	-4%
2 (PLLU)	1	0.91353	0.61	1	1	32.51	BFS	0.00%	9%
3 (PLHE)	1	1	0.56	1	1	234.32	BFS	0.00%	0%
4 (PLHU)	1	0.91018	0.54	0.96527	0.85729	4.48	BFS	-3.47%	-15%
5 (PHLE)	1	1	0.63	0.99081	0.95661	>1800	LFS	-0.92%	-11%
6 (PHLU)	1	0.91531	0.63	0.98111	1	1262.3	BFS	-1.89%	9%
7 (PHHE)	1	1	0.56	0.99081	0.99625	>1800	LFS	-0.92%	0%
8 (PHHU)	1	0.92134	0.59	0.98958	0.775	45.41	BFS	-1.04%	-7%
9 (QLLE)	0.99878	0.99211	0.68	0.97172	0.8914	>1800	LFS	-2.71%	-4%
10 (QLLU)	0.99089	0.98519	0.65	0.97154	1	32.51	BFS	-1.95%	2%
11 (QLHE)	0.99856	0.99213	0.54	0.97172	1	234.32	BFS	-2.69%	0%
12 (QLHU)	0.99889	0.99625	0.62	0.96578	0.85729	4.48	BFS	-3.31%	-22%
13 (QHLE)	1	1	0.55	0.97014	0.95661	>1800	LFS	-2.99%	-11%
14 (QHLU)	1	1	0.53	0.95019	1	1262.3	BFS	-4.98%	0%
15 (QHHE)	1	1	0.57	0.97014	0.99625	>1800	LFS	-2.99%	0%
16 (QHHU)	1	1	0.60	0.96613	0.775	45.41	BFS	-3.39%	-14%
17 (NLLE)	N/A	0.999	0.57	N/A	0.8914	>1800	LFS	N/A	-4%
18 (NLLU)	N/A	1	0.59	N/A	1	32.51	BFS	N/A	0%
19 (NLHE)	N/A	0.99773	0.59	N/A	1	234.32	BFS	N/A	0%
20 (NLHU)	N/A	0.99773	0.54	N/A	0.85729	4.48	BFS	N/A	-22%
21 (NHLE)	N/A	1	0.66	N/A	0.95661	>1800	LFS	N/A	-11%
22 (NHLU)	N/A	1	0.59	N/A	1	1262.3	BFS	N/A	0%
23 (NHHE)	N/A	1	0.57	N/A	0.99625	>1800	LFS	N/A	0%
24 (NHHU)	N/A	1	0.54	N/A	0.775	45.41	BFS	N/A	-14%

p.s. For scenario ID, the first letter, P, Q or N, stands for priority, quota arrangement and neither method; the second letter, L or H, stands for low or high diversity of provided quantities; the third letter, L or H, stands for low or high diversity of required quantities; the last letter, E or U, stands for equal or unequal due dates.

The comparison of multi-sourcing related indices and fairness index between the MSFMPA-based prototype and the MINLP model is shown in Table 1. The second to the fourth column are the priority index or the quota arrangement index, the fairness index and the execution time obtained by the MSFMPA-based prototype. They correspond to the results produced by Lingo® 17.0 in the fifth to the seventh column. The unit of the execution time is second and the sign ">" means the MINLP model has outputted local solutions but the program is still in progress in order to search for dual or best solution. The fairness indices and execution times among three methods are the same since the MINLP model only minimizes the total cost and the values of indices are computed based on the solutions generated. The eighth column is the state of solution, where LFS and BFS respectively mean the local and best feasible solution found within the given execution time. The ninth and the tenth column are the differences in percentage of multi-sourcing related indices and fairness index between the MSFMPA-based prototype and the MINLP model.

From Table 1, we discover that it takes more time for Lingo® 17.0 to solve the scenarios with equal due dates and usually only find local feasible solutions within the given execution time. The test results also demonstrate that, comparing to the MINLP model focusing on searching for the lowest total cost, the MSFMPA-based prototype can generate solutions that fulfill the multi-sourcing requirement as far as possible with average 1.41 % higher priority index and average 3.13% higher quota arrangement index. Expect for Scenarios 2 (PLLU) and 6 (PHLU) that produce lower fairness index, the proposed algorithm also can achieve 6% higher degree of fairness than the MINLP model in most scenarios.

CONCLUSIONS

The purpose of this study is to solve the multi-sourcing master planning problem considering different sourcing methods and fairness. A nonlinear multi-objective mathematical model has been formulated in this study. However, as the problem sizes increases, the complexity of solving the mathematical model grows exponentially. It takes over an hour for a software specializing in solving nonlinear mathematical to find the optimal solutions for some cases. Thus, this study proposes a heuristic algorithm, called Multi-Sourcing Fairness Master Planning Algorithm (MSFMPA), to effectively solve the multi-sourcing master planning problem.

The greatest challenge for solving the multi-sourcing master planning problem considering fairness is to fulfill different sourcing requirements and integrate the concept of fairness simultaneously. Three critical issues have to be addressed in this study. First, to enable multi-sourcing, it is necessary to meet the requirement of choosing among different sources of supply according to methods users choose. Second, quantifying fairness considering demands and suppliers and transforming quantified indicators into objective function are the keys to solving the multi-sourcing master planning problem considering fairness. Last, the final issue is to verify the results by various cases to ensure the applicability for different scenarios.

The main process of MSFMPA comprises five phases including preliminary works, maximum allocation quantity determination, supplementary measures, fair supply allocation and overall performance calculation. For preliminary works, the algorithm computes the essential weights and constructs an initial deserved quantity table. For maximum allocation quantity determination, the amount of supply from different vendors are decided on the basis of the multi-sourcing method chosen. For supplementary measures, we handle some additional problems such as the supplement for supply from previous periods and the shortage of supply. For fair supply allocation, the determined maximum allocation quantities are iteratively allocated to demands according to the deserved quantity table. For overall performance calculation, the algorithm calculates the indices and the overall cost for the plan.

A MSFMPA-based prototype is developed in this study. Total 24 scenarios are designed to compare the results of the MSFMPA-based prototype with the ones of the MINLP model solved by Lingo® 17.0. According to the results, the average total cost difference in percentage between the costs of the MSFMPA-based prototype and the ones of the MINLP model is 4% under the same constraint of indices.

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A machine-learning approach to fight pandemic diseases in elderly people

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ABSTRACT

Even though the recent pandemic COVID-19 case fatality rate did not fall under category 5 pandemic storm severity index formalized by the center of disease (CDC) prevention control, the death toll in US was close to half a million. The impact of vaccine may have started to take effect starting March 2021. The question is what will happen to our elderly group if a new category 5 COVID-19-like disease shows up. This article proposes a rule-based machine learning approach to fight the disease. The rules will have a significant impact in creating effective public health policies.

KEYWORDS: Artificial Intelligence, Machine learning, Decision rules, Pandemic diseases, Public health policy

INTRODUCTION

Past research (Yang et al., 2020, Jain et al. 2020) found that the severity of COVID-19 like diseases widely varies based on modifiable pre-existing conditions along with non-modifiable factors such as age and ethnicity. Advanced age is one of the key risk factors for case severity and progression to death. There is, however, a chasm between recommendations from past studies and the need for a new approach for treating aged people successfully for pandemic diseases in the pre-vaccination stage. Past studies mainly focused on a few factors in isolation. Health professionals and policy makers cannot apply their findings to improve the survival rate in the early life cycle of the disease. For example, we lost close to a half a million lives in US before the vaccines arrived.

The *central hypothesis* is that genetic predisposition is not always the determining factor in surviving infectious diseases. The author proposes to test the central hypothesis by researching the complex relationships between the fatality and many modifiable factors (preexisting diseases, eating style, living environment, mental attributes, and, social behavior among others) in combination with age and ethnicity, to improve the survival rate for the elderly people. This is an innovative approach that applies deep health analytics (DHA). DHA will employ machine learning algorithms to learn connections between the factors and the risk of death. The rationale for this is to prevent death from future pandemic diseases before the vaccines arrive. The overall strategy is to successfully achieve three specific aims – (i) create a large database of the relevant factors and patients' outcome by compiling and merging available data; (ii) apply ensemble methods like "random forest" that extract meaningful decision-making rule-based patterns for specific recommendations to patients; and (iii) predict the probability of patients' death using other DHA methods. The expected outcome is to create a massive set of decision rules to diagnose and treat patients successfully. The findings along with potential future meta-analytic research, will have sustainable impacts on the practice of medicine and the development of important health policies related to pandemic diseases.

PROPOSED APPROACH AND INNOVATION

To the best of our knowledge, we have not found any databases equivalent to the one we propose to build in Aim 1. The future study should work diligently with the department of health (DOH) of various cities. The DOHs had been gathering de-identified data on COVID-19 from the case tracing data base. The researchers can use the data for potential future studies.

The main problem with the previous studies related to Aims 2 and 3 is that their research focused on a few factors in isolation. Health professionals and policy makers could not suggest additional recommendations to patients to improve the survival rate in the early life cycle of the pandemic. For example, studies finding a relationship between comorbidities from diabetes and COVID-19 death do not add any additional meaningful therapeutic values for the elderly people for prevention or treatment. Physicians are already advising patients to manage diabetes whether they are infected with COVID-19 or not. The past studies also did not look at the detailed levels of modifiable factors together in multiple dimensions. For example, without recommendations for specific level of A1C, physicians treated patients with diabetes aggressively for fear of adverse outcome from COVID-19. American College of Physicians (ACP) found out that there are risks from iatrogenic causes, one of the leading causes of deaths in US, to unnecessarily treat diabetic patients with drugs to achieve A1C to 6.5 or below. ACP suggested that this aggressive approach causes more harm than good (Qaseem et al., 2018). The iatrogenic causes of unnecessary deaths arise because physicians do not pay attention to the facts that many preconceived notions in the practice of medicine are not properly vetted through DHA.

Significance of the Expected Research Contribution

Use of DHA will remove such preconceived biases from the treatment of pandemic diseases. Accurate information will prevent such costly medical mistakes and improve survival of patients. This improvement is also applicable to formalization of useful government health policies. Sometimes health policies based not on proper statistical evidence generate unnecessary anxiety into people’s mind. In addition, DHA will eliminate unnecessary cost such as testing, procedures, medicine, and drug side effects among other. This will enhance patients’ expected quality of life scores.

Innovation

The good news is that more eighty-plus infected people survived COVID-19 than those who succumbed to it. The survival rate, however, is lower in the eighty-plus age group compared to the other age group. We should ask - What characteristics does this surviving group have that the other group does not? The answer should be in the complex relationship between the death rate and several factors (both modifiable and non-modifiable).

The *central hypothesis* is that genetic predisposition is not always the determining factor in surviving infectious pandemic diseases like COVID-19. We can improve the survival rate by changing patients’ life style modifiable factors that affect longevity and favorably impact the survival. We propose to use the factors used simultaneously to find meaningful rules. For example, the proposed research might generate a rule such as – if A1C is greater than a threshold 1, and, systolic blood pressure (BP) is greater than threshold 2, and, A1C is greater than a threshold 3, and, the age is greater than a threshold 4, then the risk of succumbing to COVID-19 like disease is high. Machine leaning algorithms will learn the complex non-linear relationship between the factors and the risk categories what traditional methods like "linear regression" cannot learn.

To the best of our knowledge, no previous study exists that generated a set of rules involving modifiable factors to improve outcomes of pandemic infectious diseases. The innovation in our approach is in finding the massive set of decision rules that unlocks the key to successful survival. This means that the study needs to test the central hypothesis on hundreds of combinations of training and test samples.

APPROACH

Data Design – Aim 1, Aim 2, and Aim 3

The study should gather the socio-demographic, and economic, and archival clinical data from the participating programs and store in secured HIPPA complaint servers. The research will collect data from DOH of various cities. Case tracing data consists of all COVID 19 cases in the region. All data is anatomized and managed through an IRB agreement. The data resides on a *HIPPA compliance server* accessible to the research team.

Research Design – Aim 2

The emerging area of *health analytics* applies the process of analyzing disease databases to identify pattern rules. Future research adopting this strategy will predict the target variable – risk categories – classified from the patients' outcome. It is easier for practitioners and policy makers to understand risk categories instead of a specific probability. The initial categories can be – high risk, medium risk, and, low risk. A further analysis can suggest more categories. In that case, the study will repeat the analysis with more categories. The predictors will be the modifiable and non-modifiable factors. The research will use hundreds of combinations of training and test data to ensure *generalization* of the extracted set of rules. Automatic pruning of tree branches will also enhance generalization.

Expected Outcome – Aim 2

A previous study (Mukhopadhyay et al., 2021) performed a disease detection analytics on breast cancer and diabetes incidences. Table 1, adapted from the study) presents a sample set of rules extracted by a decision tree (DT) classifier from the study. The values of the measurement attributes and frequencies are given in the parentheses. The class assignment is based on the probability estimates and a cut-off value. The study can apply classification and regression tree (CART) (Breiman et al., 1984), along with random forests bagging approach (Ho, 1998). Physicians can assess the risk from the DHA rules. They will also be able to diagnose new patients for specific diseases.

Research Design – Aim 3

Aim 3 calls for testing the accuracies of the *repository of rules* generated in Aim 2 stage with other methods. However, the model will also look for probabilistic estimates of the target variable. The study will achieve this mainly by two methodologies. First, the study will identify the pruned tree branches and the corresponding attributes (factors). The study will check whether the other methods choose similar set of attributes (in the significant rules) that impact patients' outcomes. Second, the study will ensure that there are no statistically significant differences between the predictive accuracy of the "decision tree & random forests ensemble" and the other methods. DHA can use a collection of statistical methods such as neural network (Rumelhart et l., 1988), k-nearest-neighbor (Souman et al., 2012), support-vector-machine (Cortes & Vapnik, 1995), naïve Bayes (Duda et al., 2000), and traditional statistical method - logistic regression (Volmer, 1996). The research can compare accuracies of various classification methods. Like Aim 2 before, the research will use hundreds of combinations of training and test data to ensure generalization of the generated rules.

Expected Outcome – Aim 3

The collection of statistical methods applied on the same combinations of training and test sets will ensure that rules extracted in aim 2 are generating accurate classification. If the rules in aim 2 are not accurate then they cannot be applied in practice. However, the chance of happening that is low as the "decision tree" and the "random forest" methods use advanced pruning techniques for generalization.

Table 1: A Sample Set of Rules for Predicting Breast Cancer Malignancies (Adapted from Mukhopadhyay et al., 2021)
Note: the predicted value (0-benign and 1=malignant) and the fraction of observations for each level of the response variable are displayed for each terminal node. The nodes are not numbered consecutively because only terminal nodes (leaves) are included. The splits that lead to each leaf are shown above the predicted value and fractions.

```
*------------------------------------------------------------*
NODE = 5
*------------------------------------------------------------*
MISSING(Single Epithelial Cell Size) OR (Single Epithelial Cell Size < 4.06)
AND (Bare Nuclei < 2.08)
AND (Uniformity of Cell Shape >= 2.08)
   PREDICTED VALUE IS 0
   PREDICTED 0 = 0.931( 27/29)
   PREDICTED 1 = 0.06897( 2/29)
*------------------------------------------------------------*
NODE = 4
*------------------------------------------------------------*
MISSING(Bare Nuclei) OR (Bare Nuclei >= 2.08)
AND (Uniformity of Cell Shape >= 2.08)
   PREDICTED VALUE IS 1
   PREDICTED 0 = 0.05236( 10/191)
   PREDICTED 1 = 0.9476( 181/191)
*------------------------------------------------------------*
NODE = 6
*------------------------------------------------------------*
(Single Epithelial Cell Size >= 4.06)
AND (Bare Nuclei < 2.08)
AND (Uniformity of Cell Shape >= 2.08)
   PREDICTED VALUE IS 1
   PREDICTED 0 = 0( 0/13)
   PREDICTED 1 = 1( 13/13)
*------------------------------------------------------------*
NODE = 1
*------------------------------------------------------------*
MISSING(Uniformity of Cell Shape) OR (Uniformity of Cell Shape < 2.08)
   PREDICTED VALUE IS 0
   PREDICTED 0 = 0.9744( 305/313)
   PREDICTED 1 = 0.02556( 8/313)
```

Expected Outcome – Aim 3

The study can validate and finalize the set of rules (recommendations) for improving the survival in the pre-vaccine stage of future pandemic diseases.

CONCLUSIONS

The proposed research is relevant to public health because it focuses on developing strategies using machine-learning-generated set of rules that can help elderly people to modify factors related to their living styles. The strategy to modify living style can help elderly people to survive during a COVID-19 like pandemic. Once such strategies have been developed, there is the potential for a significant advance in improving the survival rate of aged people during the pre-vaccine life cycle stage of the pandemic disease. Thus, the proposed research is relevant to building effective health policies during a pandemic disease cycle.

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A Multi-supplier Purchase Order Allocation Model for Optimal Landed Cost

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ABSTRACT

The procurement department is central to multinational companies and the landed cost is the most essential factor that affects the selling price of products. We analyze the purchase order system of a multinational company as a case study to achieve the optimal landed cost. Through data analysis and regression fitting, we develop a multi-supplier purchase order allocation model considering factors of purchase quantity distribution, delivery delay, quality level, and landed cost. The model can be applied in annual purchase planning to set up an order quantity allocation scheme for annual order negotiation with multiple suppliers.

KEYWORDS: Purchase Order Allocation, Landed Cost, Delivery Delay, Quality Level

INTRODUCTION

The landed cost (LC), which refers to the purchase price of products plus all associated shipping and logistics costs required to get the products delivered to a final destination, is highly affected by three key factors: purchase price (PP), delivery time (DT), and quality level (QL). LC has a great impact on the business development of a company, especially a multinational company. Every company chases lower PP, shorter DT, and higher QL in order to minimize the total cost from different suppliers even though it is impossible to achieve optimal levels for all these three factors at the same time in a complex global supply network. Before the essential annual order negotiation, how do purchasing managers decide the negotiation strategy and allocate purchase orders for different suppliers to minimize LC? We investigate this issue through a case study of a multinational company.

The Supply Chain Structure

We analyze the supply chain network of a multinational company (referred to as MC) who is an innovator in the field of railing systems and provides complete solutions that are instantly recognizable for their quality, unique design, and excellent performance. MC's supply chain network extends to Europe, North America, South America, Africa, and Asia with an alliance company located in China (referred to as TCC). TCC, as a trading company, has been purchasing the parts of the railing system from various suppliers in China for stocking and exporting to subsidiaries of MC around the world.

Figure 1 Current Supply Chain Structure

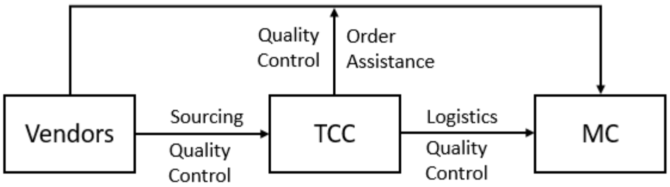


Figure 1 illustrates the current supply chain structure including MC, TCC, and vendors/suppliers in China. MC may purchase products from vendors directly or indirectly via TCC. For MC's direct purchase, TCC offers quality control (QC) function and order following assistance. Before each order is dispatched from the vendor, those orders must be checked by TCC and only qualified goods can be shipped to MC. Once MC is facing a problem on running order, TCC will provide support on checking the order production status locally. For MC's indirect purchase, TCC acts as a trader and takes the sourcing function, quality control (QC) function, and Logistic function between MC and vendors.

Table 1 Abbreviations Used in This Study

LC	Landed cost
PQD	Purchasing Quantity Distribution
PP	Purchase Price
DT	Delivery Time
DD	Delivery Delay
QC	Quality Control
QL	Quality Level
FOB	Free On Board
MC	The multinational company
TCC	The trading company

Outstanding Issues in the Supply Chain

Railing system parts are used for indoor and outdoor purposes to keep people safe and integrate into the overall architectural style. To realize these purposes, different materials and complex manufacturing methods are applied in production. The high level of process complexity enhances the production uncertainty, which has a great impact on production cost (closely related to PP), DT, and QL.

- Continuously Increasing Purchase Price (PP)

  PP covers the following cost in suppliers: direct material, direct labor, manufacturing cost, profit margin, and transportation cost to TCC. The direct material of stainless steel became fluctuated in the past couple of years. Manufacturing and transportation costs are relatively stable. Nonetheless, PP keeps increasing due to the significant increase of labor cost.

- Low Operations Management Levels in Suppliers

  Most suppliers are middle-sized and small-sized production factories who are lack of professional production management: poor production plans and the information in different production stages are not integrated as one. As a customer, it is extremely difficult for TCC to track the production upstream or obtain a reliable purchase.

- Quality Level (QL)

  QL is defined as the ratio of product orders/lots acceptance within a certain period. The higher QL is, the more accepted orders/lots will be. Most supplying companies do not invest enough in quality assurance management due to their sizes. The complex manufacturing process consists of many stages and involves a lot of handwork. Such complexity increases the difficulty of QC in the whole production process. Lower QL will lead to more rejections and rework, which will inevitably delay DT in the end.

- Delivery Delay (DD)

  DD is defined as the number of delayed days after the signed delivery date of the purchase order contract. Inefficient operations management lowers the stability of DT. A long DD generates high safety stock in MC with related extra stock costs. Shortage happens frequently and triggers more air shipments to maintain customer satisfaction, which leads to higher LC.

The Objective of the Study

The railing system is not an innovative product and customers are quite sensitive to the price. With the condition of long DT and low QL for suppliers, MC needs a purchase order planning tool to improve efficiency and effectiveness in order allocation and supplier development. This study focuses on developing a mathematical model of purchase order allocation to multiple vendors from the perspective of achieving a minimum LC. This LC model will include the following parts: 1. PP (the fluctuation of the raw material price will be ignored), 2. Tariff (the export duty for supplier and import duty for costumer), and 3. Transportation Cost (inland and Land-land transportation cost for sea shipment and air shipment).

LITERATURE REVIEW

Procurement is performing an important role in successful organizations as it has a great impact on the operation expense and profit generation of the organization. The growing outsourcing and globalization have led to numerous vendors as well as huge stocks of work-in-process. Quality has become more critical, and delivery time is fundamental to the competitiveness of the organization (Nicoletti, 2017). A study supports that sourcing in low-cost countries may save material costs by 10-35%, therefore additional costs incurred from lead time variability and operational delays may quickly ruin that savings (Crone, 2007).

In the condition of the current ever-changing competitive market, the procurement strategy has become increasingly vital to each organization due to the great influence of material costs on the creation of profits (de Boer et al., 2001). Such a situation is also appropriate for construction companies that are manufacturers of construction projects. In purchasing management, two key factors are involved, including supplier selection and order allocation. Supplier selection is a crucial mission for organizations to achieve different objectives of the supply chain and could support maintaining a stable and long relationship between the company and reliable vendors (Setak et al., 2012). To implement the selection of suppliers, lots of methodologies have been introduced, including multi-attribute decision-making techniques, mathematical programming, as well as artificial intelligence methods. In the material purchasing process, after the selection of suppliers is accomplished properly, order allocation will be the next significant stage to determine the optimal order quantity allocation scheme, especially in the case of a multiple suppliers' environment. A great number of models and methods have been delivered to solve the order quantity allocation problems, including linear programming model (Ghodsypour & O'Brien,1998), mixed integer programming model (Ghodsypour & O'Brien, 1998; Xu & Nozick, 2009), nonlinear programming (Fazlollahtabar et al., 2011; Tang et al., 2011), and others. Although these methods are commonly implemented for optimization, the structures and frameworks can help with identifying cost inputs and attempting to reach an optimal business solution. For example, linear programming can be used to find solutions such as the total supply cost, average supply cost, or order quantity that should be purchased from selected suppliers that determine a minimum cost (Freund & Bertsimas, 2004). In the practice of the supplier chain "Vender/TCC/MC", LC is taken as the most significant parameter of the entire company's performance in this study. In consideration of DD and QL, the optimal LC will be generated from a suitable purchase order allocation model.

THEORETICAL FRAMEWORK

In MC, LC is treated as a major and vital part of the basic product cost and has a great impact on the profit margin of the product. Furthermore, LC affects the pricing and promotion strategy which is an essential tool to extend market share. In general, LC consists of PP, transportation cost, tariff /tax refund, and TCC service cost.

PP means the price at which goods are purchased. To obtain a better price agreement and a service level, a transnational forwarder is chosen to arrange global deliveries, and free on board (FOB) has become the most effective purchase condition which is used for suppliers worldwide. Under the FOB condition, suppliers need to handle internal transports to the nearer port or airport, prepare customs documents for exporting, as well as bear the local charges.

Transportation cost is generally defined as a delivery expense to the destination or import ports consisting of inland cost and land-land cost. The inland cost from import port to MC will not be included in this study as there is no available data. For the land-land cost from export ports to import ports, sea-freight, air-freight and express like UPS/DHL are main delivery choices to deliver goods.

A tariff (duty cost) refers to the tax on imports or exports which is a common form of regulation in foreign trade. Export rebates (exemption) is usually used by a government as tax leverage to reward export. Generally, it contains two categories in china: the import tax return and the refund of the domestic tax. In the current international trade practice, suppliers have counted tax rebates as positive profit in quotation to a customer inquiry. To make their sales price lower and more competitive, the supplier will deduct tax rebates from the sale price and the tax rebates will not be an effective factor on the LC anymore.

Noted that TCC takes different roles into two types of MC's ordering process: direct ordering and in-direct ordering. In those activities, the labor and overhead of TCC are consumed differently. If those costs could be allocated to each product correctly, it will help MC understand the LC and make a better decision on product development. Unfortunately, no data can be collected to record those activities, so this part has to be skipped in this study.

Next, we make the following assumptions based on the above discussion:

1) All the purchase prices are based on the FOB condition.
2) In-land transportation cost from import harbor to MC is not included.
3) Rebates will not be included and have been considered in Purchase Price (FOB).
4) TCC service costs will be excluded.

The LC would be formulated in Eq.1. Notations are given in Table 2. In the formulation of LC, most parameters are constant or near-constant. PP_{FOB} would be normally fixed during annual order negotiation and can be hardly changed before the next one. MC will make the whole group transportation a package with fixed annual C_{SEA} and C_{AIR}. As for T_{IM} and T_{EX}, it is well known that those are regulated by importing and exporting countries. Usually, tariffs on imports or exports are constant unless the government states changes. Q_{SEA} and Q_{AIR} are fluctuated figures and important factors to LC due to the expensive air freight expense. Those are also decided by the supply level, customer demand, and safety stock in each step of the supply chain.

$$C_{LC}*Q = PP_{FOB}*Q + C_{SEA}*Q_{SEA} + C_{AIR}*Q_{AIR} + T_{EX} * PP_{FOB}*Q + T_{IM} *(PP_{FOB}+ C_{SEA}) *Q_{SEA} + T_{IM} * (PP_{FOB}+C_{AIR})*Q_{AIR} \quad (1)$$

And

$$Q = Q_{SEA} + Q_{AIR} \quad (2)$$

This research focuses more on the supply side to build up the relations between air freight cost/quantity and the main factors to the supply level, such as QL and DD. On this relation basis, C_{LC} can be finalized and then becomes the most essential condition to the annual order allocation. Other factors, like supplier capacity limitation and delivery time, need to be taken into consideration as well.

Table 2 Notations Utilized in the Study

PP_{FOB}	Purchasing price under the FOB condition
Q	Purchase order quantity
C_{SEA}	Unit sea-freight cost
Q_{SEA}	Delivered quantity by sea freight.
C_{AIR}	Unit air-freight cost
Q_{AIR}	Delivered quantity by air freight.
T_{IM}	Tariff on import
T_{EX}	Tariff on export
C_{LC}	Unit landed cost

THE MODEL OF AIR-FREIGHT, DELIVERY DELAY, AND QUALITY LEVEL

In the MC system, air-freight Cost data, DD data, and QL data are generated from different platforms: air-freight from the logistic system, DD from the ERP system, and QL (acceptance) from the QC system. The data from 2017 to 2018 are collected and integrated for this study.

Model Regression and Analysis I: Air Quantity/Order Quantity

By reviewing the formulation of LC, Eq.1 can be converted to

$$C_{LC} = [PP_{FOB} + C_{SEA} + T_{EX} * PP_{FOB} + T_{IM} *(PP_{FOB} + C_{SEA})] \\ + [C_{AIR} - C_{SEA} - T_{IM} *(PP_{FOB} + C_{SEA}) + T_{IM} * (PP_{FOB} + C_{AIR})]*(Q_{AIR}/Q) \quad (3)$$

The Q_{AIR} /Q indicates the proportion of air shipment which is a relative value and is more objective than Q_{AIR}. It is noted from the data that when DD gets longer, the percentage of Q_{AIR}/Q gets larger. In other words, with long DD, more quantity in one order needs to be delivered by air shipment. Further correlation analysis for those three factors is implemented by SPSS 19.0 and the results are shown in Table 3 and Table 4 that only Air Qty/Order Qty (Q_{AIR}/Q) and QL have a significant correlation. DD is not a driver of Air Qty/Order Qty.

Table 3 Correlations analysis on Q_{AIR}/Q, Delivery Delay and Quality Level

		Air Qty/Order Qty	Delivery Delay	Quality Level
Air Qty/Order Qty	Pearson Correlation	1	0.075	-0.441**
	Sig. (2-tailed)		0.523	0
	N	74	74	74
Delivery Delay	Pearson Correlation	0.285	1	0.027
	Sig. (2-tailed)	0.079		0.82
	N	74	74	74
Quality Level	Pearson Correlation	-0.441**	0.027	1
	Sig. (2-tailed)	0	0.82	
	N	74	74	74

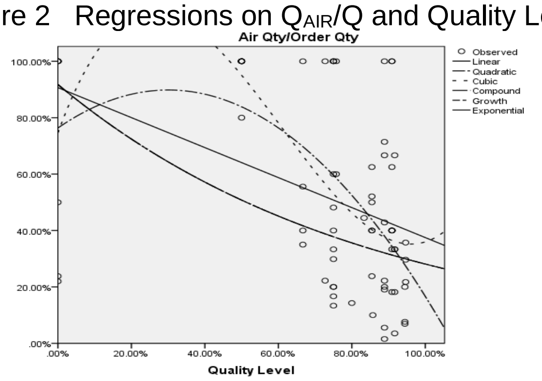
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4 Regressions on Q_{AIR}/Q and Quality Level

	Model Summary					**Parameter Estimates**			
Equation	**R Square**	**F**	**df1**	**df2**	**Sig.**	**Constant**	**b1**	**b2**	**b3**
Linear	.194	17.335	1	72	.000	90.656	-.532		
Logarithmic[a]	.	.	.	.	.	.	.		
Inverse[b]	.	.	.	.	.	.	.		
Quadratic	.303	15.397	2	71	.000	76.340	.897	-.015	
Cubic	.330	11.506	3	70	.000	74.612	3.591	-.088	.000
Compound	.141	11.853	1	72	.001	91.756	.988		
Power[a]	.	.	.	.	.	.	.		
S[b]	.	.	.	.	.	.	.		
Growth	.141	11.853	1	72	.001	4.519	-.012		
Exponential	.141	11.853	1	72	.001	91.756	-.012		

a. The independent variable (Quality Level) contains non-positive values. The minimum value is .00%. The Logarithmic and Power models cannot be calculated.
b. The independent variable (Quality Level) contains the values of zero. The Inverse and S models cannot be calculated.

Figure 2 Regressions on Q_{AIR}/Q and Quality Level



Model Regression and Analysis II: Air Quantity/Order Quantity in the Casting Group

In MC, DD, and QL issues about investment casting products are frequently discussed, which is caused by the long and complex manufacturing process: Investment Casting-Stamping-Machining-Hand Polishing-Packing. Many small steps are involved in the investment casting process. Compared to other product groups, it is apparent that lower QL and longer DD are experienced by the casting group. We clean the basic data set 2017-2018 and picked the DD and QL data only for the investment casting group to conduct a statistical analysis.

Based on the correlation analysis in Table 5, DD and QL do not correlate to Air Qty/Order Qty (Q_{AIR}/Q) very strongly as expected. Nonetheless, both of them present a negative correlation with each other: lower QL relates to longer DD. Results of other regression analyses are presented in Table 6. All the R square values are too low to explain the relation of Q_{AIR}/Q, DD, and QL.

Table 5 Correlations Analysis on the Investment Casting Group

		Air Qty/Order Qty	Delivery Delay	Quality Level
Air Qty/Order Qty	Pearson Correlation	1	.285	-.275
	Sig. (2-tailed)		.079	.090
	N	39	39	39
Delivery Delay	Pearson Correlation	.285	1	-.353*
	Sig. (2-tailed)	.079		.027
	N	39	39	39
Quality Level	Pearson Correlation	-.275	-.353*	1
	Sig. (2-tailed)	.090	.027	
	N	39	39	39

*Correlation is significant at the 0.05 level (2-tailed).

Table 6 Regressions on Q_{AIR}/Q and Delivery Delay for the Investment Casting Group

	Model Summary					**Parameter Estimates**			
Equation	**R Square**	**F**	**df1**	**df2**	**Sig.**	**Constant**	**b1**	**b2**	**b3**
Linear	.081	3.266	1	37	.079	43.081	.395		
Logarithmic	.109	4.504	1	37	.041	12.248	13.641		
Inverse	.099	4.076	1	37	.051	66.990	-183.558		
Quadratic	.105	2.114	2	36	.136	32.536	1.106	-.008	
Cubic	.107	1.402	3	35	.259	27.026	1.737	-.024	.000
Compound	.075	2.984	1	37	.092	34.862	1.008		
Power	.096	3.931	1	37	.055	19.224	.266		
S	.106	4.382	1	37	.043	4.041	-3.926		
Growth	.075	2.984	1	37	.092	3.551	.008		
Exponential	.075	2.984	1	37	.092	34.862	.008		
Logistic	.075	2.984	1	37	.092	.029	.992		

*The independent variable is Delivery Delay.

The Tobit Model

The Tobit Model, also referred to as the censored regression model, is designed to estimate the linear relationship between different variables when there is either left- or right-censoring in the dependent variable (also known as censoring from below and above, respectively). The Tobit Model could be a proper regression tool for the casting group. The model has a lower censoring limit (ll=0) and an upper censoring limit (ul=1), where "ll=0" represents Air Qty/Order Qty = 0% which means no Air shipments exists and "ul=1" represents Air Qty/Order Qty = 100%. The objective dataset will be enlarged by adding air freights without delays and will be used in STATA/MP 15.

Index
airpct = Air Qty/Order Qty
dd=Delivery Delay
ql=Quality Level
dl=1-ql (note: rejection rate)
dl^2=(1-ql)^2
i.pid=Item Number

The Tobit model indicates that both dl and dl^2 are statistically significant in Table 7, which indicates that the variable could be used to explain airpct (Air Qty/Order Qty) properly. In Table 8, Akaike's and Bayesian information criterion below shows the goodness-of-fit of the Tobit Model. The link test is also implemented to approve that there is no evidence of model misspecification.

Table 7 Tobit Model Regression

Tobit regression					**Number of obs=**	252
					Uncensored=	197
Limits: lower=	0				**Left-censored=**	0
upper=	1				**Right-censored=**	55
					LR chi2(191)=	392.93
					Prob > chi2=	0
Log likelihood=	44.104305				**Pseudo R2=**	1.2895
airpct	**Coef.**	**Std. Err.**	**t**	**P>|t|**	**[95% Conf.**	**Interval]**
dl	0.9579545	0.3113567	3.08	0.003	0.3353582	1.580551
dl^2	0.8153882	0.3268797	-2.49	0.015	-1.469025	-0.161752
i.pid(omitted)						
_cons	0.4	0.1690135	2.37	0.021	0.0620365	0.7379635
var(e.airpct)	0.0285656	0.0029785			0.023194	0.0351812

Table 8 Akaike's and Bayesian Information Criterion

Model	**Obs**	**ll(null)**	**ll(model)**	**df**	**AIC**	**BIC**
	252	-152.3585	46.09443	194	295.8111	980.5204

As mentioned, DD and QL are two key factors on LC. The basic Tobit model is designed to contain both DD and QL. As the regression analysis above shows that DD is not significant, Eq.4 is implemented as an adjusted Tobit model to predict the Air Qty/ Order Qty (Q_{AIR}/Q) of the casting group, which will generate the unit LC. The link test also approves that in general, the adjusted Tobit model (Eq.4) is better than the basic Tobit model. Nonetheless, for the other groups, the Tobit regression results are not qualified to build similar formulas.

$$\frac{Q_{air}}{Q} = c_1 * (1 - QL) + c_2 * (1 - QL)^2 + c * \text{ItemNo} + \epsilon \quad (4)$$

Where $\frac{Q_{air}}{Q} \in [0,\ 1]$.

From the regression analysis results in this section, it can be summarized that although Q_{AIR}/Q has a certain negative relation with QL or positive with Delivery Delay, it failed to set up the regression model within those variables successfully. By implementing Tobit Model, it discovered the relation of Q_{AIR}/Q, reject rate (1-QL), and reject rate square; and Eq.4 is implemented. It may be used for the casting group, yet it is still difficult to build an appropriate formula to forecast Q_{AIR}/Q of any product when the QL and DD of suppliers are given. However, the negative correlation between QL and DD discovered in this section is worthy of further study.

ALTERNATIVE MODEL FOR PURCHASE ORDER ALLOCATION

In the previous section, the apparent negative relation between DD and QL is discovered for the casting group. How about the relation between DD and QL considering air shipments for all the groups? Table 9 shows the correlation coefficient of -0.335 which is smaller than -0.353 in the casting group. Even if the difference is minor, it still indicates that QL in the casting group has a stronger impact on DD than in other groups.

Table 9 Quality Level and Delivery Delay Correlation Analysis for Air Shipments

		Delivery Delay	Quality Level
Delivery Delay	Pearson Correlation	1	-0.335**
	Sig.(2-tailed)		0.001
	N	102	102
Quality Level	Pearson Correlation	-0.335**	1
	Sig.(2-tailed)	0.001	
	N	102	102

**.Correlation is significant at the 0.01 level (2-tailed)

The Alternative Mathematical Model

According to the adjusted Tobit model, Eq.1 with variable QL can be successfully built up only for the casting groups. How about the other groups of products? An alternative solution needs to be implemented by using historic data on the building of the LC model.

The data of purchase cost, transportation cost, tariff, and export rebates on each finished order have already been existed in different systems of MC and TCC. By collecting related historic data and inputting it into the formulation of LC, the average LC of each product in different time frames can be calculated. The average LC will be the key variable applied to the annual order or daily order allocations. The following notations are utilized (Table 10).

Table 10 Additional Notations Used In the Study

i	Index of order number, i=1, 2,…, I
j	Index of supplier, j=1, 2, …, J
p	Index of product , p =1, 2, …, P
l	Required lead time of product
L_{pj}	Average unit landed cost of product p which is supplied by supplier j
Q_{ipj}	Quantity of product p in order i which is placed to supplier j
P_{ipj}	FOB Purchase Price of product p in order i which is placed to supplier j
S_{ipj}	Sea shipment cost of product p in order i which is placed to supplier j
A_{ipj}	Air shipment cost of product p in order i which is placed to supplier j
E_{ipj}	Export tax of product p in order i which is placed to supplier j
I_{ipj}	Import tax of product p in order i which is placed to supplier j
DD_{ipj}	Delay days of product p in order i which is placed to supplier j
AOQ_p	Annual order quantity of product p
AC_j	Max annual capacity of supplier j
ROQ_{pjl}	Running order quantity of product p in lead time l
C_{jl}	Max capacity of supplier j in required lead time l
LT_{pj}	Lead time of product p in supplier j
LT_p	Required lead time of product p.
D_{pj}	Allocation Scale of product p for supplier j

Alternative Model for Landed Cost

$$L_{pj} \sum_{i=1}^{I} Q_{ipj} = \sum_{i=i}^{I} P_{ipj} Q_{ipj} + \sum_{i=1}^{I} S_{ipj} + \sum_{i=1}^{I} A_{ipj} + \sum_{i=1}^{I} E_{ipj} P_{ipj} Q_{ipj} + \sum_{i=1}^{I} I_{ipj}(P_{ipj} Q_{ipj} + S_{ipj} + A_{ipj}) \quad (5)$$

Subject to

$$DD_{ipj} > 0 \quad (6)$$

Mathematical Model for Purchase Order Allocation

The Alternative LC model will be applied for either annual order allocation or daily order allocation. The annual order is a forecast of the whole year, which is generated by the sales forecast. It will form a quantitative advantage to acquire the best purchase conditions, like PP, DT, payment terms, and others during the negotiation with suppliers. The optimal annual order allocation policy will be achieved by minimizing the LC of each product for the whole year. The annual capacities of suppliers need to be considered as a constraint.

Minimize

$$\sum_{j=1}^{J} L_{pj}\ AOQ_p\ D_{pj} \quad (7)$$

Subject to

$$\sum_{p=1}^{P} D_{pj}\, AOQ_p \le AC_j \quad (8)$$

The daily order allocation policy will be applied for each real demand. This order quantity is determined by the service level, safety stock, and demand. The required lead time needs to be fully filled. If the LC of one supplier is lower, yet the delivery time is much longer than the required lead time, the order should be allocated to other suppliers with the corresponding DT first. If the ordered quantity has run out of the max supplier capacity, the order quantity is not allowed to be allocated to this supplier.

Model of Daily Order Allocation with Capacity and Lead Time Constraints

Min

$$\sum_{j=1}^{J} L_{pj}\ AOQ_p\ D_{pj} \tag{9}$$

Subject to

$$\sum_{p=1}^{P} ROQ_{pjl}\ \leq C_{jl} \tag{10}$$

$$LT_{pj} < LT_p \tag{11}$$

Models Application

Next, data 2017-2018 of one item is applied to the Tobit model casting group (Eq.4), Alternative LC model (Eq.5 and Eq.6), and Model of Daily Order Allocation (Eq.9, Eq.10, and Eq.11). After calculation, both results of Tobit model and Alternative LC model (Table 11) suggest that the lowest PP does not lead to the lowest LC in the end and all the order quantity should be placed to the vendor for the lowest LC with higher PP, shorter DD, and better QL.

Table 11 Result of models operation

Item No	Category	Vendor	Unit LC ($) Tobit Model	Unit LC($) Alternative model	Order Allocation
*****0422	Investment casting	**0046	3.54	3.42	0
*****0422	Investment casting	**0062	3.37	3.40	720

While QL is not at a high level and DD does not appear, the suppliers' DTs and safety stock levels should be reviewed and revalued. Long DT and large supplier safety stock will increase the production cost directly and affect LC eventually. By collecting historic data, the alternative LC model and order allocation model are initialized. It could be used if the supplier had produced and delivered the product to MC.

CONCLUSION AND FUTURE WORK

By collecting and inputting historic transaction data, we conduct statistical analysis for the impacts of the essential factors on the laded cost. Various types of regression and a Tobit model are utilized to predict purchase order allocation (Q_{AIR}/ Q) and landed cost considering delivery delay and quality level. Although it is not fully successful to build up an air shipment formulation with the variables through statistical analysis, some valuable findings are still discovered and meaningful for guiding the management in solving a massive air freight cost, which leads to a prompt increase in the landed cost. We further develop an alternative model for optimizing the purchase order allocation to achieve the minimum landed cost, based on which the average landed cost of any product could be calculated and applied to the annual order or daily order allocation with multiple suppliers. By acquiring the minimum landed cost of any product, the allocation coefficient will be optimized and will also be a key factor for annual order negotiation, supplier development, and procurement strategy planning.

Restricted by information source authority, only partial categories of data can be collected from MC and TCC and applied to this research. The data like customer demand, safety stock level, and supplier stock buffer cannot be acquired for further investigation on air shipment regressions. Those could be possible key variables for the regression analysis of the air shipment cost, which leads to future studies.

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A Paradigm Shift for Addressing the Plastic Crisis: A Data-Driven Study

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ABSTRACT

Plastic management is essential to addressing the burgeoning consequences of plastic consumption and waste. This study investigates the research areas related to plastic management from various perspectives based on the literature between 2016-2021 using Text Mining analysis on thousands of abstracts. We emphasize research opportunities and streamline potential directions. Our key contributions are the visualization of the research gap, discussions, and recommendations of future research directions by analyzing. In addition, this study gleans valuable insights from a large dataset shared by the U.S. Department of State to respond to the needs of practitioners and regulators to address the crisis.

KEYWORDS: Plastic, Sustainability, Circular Economy, Value-chain, Corporate Social Responsibility, Business Models, and Text Mining.

INTRODUCTION

Plastic was first introduced in 1862 by Alexander Parks as a replacement for Ivory at London International Exhibition. Over the past 50 years and until today, there has been a dramatic increase in plastic consumption. It is a core material for almost all industries, including construction, packaging, medical, and end-user products (Plastic-Industry-Association, 2017). The growing consumption of plastic material is becoming an intriguing issue due to its detrimental impact on resource scarcity. Recently, plastics have been classified as one of the supply chain disruptions (Vakil, 2021). Reportedly, 40-48% of the annually produced plastic is non-recyclable. Although most of those non-recycling plastic might be converted to energy, it is ultimately dumped in landfill or oceans, which imposes a sustained threat to our environment (Chidepatil et al. 2020).

LITERATURE REVIEW

It is critically important to design and streamline the value chain with supporting innovations to help enhance economic development (Lee, 2021). In 1985, Michael Porter developed the competitive advantage model to illustrate how sustainability impacts superior performance. Stemming from that study, Porter et al. (2006) map the value chain components to corporate social responsibility. Recently, Dijkstra et al. (2020) extended the sustainable business model by considering the dimensions of social and environmental responsibility. Lee et al. (2017) review the literature between 1980 and 2015 and suggest a direction related to a responsible social and environmental value chain concerning three dimensions, i.e., Context, Objectives, and Stakeholders. Organizations embracing socially and environmentally responsible value chains often face operational challenges. Those issues/challenges render considerable research opportunities for operations management; cf. Lee et al. (2017) and Zhang et al. (2020). Technological development and adoption, e.g., the Internet of Things (IoT), Artificial Intelligence

(A.I.), Blockchain Technology (BCT), 3D printing, and many other technologies, provide business solution tools to address information and financial flow; cf. Zhang et al. (2020). Among those technologies mentioned above, BCT, IoT, and A.I. are often cited as promising technologies to address the plastic crisis (e.g., Walden 2020, Chidepatil et al. 2020, Ellen MacArthur Foundation 2019b). In particular, BCT is more valuable with credence goods followed by experienced goods (Chang et al. 2018 and Chang et al. 2022). In addition, REMADE road map in the year 2019 evaluated the technology situation and gap in the industry and what solutions are needed to tackle waste, energy consumption, and CO2 emissions (REMADE, 2019). Circular Economy (CE) is essentially the standardization of components, starting from the design/re-design of (Products), for improved materials flow and practical disassembly, in addition to promoting technology licensing and having access to products rather than owning them (Ellen MacArthur Foundation, 2019b, Ellen MacArthur Foundation 2013). Geissdoerfer et al. (2020) recently revisited 114 definitions for Circular Economy. They proposed a modified definition: "Circular economy is an economic system in which resource input and waste, emission, and energy leakages are minimized by cycling, extending, intensifying, and dematerializing material and energy loops. This can be achieved through digitalization, sterilization, sharing solutions, durable product design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling." Sustainable plastic is defined as "plastic that is fit for purpose, resources, generates minimal waste, and involves minimal risk to social and environmental systems." (Landon-Lane 2018). Consequently, Sustainable Plastic Management (SPM) leverages techniques across the waste hierarchy to mitigate environmental damage. Dijkstra et al. (2020) review and classifies forty-four management business models into eight archetypes: (1) maximize material and energy efficiency; (2) create value from waste; (3) substitute with renewables and natural processes; (4) deliver functionality rather than ownership (i.e., product-as-a service); (5) adopt a stewardship role; (6) encourage sufficiency; (7) re-purpose the business for society/environment; and (8) develop scale-up solutions (Bocken et al., 2014).

PROBLEM STATEMENT, OBJECTIVES, AND RESEARCH QUESTIONS

Global plastic production increased by 26% from the year 2010 to the year 2016 (Geyer et al. 2017). The cumulative global plastic production since the year 1950 is 8.3 billion metric tons; out of those, the amount of waste is 6.3 billion metric tons (until the year 2015), and the cumulative waste is expected to grow steadily up to 12 billion tons by the year 2050; cf. Statistica (2017). Ironically, the U.S. is ranked as the top one in terms of the average plastic waste per year per capita, estimated at around 231 lbs. (Vetter, 2020). According to an MIT Sloan Management Review study, out of 3057 participants from various global organizations, 60% reported that their firm has a sustainability strategy, but only 25% reported business cases (Unruh et al., 2016). Some top issues to address sustainability are the lack of consumer demand for sustainable products, short-term thinking of businesses, and quantifying the impact and effect of sustainability (Unruh et al., 2016). The objective of the study is to develop a framework for both practitioners and academic researchers with the following two aspects: (1) from the practicing perspective; we analyze the data shared by the U.S. State Department between the years 2016-2021 to provide more up-to-date insights to the research community, as most of the results considered in various literature go back to the year 2015 and before; (2) from the academia perspective, we perform a holistic and deep literature review over the same time frame to spot the gaps, and future areas of research related to plastic management from business, technological, and environmental perspectives. The lack of business-related literature is one of the challenges in this research regime. Therefore, to bridge the gap, we address the research questions below to shed light on the status of the plastic crisis from a quantitative perspective.

(1) What is the current status of research concerning plastic management from a business and data science perspective?
(2) Where is the gap between scholarly research and industrial practice? What are the open (unsolved) questions or challenges in literature?
(3) What are the disruptive technologies involved in plastic crisis management and the degree of inclusion?
(4) What are the main business models developed in the literature to address SPM?
(5) How does Operations Management, e.g., Supply Chain Management (SCM) and value chain, role in addressing the growing SPM?
(6) What are the primary roles of different stakeholders in addressing the plastic crisis?

These questions may help tackle the global plastic crisis through a paradigm shift, especially after the U.S. was reported as the top country exporting plastic (World Bank, 2018).

METHODS
In this study, we leverage Text Mining methodology to address the above research questions.

Text Mining
This study is featured with data-driven results of interpretation, discussions, and implications, which are developed by analyzing large-scale datasets. In particular, this study is performed through two stages: (1) the analysis of the collected quantitative secondary datasets (Table 3), including a dataset from the U.S. Department of State (approximately one million records) from 2016 to 2020, and (2) text mining of thousands of publications related to the plastic crisis. The literature and publications considered in this study are based on an exploratory manual screening across various sources (i.e., Harvard Business Review (HBR), MIT Sloan, Google Scholar, and Science Direct.) to determine the themes for which the publications will be retrieved (cf. Table 1). For the 53 publications retrieved from POMS, only nine are relevant to the plastic crisis.

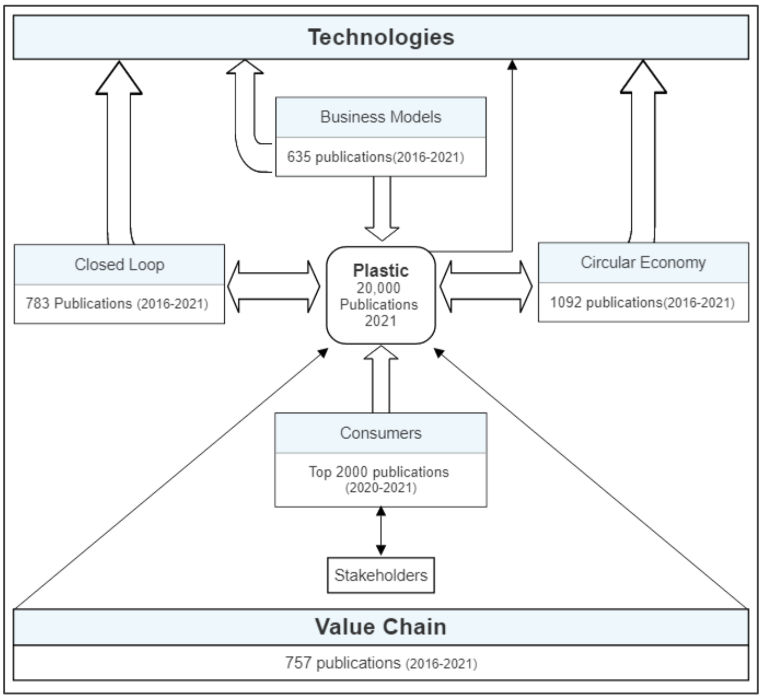
Table 1: Preliminary Sources Screened for Themes Extraction

KEYWORD	SOURCE	TIME RANGE	FREQUENCY
Plastic Management	Google Scholar	2015-April 2021	610 K
Plastic Management	Science Direct	2015-April 2021	84 K
Sustainable Plastic	Google Scholar	2015-April 2021	224 K
Plastic	Harvard Business Review	Until April 2021	149
Plastic	POMS	2015-April 2022	53
Plastic	MIT Sloan	2019-2021	13

Based on the resources reviewed and screened in Table 1, six themes are defined for further investigation using text mining which are 'Plastic Business Models,' 'Plastic and Circular Economy', 'Plastic and Consumers', 'Plastic and Closed Loop,' 'Plastic and Value Chain,' and 'Plastic and Technology.' Consequently, 5,267 publications were retrieved from the Scopus Database to be analyzed using text mining techniques (see Figure 1 and Table 2). The publications in each theme are extracted in a separate dataset with details, such as authors, year, journal, volume, issue, citation, affiliation, abstract, keywords, references, publisher, corresponding author address, document type, publication stage for cluster, text, and bibliometric analysis. For the top 20,000 publications with the keyword 'Plastic' as of 2021, we screened those publications manually to exclude non-business-related publications. The remaining subset is then merged with the publications under the six themes listed earlier to remove the duplicates and the

publications not available in full text (see Figure 1). As depicted in Figure 1, each rectangular structure is a theme retrieved from the Scopus database, and the number inside it is the frequency of documents included within the range of years selected. The direction of the link reflects the perspective upon which a theme is evaluated concerning plastic. For the 'Technology' theme with 'Plastic,' the results are generic and irrelevant.
Consequently, we decided to evaluate the technological aspect through the publications retrieved under the other themes. Accordingly, the arcs flow into the technology's entity. Furthermore, the 'Stakeholders' role concerning 'Plastic' returns irrelevant and broad results. After manually examining a sample of the publications retrieved under the 'Consumers' theme, we chose to evaluate the different stakeholders' roles through the research under the 'Consumers' theme because of the co-existence of other parties and customers in that theme.

Figure 1: Publications Frequency by Theme Scopus Database



Text Mining Algorithm
VOS viewer (VOS: Visualization of Similarities) is a two-dimensional visualization software [https://www.vosviewer.com/]. We applied for data cleaning and analysis. VOS viewer is based on the Apache OpenNLP library, enabling the development of distance-based visualization, where the distance between the nodes reflects the strength between the nodes; viz., the farther, the weaker. Furthermore, it provides more satisfying results than Pajeck or SPSS (Van Eck et al. 2010). In our analysis, any copyright statements in the abstract are removed, then a sentence detection algorithm is used to split the abstract into sentences. Afterward, a 'part-of-speech' tagging algorithm is applied to break down the sentence by the verb, adjective, preposition, noun, etc. Then the terms are converted from plural to singular, stop words are removed, and any term that appears less than ten times is excluded. The output of these steps is a list of terms consolidated from all the documents with the theme. Finally, that list is reviewed manually to exclude any terms that do not seem relevant to the context. The difference between columns 4 and 5 in Table 2 reports the frequency of terms excluded due to being out of context.

Table 2: Themes Breakdown by Documents and Terms

THEME	DOCUMENTS	TOTAL KEYWORD ABSTRACTS	KEYWORDS FULFILLING THRESHOLD	KEYWORDS INCLUDED IN THE NETWORK DIAGRAM	CLUSTERS
Consumers	2000	18213	846	802	5
Circular Economy	1092	9530	403	376	5
Closed Loop	783	6937	182	165	5
Value Chain	757	6781	166	155	4
Business Models	635	4794	118	107	5

Table 3: Datasets Collected

THEME	DOCUMENTS	TOTAL KEYWORD ABSTRACTS	KEYWORDS FULFILLING THRESHOLD
Plastic waste	AAAS	2016	125
Marine Debris Tracker	C.S. Cloud	2016-2020	≈1.04 million
Top Items (by continent)	C.S. Cloud	2015-2018	153
Plastic Waste	GCDL	2016	125
Population Size	OECD	2010-2016	125
Waste Management	OECD	2010-2016	23
Plastic Waste	Tides	2015-2020	≈83 K

RESULTS

Text Mining

The Clustering Algorithm in VOS viewer is based on minimizing the weighted sum of the squared Euclidean distance between the pairs of terms, which determines the optimal number of clusters in a dataset (Van Eck et al. 2010). In particular, the algorithm is based on a similarity matrix developed based on a co-occurrence matrix, as shown in Eq. (1). Here, $\boldsymbol{Sij}$ measures the similarity between two items, i and j, $\boldsymbol{Cij}$ denotes the co-occurrence of items i and j, and ($\boldsymbol{\omega i \omega j}$) represents the total frequency of each term. The distance between the nodes (i.e., terms) on the 2-dimension grid is based on the similarity score between the two terms (Van Eck et al. 2010).

$$\boldsymbol{S_{ij}} = \frac{\boldsymbol{C_{ij}}}{\boldsymbol{\omega_i \omega_j}} \quad (1)$$

Business Model theme: the top three terms are (1) ‘Circular Economy,’ which occurs 234 times, (2) ‘sustainable development, which occurs 163 times; and (3) ‘recycling,’ which occurs 109 times. ‘Plastics’ has no ties (links) with ‘sustainable development’; more research is needed to examine ‘SPM’ models. In addition, there is a complete absence of two of the Five ‘R’ (Reduce and Re-purpose). Figure 3 depicts the Five ‘R’ mapping across the themes studied, where the horizontal bars represent the availability of publications that cover the overlap between the ‘R’ terms and the theme. The shaded bars reflect that the ‘R’ term is listed in the publications collected by the theme. For example, recycling terms appear extensively across all the themes. However, ‘Reuse’ has a minor occurrence under the business model theme. More research is needed to investigate

'Reduce' and ‘Re-purpose’ methods. Value Chain theme: As depicted in Figure 2, some of the top terms are ‘Sustainable development which occurs 145 times, with 145 links out of a total link strength of 972. The total link strength is a score assigned by the VOS viewer based on the strength of the co-authorship among researchers (Van Eck et al., 2010). ‘Recycling’ occurs 138 times, with 151 links out of a total link strength of 1257, ‘waste management’ occurs 132 times, with 152 links out of a total link strength of 1145, ‘circular economy’ occurs 126 times, with 141 links out of a total link strength of 866. This dataset has four significant clusters: Cluster 1 (Red) is related to sustainable development, decision-making, and methodologies used in the related studies; Cluster 2 (Yellow) is related to countries' waste management and its connection with recycling; Cluster 3 (Blue) covers materials flow analysis and chemical components; finally, Cluster 4 (Green) is related to environmental management, protection, and sustainability. Consumer theme: some of the top terms are ‘human,’ which occurs 367 times, with 763 links out of a total link strength of 7739, ‘recycling,’ which occurs 308 times, with 630 links out of a total link strength of 4382, ‘polymer’ that occurs 190 times, with 652 links out of a total link strength of 3795. Two areas have been found under the consumer theme covered from various aspects, ‘Environment’ and ‘Food.’ However, ‘Environmental monitoring’ appears merely 16 times in the documents related to the CE theme. However, it appears more frequently under the Consumer theme, around 147 times, with 613 links out of a total link strength of 3622. The second top area investigated by researchers under the consumers' theme is ‘packaging.’ Closed loop theme: the top three terms are ‘recycling’ which occurs 271 times, with 163 links out of a total link strength of 2101, and ‘circular economy’, which occurs 166 times, with 148 links out of a total link strength of 992, ‘sustainable development’ that occurs 149 times, with 156 links out of a total link strength of 1024. ‘Closed Loop’ is more frequent than ‘waste management’ or ‘recycling.’ This dataset has a cluster associated with SCM and ‘environmental protection’ terms. Moreover, a cluster has terms related to ‘single-use plastic’ (mainly bottles) from life cycle analysis and its connection with consumers' behavior. Circular Economy theme: the top three terms are ‘recycling’ which occurs 473 times, with 401 links out of a total link strength of 7046, and ‘circular economy’ which occurs 401 times, with 399 links out of a total link strength of 4506, ‘waste management’ that occurs 377 times, with 399 links out of a total link strength of 5926. In addition, ‘Analysis’ is tied to ‘Waste management,’ ‘Waste disposal,’ and ‘procedures.’

Table 4: Terms with Low Frequencies

TERM	OCCURRENCES	THEME	LINKS	TOTAL LINK STRENGTH	CLUSTER COLOR
Industry 4.0	48	Circular Economy	48	75	Red
Textiles	36	Consumer	276	478	Blue
Industry 4.0	25	Business Model	59	96	Red
Textile Industry	20	Consumer	192	289	Blue
Environmental Technology	19	Value Chain	77	177	Green
Bioeconomy	22	Value Chain	78	144	Green
Environmental Technology	16	Circular Economy	164	286	Green

Figure 2: VOSviewer Report: Co-Occurrence & Clusters nuder Value-Chain Theme

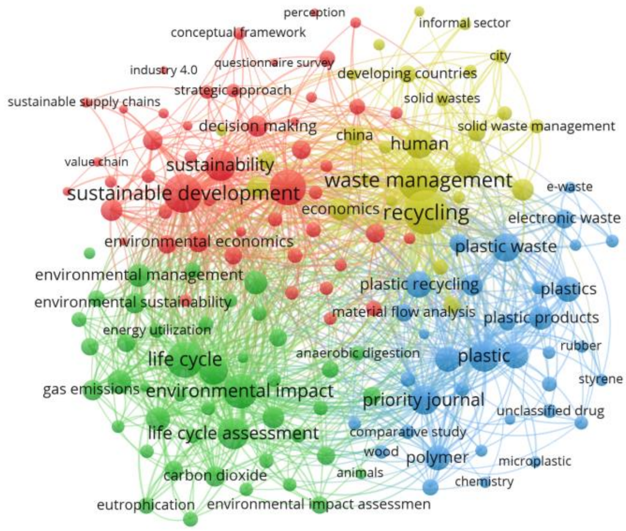
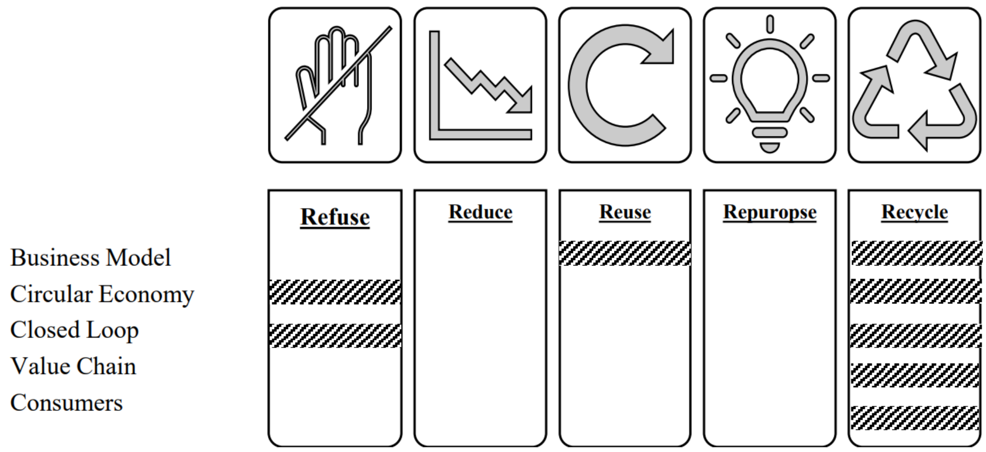


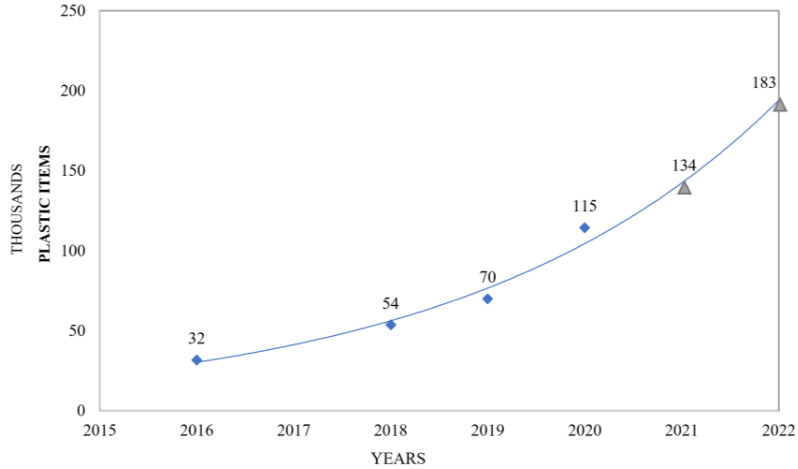
Figure 3: The 5 ‘R’ across the themes reviewed



Analysis of Marine Debris

Based on the data retrieved from the U.S. Department of State, the top three single-use plastic items collected in the U.S. are (1) cigarette butts, (2) bottles, and (3) caps or lids. The data also show that the top states from which the plastic waste was collected are Florida, California, Illinois, Hawaii, and Texas. In addition, between the years 2015 and 2020, 113 million plastic pieces were collected from marine debris across the globe, followed by 27 million packaging/wrappers and 14.5 plastic bottles. The items of marine debris in the U.S. have grown over the years exponentially. Figure 4 provides an exponential regression fitting curve. Following the same pattern, the forecasted marine debris is expected to reach 183K by the end of 2022.

Figure 4: Marine Debris in the U.S.



DISCUSSION AND CONCLUSION

Through our holistic review and extensive analysis of the collected 5,267 publications, we have identified a gap between industrial practice and scholarly research regarding the level and depth of mechanisms and tools proposed to tackle the plastic crisis in industrial reports versus scientific publications. Policies and regulations are covered in detail across the scientific landscape, but there is a shortage of publications harnessing Industry 4.0 technologies to tackle and propose solutions for the crisis. Furthermore, technology has not been discussed with enough attention in the literature. To illustrate, A.I., BCT, Machine Learning, Robotics, and Sentiment, did not appear in any of the themes investigated, so either it means it appeared less than ten times or did not appear at all. Accordingly, more attention is needed from the research community to study and investigate the power and effectiveness of various Industry 4.0 technologies as prospective solutions to the plastic crisis. That opens an area of business data science and analytics research related to sustainable plastic management.

Optimistically, implementing Industry 4.0 technologies may provide organizations with more efficient, resilient, and sustainable solutions. Some keywords/terms appeared more frequently and in almost every theme, some of which are 3D printing, innovation, behavior change, and carbon emission. But there is no clear evidence or connection between ‘Innovation’ and ‘Repurpose.’ Some nodes are related to ‘Product development or ‘re-design,’ but that is insufficient to foster a ‘Re-purpose initiative, especially in the scope of scholarly research.

There exists an estimated $12 Trillion in new business opportunities for developing solutions or business models to implement the United Nations’ Sustainable Development Goals (SDG); cf. Business Sustainable Development Commission (2017). Recently, Dijkstra et al. (2021) evaluated the status of 105 start-ups and SMEs active in the plastic management field and provided an overview of the innovations and solutions for managing the plastic problem for marine. Commercial companies, rather than academic scholars, develop many proposed business models. To illustrate, Ellen MacArthur's foundation proposes four models underneath it: (1) refill at home, (2) return from home, (3) refill on the go, and (4) return on the go (Ellen MacArthur Foundation, 2019a). One of the effective industry practices is the Performance with Purpose (PWP) model developed by PepsiCo, which is raised by four pillars: (1) deliver a superior financial return, (2) transform product portfolio, (3) limit environmental impact, and (4) talent sustainability (Nooyi al., 2020). Dijkstra et al. (2021) conclude that SPM is used inconsistently in the literature and urges researchers to describe their business model based on four components (i.e., infrastructure, value proposition, financial structure, and customer interface). Therefore, new business models must be developed to deal with the inconsistencies in the literature. “Recycling” has been covered thoroughly across the themes in our study. However, more research studies are needed to explore the other four ‘R’s, i.e., Reuse, Refuse, Re-purpose, and Reduce (see Figure 3).

From a Supply Chain perspective, the two main drivers mentioned in the reviewed literature are (1) accessing green markets and (2) maintaining a competitive advantage. Weak sustainability urgently needs to be monitored, guided, surveilled, and relegated to prevent environmental pollution from the early stage. There are four significant clusters under the value-chain theme (See Fig.2), which may guide researchers in building on the existing literature or exploring new areas not listed in the collected publications.

Considering end consumers as one of the reasons behind the increasing plastic consumption and waste (specifically with single-use plastic consumption), raising awareness on the consumer level may guarantee quick fixes. Unfortunately, using different social media platforms to raise the end consumers' awareness of the plastic crisis and the usage of sustainable products has not been covered in the publications we studied. That would be an area of interest mainly for researchers evaluating consumer behavior. With the increase in social media platform usage among the public, social media may be used to force organizations to re-wire their SPM strategies. That method has been adopted and implemented by the Chinese government, which has already illustrated the effectiveness and the power of the crowing in facing suppliers that have environment-related violations (IPE, 2022).

Definitely, consumers alone are not only the player. Instead, collaboration among the various stakeholders, specifically policymakers, regulators, researchers, practitioners, government, non-governmental agencies, producers, and suppliers, is essential to link research to global economy areas; and to enforce laws and policies to curb unnecessary plastic involvement in products and foster switching to reusable products replacing single-use plastics to have an impact at the state, national levels at large. Otherwise, the study's relevance and value will be questioned (Lee et al., 2017). Stakeholder enablers and enabling environment are the two halves that enclose a sustainable model (Pankaj, 2015). Undoubtedly, governments are among the top leading stakeholders by setting policies and regulations to elevate and accelerate the waste collection, build facilities for safe waste disposal, and reduce plastic waste exports to countries with low waste collection and high leakage rates (PEW Charitable Trusts, 2020).

Moreover, the governments alone are not enough to support a Circular Economy. Unruh et al. (2016) suggest that financial investors can play a critical role in enforcing organizations' sustainability goals, as investors avoid stocks for organizations with poor sustainability. There are four core groups to tackle the plastic crisis pollution: multinational corporations, developed country governments, developing country governments, and citizens who may put public pressure to save the environment, each of which holds roles and responsibilities in the plastic crisis (Williams et al., 2019).

Collaboration is needed across multiple stakeholders to take actions on the policy level to foster and encourage organizations toward a circular economy and environmental responsibility. Policies and regulations are fully saturated from a research perspective; many papers and reports cover this dimension's plastic crisis and implications. But there is a shortage of mechanisms and practical measurement tools to concisely manage the plastic crisis and ensure the effectiveness of the policies and regulations. Furthermore, ‘Social Media’ is one of the terms that have a shortage in literature (cf. Table 5 in the Appendix).

In summary, clear actions are needed at the organizational, business, and consumer levels to mitigate the average plastic waste. Investors can function as enablers for a sustainable supply chain, especially investors who avoid investing in organizations that do not have sustainability-related actions or strategies. Since various types of polymers are included in everyday plastic products (Table 6 in the Appendix), there is no one-for-all optimal solution, and various technologies need to be investigated to tackle the various types of plastic waste.

ACKNOWLEDGEMENT: The authors are grateful to Landon Van Dyke, the State Department Senior Advisor for Environmental Performance and Sustainability, for his valuable support in sharing the latest data sets that helped us build the analysis and conclusion on the most recent data.

APPENDIX

Table 5: Methods/ techniques/Technologies in the Literature by Cluster

TERM	OCCURRENCES	THEME	LINKS	TOTAL LINK STRENGTH	CLUSTER COLOR
Questionnaire/Survey	82	Consumer	673	1444	Red
Materials flow analysis	78	Circular Economy	279	1166	Yellow
Fourier transform infrared	61	Consumer	410	1244	Blue
Questionnaire/Survey	71	Circular Economy	353	773	Red
Comparative study	54	Consumer	468	1061	Purple
3D printing/printers	48	Business Model	97	252	Red
Sensitivity analysis	46	Circular Economy	230	709	Blue
Experimental study	40	Consumer	361	738	Blue
3D printing/printers	37	Consumer	247	422	Blue
Sensitivity analysis	31	Consumer	278	534	Red
Correlation	30	Consumer	471	695	Green
Optimization	30	Closed Loop	101	238	Green
Optimization	28	Circular Economy	206	407	Red
Materials flow analysis	26	Consumer	169	396	Red
Surveys/Questionnaire	25	Value chain	94	141	Red
Comparative study	23	Circular Economy	168	390	Blue
Sensitivity analysis	23	Value chain	23	100	Green
Regression Analysis	23	Consumer	196	372	Green
Optimization	22	Consumer	174	240	Red
Integer Programming	22	Closed Loop	65	148	Green
Materials flow analysis	21	Value Chain	93	212	Blue
Fourier Transform infrared spectroscopy	18	Circular Economy	111	258	Green

Fourier Transform infrared spectroscopy	18	Closed Loop	57	143	Red
Surveys	17	Business Model	55	91	Red
Simulation	16	Circular Economy	145	260	Green
Simulation	15	Consumer	219	307	Blue
Materials flow analysis	13	Business Model	54	105	Green
3D printing/printers	13	Closed Loop	56	94	Red
Regression Analysis	12	Circular Economy	95	145	Red
Optimization	12	Value Chain	52	75	Green
Comparative Study	10	Closed Loop	56	79	Red
Comparative study	10	Value chain	82	141	Blue
Process optimization	11	Circular Economy	130	210	Green

Table 6: Polymers and Resin Types and Production in the U.S.

ABBREVIATION	RECYCLING CODE	SAMPLE PRODUCTS	U.S. PRODUCTION (2019)
PET	1	Bottles, furniture, carpet	22,674 MMT
HDPE	2	Pipes, household goods, bags, containers.	9,999 MMT
PVC	3	Cables, shoes, toys, non-food bottles, window frames, and garden hoses.	7,227 MMT
LDPE	4	Bags, containers.	3,460 MMT
PP	5	Food packaging, snack wrappers, microwavable containers, automotive parts, dishware, and child seats.	7650 MMT
PS	6	Dairy & meat packaging, disposable cutlery, coffee cup lids, utensils, and office stationery.	2,527 MMT
PETG	NA	Manufacture, Building, and Construction.	N.A.

Sources: American Chemistry Council, U.S. Census Bureau, U.S. International Trade Commission, Heinrich Boll Foundation, Statistica, and Science AAAS.

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DECISION SCIENCES INSTITUTE

A Supply Chain Model for Fast and Reliable Delivery of Vaccine: COVID-19 Crisis

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ABSTRACT

The timely delivery of vaccines in major crisis events, such as Covid-19, has come into the spotlight. The uncertainty caused by this recent pandemic has made the development of a vaccine distribution model, necessity. This research develops a mathematical model that can be used for vaccine delivery. Our model outlines vaccine distribution networks at two decision levels influenced by the distribution of Covid-19 vaccine in the U.S. The model can be enhanced further to reduce the gap between vaccine supply and demand.

KEYWORDS: Covid-19, Distribution Network, Vaccine Delivery, and Mathematical Modeling

INTRODUCTION

The aim of a management of vaccine delivery should be to deliver quality vaccines to maximum people in a minimum time to reduce the impact of the coronavirus and minimize loss of life .Sadly, improper storage and transportation can result in the degradation of the vaccine products. This can stall the vaccination program delivery. Therefore, it is pertinent to develop an effective vaccine supply chain coupled with a technology-based transportation system to secure the quality of the vaccine (Baškarada et al., 2013; Path et al., 2011) up to the last mile delivery. The present study is an attempt to optimize and improve the current process of vaccine logistics in the USA market by developing a model for vaccine delivery within the present facilities and constraints, if any, in the US market. Past literature reflects on the evidence of efficient application of mathematical methods in managing the vaccinations (Nokes& Anderson, 1988; Gay et al., 1995; Dietz &Heesterbeck, 2000;Scherer & Mclean,2002).In 2019-2020, the vulnerability of the global supply chains became evident, primarily due to the battle with the coronavirus (Linton &Vakil, 2020) and the resulting pandemic.. There are around 248,467,363 confirmed cases and 5,027,183 confirmed deaths in world as of Nov 2021 (WHO, 2021a; 2020).

A better vaccine management program with a well-defined vaccine supply chain and logistics system (Wu & Chaipiyaphan, 2020) can play a role in managing high impact cases of Covid-19 in the USA. While the whole world grapples to fight with the coronavirus, all attention is on the two important aspects.Firstis organizations involved in the process of developing vaccines; second is the vaccination of all individuals globally (Nature, 2020). The pandemic has posed several challenges such as vaccine development, vaccine delivery, and innoculations in the fight against coronavirus (Samson &Kalchschmidt, 2019; Samson, 2020).

Around 110 vaccines are in development around the world as of now. There are at least three vaccines that have received federal funding so far in the USA (GAO, 2020).While vaccine development is still in the process, one can clearly understand the next hurdle fast approaching, i.e. vaccine distribution and delivery. The management of these challenges, particularly in turbulent times, will depend on the extent to which the stakeholders such as government, healthcare experts, and supply chain firms connect the gaps among the required resources and prepare a road map for the effective management of vaccine delivery programs. It is also important to instill confidence in vaccination through transparent and open communication of the essential data (Nature,2020).There is a current need for a high-performance work system that can influence customer satisfaction (Martinaityte et al. 2019) by delivering vaccines at the right time and in the correct form. Organizations can utilize the pandemic as an opportunity to enhance corporate stakeholder responsibility (ElAkremi et al. 2018) and drive vaccine delivery. This will also force organizations to stretch their technological (Wang and Chen, 2018) and dynamic capabilities (Barreto, 2010) to cover the gap between "old and new normal". Companies will have to explore more in order to learn more strategically (Walter et al., 2016) and allocate assets strategically (Maritan& Lee, 2017).

The study aims at proposing a model for the best use of current facilities and the infrastructure for vaccine delivery in the USA. The proposed model intends to develop a vaccine delivery and distribution model through connected supply chains at different tiers. It will reflect on the estimation of the inventory and demand patterns and optimize the production and distribution schedules for efficient vaccination. The collaboration among supply chain firms can ensure certainty in procurement and replenishment of inventory. Such collaboration programs will heavily rely on information sharing (Daugherty et al.1999; Williams, &Tokar, 2008) rather than just on cost saving or labor access (Lehdonvirta et al., 2019; Bunyaratavej et al., 2011).This information can be shared across business firms in managing vaccine administration. It will be equally pertinent to develop a logistics network for transportation and distribution according to demand and capacity. Further, companies will have to manage cash flows carefully keeping in mind the uncertain nature of demand and supply (Mckinsey& Company, 2020). Finally, the government can play a crucial role by modifying the policies or enactments to speed up the review and approvals of the treatment. There can also be emergency approvals according to sufficient scientific proof for the safe usage of the vaccine (GAO, 2020).

The paper is constructed as follows: Section ‘Literature Review’ explores the available literature on the topic of the paper. ains the proposed mathematical model in the paper. In Section ‘Methodology’ explains the proposed vaccine administration model that can be applied while vaccine administration globally. Section ‘Analysis and results’ contains the discussion and analyzes the findings. The last section ‘Conclusion’ concludes the paper and suggests areas of future research.

LITERATURE REVIEW

Historical records indicate several outbreaks such as measles and polio have been noticed in Italy, Japan, Laos, and Namibia initially, countries where the disease in question was once in control (Mayxay et al., 2007; Moszynski,2007; Prato et al. 2007;Sidley,2006; Currier et al., 1972; Landrigan&Griesbach,1973; Markowitz et al. 1990; Wyll& Witte,1971). Reoccurrence of such outbreaks has created concern and alarm about the efficacy of the vaccine administered (Casto&Brunell,1991). One particular concern is the impairment of vaccines due to extreme high and low temperatures and even excessive light. Vaccines normally have a limited life span at room temperature. Therefore, inappropriate transportation can result in less than optimal performance of the vaccine (Casto&Brunell,1991; Adu et al., 1996; Briggs&Ilett,1993; Thakker&Woods, 1992).

There are various studies highlighting a strong correlation between vaccine quality and appropriate transportation and storage of vaccines ((Lerman&Gold, 1971; Wyll& Witte, 1971; Aduet et al., 1996; UNICEF, 2020; WHO, 2021b; OECD, 2021);. In the case of Nigeria, the quality of vaccines for yellow fever, measles and theoral polio vaccine (OPV) has dropped below international standards levels while transporting them from the national warehouse to the different health facilities. This is due to several reasons such as freezing and thawing of vaccines repeatedly, use of inefficient cold storage systems, unsuitable storage of vaccines, and inefficient distribution of electricity (Aduet et al., 1996). A health project in Australia concluded that indecorous storage of vaccines might be associated with an epidemic of diphtheria in the 1990s (Wyll& Witte, 1971). Another example of an outburst of localized measles in the USA in the 1970s has been said to be linked with vaccine storage. The vaccine is said to be stored on the door shelf rather than in the central core part of the refrigerator (Lerman&Gold, 1971). A similar situation of inefficient vaccine storage was observed in Thailand where 180 measles cases was observed (Division of Epidemiology, Ministry of Public Health, 1994; Path et al., 2011).

The ideal temperature range of storing vaccines is 2ºC to 8ºC. There have been instances in the U.S. and Australai of vaccine transportation and storage at temperatures higher than the defined temperature (Miller&Harris,1994; Woodyard et al.,1995) and even vaccine freezing in some othercountries (Casto&Brunell, 1991; Thakker& Woods,1992;Briggs & Ilet,1993; Hanjeet et al., 1996;Reiner et al. 1998; Gazmararian et al. 2002;Edstam et al., 2004; Nelson et al. 2004,;Thopwongsri, 2005;Nelson et al. 2007, Wirkas et al.,2007).A research study discerned the temperature of the Hepatitis B vaccine that is shipped from the manufacturer in Indonesia. Almost 75% of the vaccines were found to be frozen. This freezing is observed to be highest during transit to the local warehouses (Nelson et al. 2004). In Bolivia too, vaccine freezing has been noticed while transporting DTP-HepB-Haemophilus influenza type b vaccines to different community areas with the temperatures of the vaccines higher than 8ºC (Nelson et al. 2007; Path et al., 2011). In Papua Guinea, vaccines were found to be frozen due to faulty insulation (Wirkas et al., 2007). A similar study was conducted in the U.S.A. to monitor temperatures inside refrigerators in medical clinics. It was found that in most of the clinics, the temperature of the refrigerator was within the required temperature range (Woodyard et al., 1995). Another study used data loggers to record temperatures maintained in the refrigerators in the pharmacies; only a few had temperatures within prescribed limits (Reiner et al., 1998). It is clearly evident and critical that control and handling of the vaccine, while it is being transported to the different parts of the U.S.A. from the warehouse to pharmacies or from the airport to the warehouses, be scrutinized and enforced.

In order to maintain temperature and other requirements of vaccine handling, there has to be an adoption of the latest technologies and redesigned trial systems to speed up results (PwC,2020). Well-connected, techno-savvy, and committed supply chains(United Nations Global Compact,2010) will be the need of the hour to avoid further denting of economic growth (PwC, 2020; United Nations Global Compact, 2010). The well-coordinated and opportune reaction from authorities can ensure safe and fast vaccine delivery. This can be the deciding factor between the success and failure of vaccine administration. The process of vaccine delivery will have to bank on the adoption of the technology-based distribution system for integration of information and better operational coordination (Chaudhuri et al., 2020; Irfan et al., 2019; Kim, 2017), vaccination model on the basis of consumer preferences and requirements, and lastly, advanced analytics (Fosso et al., 2018; Brinch et al., 2018; (PwC,2020).There are prior examples, such as HINI that showed a mismatch in demand and supply requirements due to inefficient supply chains (PwC,2020).Further, logistics challenges, price of vaccines, and convincing people to get vaccinated, lurk in the next round of the race against coronavirus (Nature,2020). Surely, supply chain organizations cannot afford to repeat the history in this time of highly contagious viruses. The goal must be to develop a well-connected web of supply chain organizations including transporters and logistics management organizations (Wu and Chaipiyaphan, 2020) to deliver vaccines to every individual in the USA. In the past, researchers have identified different types of competitors with respect to the industry, functional groups, executives, and customers (Gur&Greckhamer,2019). While, the pandemic has been become a major threat for global trades. Supply chain firms will have to be resilient and augment their potential to adapt according to the changes in the environment (Gittell, Cameron, Lim, & Rivas, 2006; Gunderson & Pritchard, 2002; Markman&Venzin, 2014; Ortiz-de-Mandojana&Bansal, 2016; DesJardine et al., 2019). As the pandemic evolves, it is not know what these changes might be but certainly supply chain firms will have to be proactive in adapting as.

One might see a different mode of the technology-based transport system to deliver vaccines without human intervention. Drones could be one of the faster options for this problem. Transport efficiency plays a crucial role in providing early diagnosis, especially for children (United Nations Children’s Fund, 2020). But the pandemic has made ita necessity for all individuals irrespective of age. In the U.S.drones are already being utilized to deliver medical samples in an emergency eventhough commercial drone delivery will entailmuchregulatory control (Schneider,2020).

Literature has highlighted on the resiliency of systems in response to the external crisis. There are several examples across the different functional streams in this regard, i.e. economics (Kyle, 1985), engineering (Hollnagel, Woods, &Leveson, 2007), psychology (Rutter, 1987), and socioecology (Holling, 2001). Supply chains have been streamlined in the past to manage vaccine distribution. For example, in Thailand, the conventional supply chain for vaccine distribution was transformed into a vendor-managed inventory system (VMI) to limit the costs, manage the inventory issues and dissipate the overall inefficiencies of the old supply chain system (Path etal., 2011).The VMI system involved private logistics organizations to distribute vaccines. The focus was to develop a continuous flow of goods for suppliers and consumers and control wastage of vaccines (Path et.al, 2011). In the present scenario, a similar transportation model involving more stakeholders could be developed for distributing vaccines.

Organizations will have to deploy the latest models including technical and non-technical resources for the barrier-free flow of resources for a fast vaccine delivery network. Organizations need to be ready for the challenges revolving around demand uncertainty, road and IT infrastructure, availability of skilled personnel (Galeazzo et al., 2017; Galbreth et al., 2012;van Wassenhove, 2006) in orderto execute the management of vaccine delivery and distribution. At the same time, deliberations regarding the type of transportation, travel route, and handling requirements of vaccines will take centerstage in the vaccine distribution and delivery system. Organizations will have to work as a well-coordinated and flexible global team to accommodate changing needs (Santistevan, &Josserand, 2019).

The innovative use of technologies such as sensors, artificial intelligence, etc. can be deployed to track the movement of vaccine distribution and delivery systems. Concernsmust be addressed in regardto training the staff involved in the distribution and delivery system to contain further infections. Delivery systems will have to focus on innovative packaging material to secure vaccine-handling requirements such as cold storage etc. (Bremer, 2018; Chaudhuri et al., 2018; Hsiao et al., 2018; Ali et al., 2018).

The innovative application of entrepreneurship, operations management, and supply chain management (Ketchen Jr. & Craighead, 2020) can be utilizedfor developing the best model for managing the delivery and distribution of vaccines. Certainly, the focus will be on the agile supply chain that can react swiftly to the different needs of customers according to a shift in demand and supply (Swafford et al., 2006;Ketchen Jr. & Craighead, 2020; Zhu &Gao, 2021).Delivery schedules need to be synchronized across the different regions of the USAto deliver vaccines according to requirements.The Omni-channels interwoven with information regarding product flows, region, supplier, distributor, mode of transport, etc. will gather a major spotlight during these times (Ketchen Jr. & Craighead, 2020). The Omni-channels involve the deployment of different avenues to augment the customer-driven value system (Song, Wang, Liu, & Li, 2020). Thus, one might see a combination of online and offline delivery modes facilitated by accepted logistics handling requirements for the efficient management of delivery and distribution systemsc (Wu and Chaipiyaphan, 2020).

Supply chains should adopt a transparent approach across the multi-tier systems of firms manufacturing different resources such as type of logistics, handling conditions. They may also tie-up with the different transporters to provide the last mile connectivity. In order to avoid cost overruns, inventory levels at different locations can be tracked for effective dissemination of vaccines. Therefore, optimization of production and distribution schedules will be required along with the management of logistics capacity through proper cash management (Chen et al., 2018; McKinsey, 2020).

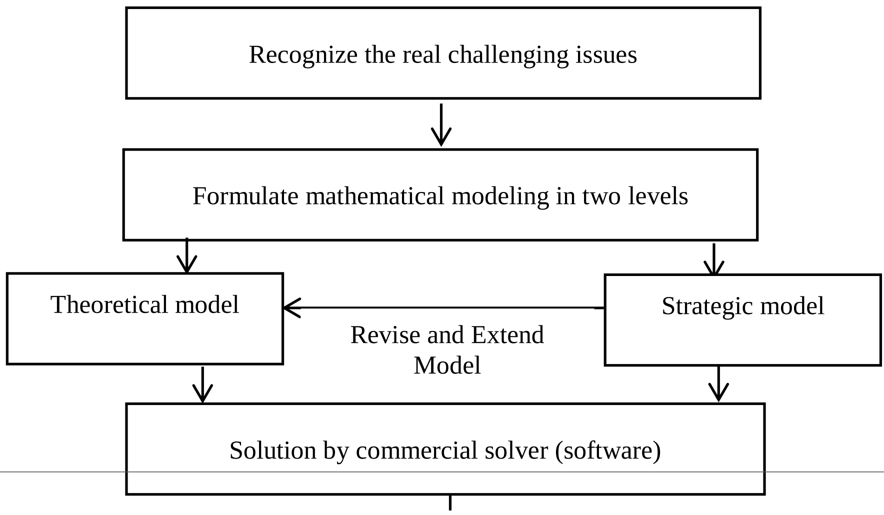
There will be more focus on customer service in terms of getting vaccines at the right place at the right time and in the right quantity. Much needed is a merger of both internal and external operations across the business entities (Stank et al. 2001; Williams, &Tokar, 2008). There will be need for rapid monitoring since the after effects of the vaccine are yet to be explored (The National Academies Press, 2020). Integration and surveillance of individual’s data will be required for proper vaccination (The National Academies Press, 2020).

METHODOLOGY

After the Covid-19 vaccine arrival to the country, the focus will be on vaccine distribution. Covid-19 vaccine distribution is a critical challenging problem at the developing stage that needs a vast research area. This study aims to answer these challenges and provide the policy and decision-makers with practical and considerable insights. This study will bridge the gap and design all aspects of vaccine distribution as well as confront the questions of how to distribute the vaccine all over the U.S. and how long it takes. Suchquestions are addressed by applying operation research techniques through a model. To design a responsive and resilient vaccine distribution network, different centers are considered to satisfy the demands within the cold supply chain (Bremer, 2018). In addition, it is classified into two decision levels that study different situations of vaccine supply. In order to describe the idea of the vaccine distribution problem discussed in this study, mathematical modeling is established. Mathematical methods have been applied extensively since 300 years ago to manage the infectious and distribute the controlling interventions such as vaccination (Dietz &Heesterbeck., 2000). Thesemethods createa better understanding of the vaccine distribution network within different constraints and limitations by applying mathematics to find the optimal solution. By this means, we translate our idea for Covid-19 vaccine distribution network into mathematical representation by suitable assumptions, variables, parameters, and explanations. The proposed models are implemented by optimization software, CPLEX solver in GAMS 25.1.2. GAMS advantages make us motivated to apply. It has been successfully applied to solve various types of problems optimally like network design, routing,etc. It is popular in solving various mathematical modeling, easy in implementation, portability between easy accesses to technical updates.

Prioritization in the lack of enough doses of vaccines and the optimal approach of vaccine distribution within the least delivery time to the vaccine receivers are the main aims of two different levels of Covid-19 vaccination, respectively (Arifoğlu et al., 2012). The first level is the strategic model that the vaccine demand is more than vaccine supply. It occurs at the beginning of pandemic due to limited available Covid-19 vaccine doses and the effort is needed to support individuals based on the priority that is determined by the Centers for Disease Control and Prevention (CDC, 2020). Prioritization is considered as three categories in phase1. 1a) health care workers and long-term care facility residents (frontline health workers), 1b) frontline necessary workers and senior in 75 years old and upper, 1c) senior with 65 to 74 years old, people with 16-64 years old at the risky condition and other essential workers. The prioritization approach causes to decrease the death, promote the functioning of society and revitalize economics. Vaccination of priority in high-risk states is done first and continued for the lower-risk states. It is also continued for the next priorities. The color of states shows the risk level of Covid-19. The red states are at high risk in comparison with orange and yellow states. As reported by National Academy for State Health Policy (NASHP, 2020), in phase 2 larger vaccine supplies that meet the demand are available to have equitable vaccine distribution. In phase 3 to 5, sufficient vaccine supplies are accessible that exceeds the demand and broad vaccine distribution. These lead to the second level of vaccination. The theoretical model is extended to support all population demand with different limitations and constraints related to the cold supply chain. The research flow diagram for the vaccine distribution network is shown in Figure 1.

Figure 1: Proposed research flow diagram for vaccine distribution network



MATHEMATICAL MODELING

The proposed modelsaim is to design the vaccine distribution network. Due to lack of vaccine supply, there would be two decision level models which are motivated by Covid-19 vaccine distribution in the U.S. The theoretical model considers the vaccine distribution network generally to satisfy all vaccine demands. First, vaccines are transferred to the central distribution center (CDC), and then they are distributed to the local distribution centers (LDC). They support the vaccine demand of local server centers (LSC) to satisfy the vaccine receivers. The vaccines can be transported by air or land. All carriers have the characteristics of a cold supply chain to keep the vaccine quality. In the theoretical model, the distribution network design is proposed to determine the routes and sequences of vaccine distributionin order to minimize the total distribution time to satisfy the vaccine demand. The proposed mathematical model provides the optimized network design to connect different centers with demand. This model presents the managers to plan for the total time to cover all over the U.S with Covid-19 vaccine. The strategic model focuses on vaccine prioritization with consideration of risky states in the initial period of the pandemic when vaccine supply doesn't meet the demand. The models are discussed and formulated in two separate mathematical modeling's to cover all constraints to satisfy objectives mathematically as follows. The following notations of the two models are introduced integrated into Table 1. It explains the index sets, parameters, and variables of these two models.

Table 1: Notation of models

Index sets	
C	Central distribution center = {0}
D	Local distribution centers = { 1,2,…,$\|D\|$ }
S	Local server centers = { $\|D\|$+1,…,N }
V	Vertices: $CUDUS$
A	Arcs: $(i,j) \mid i , j \in V ; i \neq j$
Parameters	
ds_i	vaccine demand of local server i
d_{ik}	distance between local server k and local distribution i
dd_i	local distribution center i demand
dr_{rg}	vaccine demand with priority r in state g
ρ_{rg}	importance range of vaccine receiver with priority r in state g
o_i	arbitrary real number
v_k	velocity of vehicle k
d_{ij}	driving distance between node i and j
ρ_{rg}	the importance of vaccine demand with priority r in state g
t_k	recharging time for dry ice

P total population of a country that is directly related to vaccine demands
δ the total available vaccine dose, δ<P
Variables
v_{rg} binary variable, which is equal to 1 if demand with priority *r* lives in state *g* is satisfied, 0 otherwise
x_{ijk} binary variable, which is equal to 1 if local distribution center j is served after j by vehicle k, 0 otherwise.

Strategic Model

Prioritization is applied based onthe lack of vaccine supply. In order to do vaccine distribution to vaccine receivers based on priority, the importance of each priority in a state is shown by ρrp. By introducing vrg the vaccine doses allocated to the priority r in state g is considered to satisfy the priority demands that are limited to the total available vaccine shown δ in all distribution centers. Equation set (1) maximizes the total importance of vaccine doses allocated to priority r in state g. Constraint set (2) satisfy vaccine allocation to priority r in state g according to the total available vaccine dose in all distribution centers.

$$\max \sum_{r\in P}\sum_{g\in G}\rho_{rg}v_{rg} \tag{1}$$

$$\sum_{r\in P}\sum_{g\in G}dr_{rg}v_{rg} \le \delta \tag{2}$$

Strategic Model

In this model, supply is enough to support all individuals' demands. Vaccine distribution to the local distribution centers aim is to minimize the sum of total distribution time and recharging time of dry ice for vaccine distribution stated as Equation (3). The main task in distribution is to find a set of tours for several vehicles that may be trucks or airplanes from the central depot to the local distribution centers in various geographical regions. By introducing binary variable x_ijk, constraint sets (4) and (5) assure that each local distribution center to be serviced by only one vehicle. Constraint set (6) prevents the sub tour by presenting a positive variable o_i (Miller et al., 1960). Constraint set (7) ensures flow conservation. Constraint sets (8) and (9) ensure that a vehicle should leave the center and return to the central distribution center at most once. Capacity restriction of vehicles is guaranteed by constraint set (10), where the maximum loading capacity of vehicle v does not exceedQ_k. Constraint set (11) is the flow connection of two stages that are central distribution center to local distribution centers and local distribution centers to local service centers. Each local server center should be met by only one vehicle that is asserted by constraint sets (12) and (13). Constraint set (14) omits the sub tour. Flow conservation is declared by constraint set (15). Constraint sets (16) and (17) ensure the arrival and departure of vehicles to the local distribution centers almost once. Constraint set (18) satisfies the vehicle capacity.

$$Min\sum_{i\in V}\sum_{j\in V}\sum_{k\in K}(\frac{d_{ij}}{v_k})x_{ijk}+t_k \tag{3}$$

$$\sum_{i\in C\cup D}\sum_{k\in K}x_{ijk}=1,\forall j\in D \tag{4}$$

$$\sum_{j\in C\cup D}\sum_{k\in K} x_{ijk} = 1, \forall i \in D \quad (5)$$

$$u_i + 1 \le u_j + |D|(1 - x_{ijk}), \forall i, j \in D, k \in K \quad (6)$$

$$\sum_{i\in C\cup D} x_{ilk} - \sum_{j\in C\cup D} x_{ljk} = 0, \forall l \in C \cup D, \forall k \in K \quad (7)$$

$$\sum_{j\in D} x_{ijk} \le 1, \forall i \in C, \forall k \in K \quad (8)$$

$$\sum_{i\in D} x_{ijk} \le 1, \forall j \in C, \forall k \in K \quad (9)$$

$$\sum_{i\in D}\sum_{j\in C\cup D} dd_i x_{ijk} \le Q_k, \forall k \in K \quad (10)$$

$$\sum_{i\in C}\sum_{k\in K} x_{ijk} \ge \sum_{i\in S}\sum_{k\in K} x_{jik}, \forall j \in D \quad (11)$$

$$\sum_{i\in D\cup S}\sum_{k\in K} x_{ijk} = 1, \forall j \in S \quad (12)$$

$$\sum_{j\in D\cup S}\sum_{k\in K} x_{ijk} = 1, \forall i \in S \quad (13)$$

$$u_i + 1 \le u_j + |S|(1 - x_{ijk}), \forall i, j \in S, k \in K \quad (14)$$

$$\sum_{i\in D\cup S} x_{ilk} - \sum_{j\in D\cup S} x_{ljk} = 0, \forall l \in D \cup S, \forall k \in K \quad (15)$$

$$\sum_{j\in S} x_{ijk} \le 1, \forall i \in D, \forall k \in K \quad (16)$$

$$\sum_{i\in S} x_{ijk} \le 1, \forall j \in D, \forall k \in K \quad (17)$$

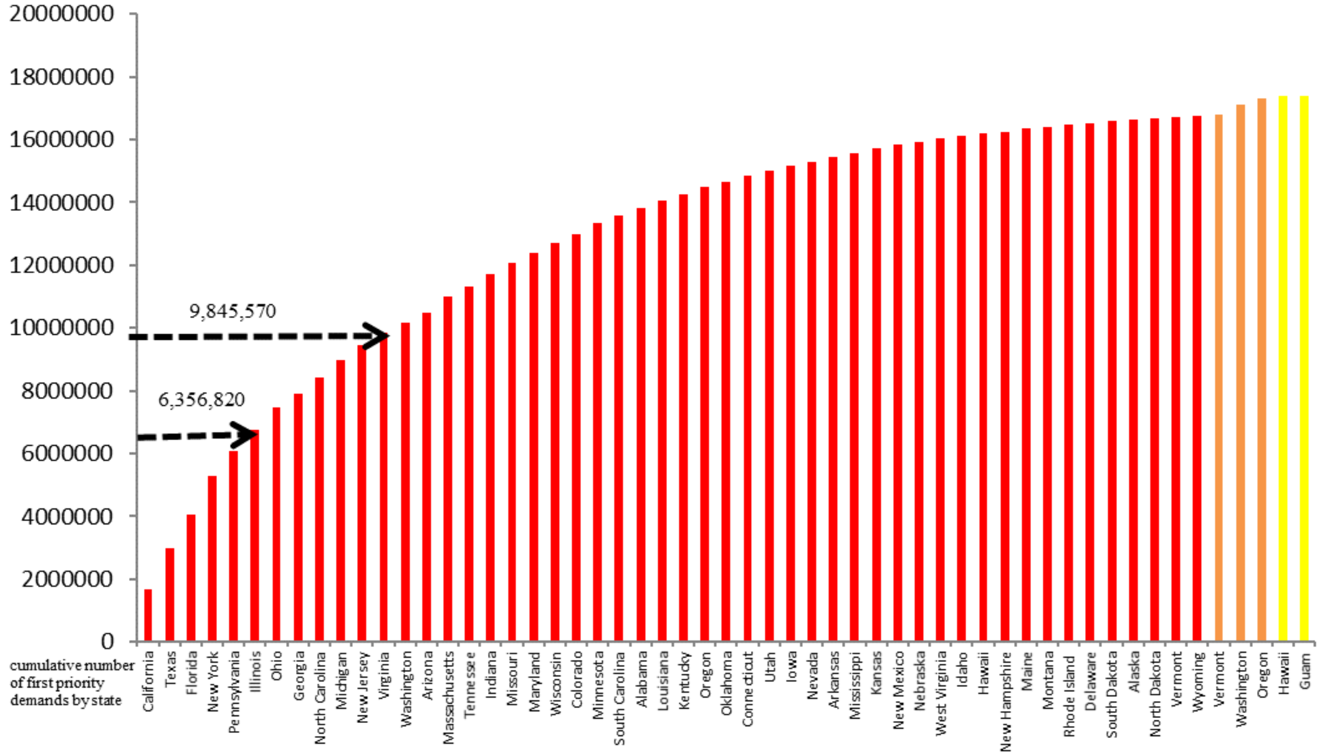
$$\sum_{i\in S}\sum_{j\in D\cup S} ds_i x_{ijk} \le Q_k, \forall k \in K \quad (18)$$

MODEL VALIDATION

For validating the developed model and demonstrating the actual behavior of vaccine distribution, real data fromthe United States isused(JHU, 2020) and (BLS, 2018). In the strategic model, data provide the status of risky states and the healthcare workers' statistics by states, respectively. As explained in subsection 2.1, the strategic model determines the allocation of vaccine doses to each priority by states. The first priority, 1a involves healthcare employments consist of ambulatory healthcare services, hospitals and nursing, and residential care facilities. Vaccination of first priority (1a) in high-risk states is done at first and continued for the lower risk states. It is also continued for the next priorities respectively. The color of states shows the risk level of Covid-19. The red states are at the highest risk in comparison with orange and yellow states.

In order to do vaccine prioritization model validation, the importance of each priority in a state (ρrg) is considered proportionally to the state population. As the vaccine supply is less than vaccine demand, the supply dosesare determined by generating a random number less than the total population , . The vaccine prioritization is done based on total available vaccine supply and vaccine demand in the first priority (1a) within different risk level states. Figure 2 shows the schematic presentation of vaccine doses allocated to the state based on available supply shown by the arrow.In Figure 2, the x-axis depicts the cumulative number of healthcare employments in the United States by the risk level of states. The vaccine doses allocated to this priority based on the state's demand and available supply are calculated by solving the strategic model explained in subsection 2.1. The arrow in Figure 2 illustrates the different available vaccine supplies for prioritization. The arrowhead shows the last state that vaccine doses are allocated to. For instance, 9,845,570 vaccine doses are available, California, Texas, Florida, New York, Pennsylvania, Illinois, Ohio, Georgia, North Carolina, Michigan, New Jersey, and Virginia demands are satisfied fully (vrg=1) and Virginia is the last states shown by the arrowhead. In the case of availability of 6,356,820 vaccine doses, California, Texas, Florida, New York, Pennsylvania demands are satisfied fully (vrg=1)and Illinois demand is satisfied partially. It means 300,000 vaccine doses would be allocated to Illinois. Both strategic and theoretical mathematical models are implemented via the CPLEX solver in GAMS 25.1.2. The strategic model is discussed. The results and analysis of the theoretical model are presented in Section 4.The model verification done by commercial software ensures that the models are correct without errors.

Figure 2: Schematic presentation of vaccine doses allocated to the state based on available supply shown by arrow



ANALYSIS AND RESULTS

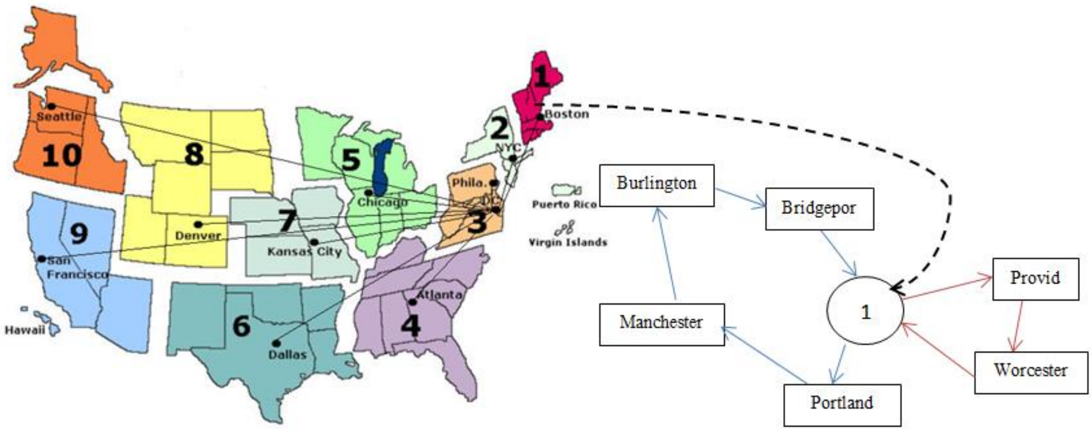
The optimization model presented in Section 2 is employed on a real case study concerning the 2020 Covid-19 outbreak in the U.S. It is chosen as a case study in this research due to its knowledge to produce the first Covid-19 vaccine. Field research is conducted to obtain data related to the real-world proposed vaccine distribution network. Data is gathered from U.S. Census Bureau Population Estimates, (2020) and U.S. Department of Health & Human Services (2020). It involves geographic information such as the location of centers and driving distance between them, and population data to determine the vaccine demands. Table 2 shows a sample of driving distance between Boston (LDC1) and the covering LSCs calculated by Google Maps.

Table 2: Sample-driving distance between Boston (LDC1) and the covering LSCs

LDC_1	Boston	Bridgeport	Portland	*Manchester*	Providence	Burlington	Worcester
Boston	0	183	519	174	117	279	78
Bridgeport	183	0	685	333	141	333	116
Portland	519	685	0	491	635	621	557
Manchester	174	333	491	0	288	165	188
Providence	117	141	635	288	0	394	78
Burlington	279	333	621	165	394	0	374
Worcester	78	116	557	188	78	374	0

Washington DC as the capital city of the United States is selected for central distribution center (CDC). The CDC receives the total doses of vaccine imported to the United States. After the arrival of vaccines to the capital of the United States, the distribution of vaccines to the regional offices of the U.S Health and Human Service department (HHS) is started based on the regional demand likely from CDC to local distribution center (LDC) by air. The air transportation mode is selected to have an agile and fast way of vaccine distribution all over the U.S. Then, vaccines are distributed from LDCs to local server centers (LSC) by land.Figure 3 illustrates the sample mapping of the proposed vaccine distribution network. LDCs are Boston, New York, Philadelphia, Atlanta, Chicago, Dallas, Kansas City, Denver, San Francisco, and Seattle. Each HHS regional office covers some states (HHS, 2020).

Figure 3: Sample mapping of proposed vaccine distribution network in the U.S.



In order to determine the number of LSCs, ten LSCs are supposed to be assigned to the most populous state, California. The number of LSCs in each state ($N_{LSC,state}$) is determined proportionally to the state population (pop-state) calculated as $N_{LSC,state} = [\left(\frac{10}{pop-California}\right) \times pop - state]$. The top $N_{LSC,state}$ populated cities in each state are supposed to be the locations of LSC. LSC consist of big hospitals to small clinics, and other facilities to satisfy vaccine receivers' demand. The number of centers is explained in Table 3.

Table 3: Total number of centers in the vaccine distribution network

Type of centers	Central distribution center (CDC)	Location	Local distribution center (LDC)	Location	Local server center (LSC)
Total number	1	Washington DC	10	Boston New York Philadelphia Atlanta Chicago Dallas Kansas City Denver San Francisco Seattle	89

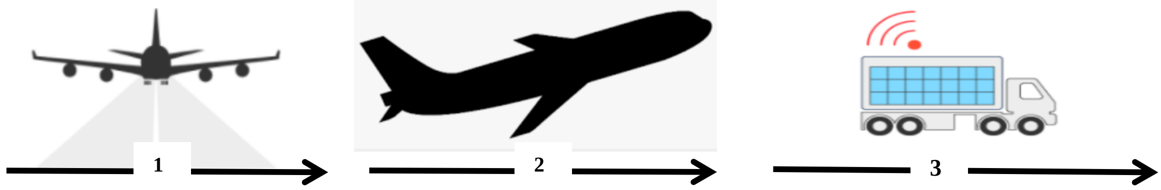
People go to the LSCs for receiving vaccines according to predetermined scheduling with detailed information to make an appointment on the state government website. It means that people should find the LSC located near their location for vaccination and register for it online. The plan already is implemented in Texas right now (AARP,2021). The data permits the determination of the routes and sequences of vaccine distribution to the LSCs in order to minimize the total delivery time in the distribution network. It concludes by solving the proposed theoretical model with GAMS. Sample information about the route and vaccine distribution sequence started from Boston as the LDC1 to their covering states and LSCs are explained in Table 4.

Table 4: Sample information about LDC1, LSC, and vaccine distribution routes in Boston

#	LDC_1	States	LSC	Vaccine distribution routes	Route color
1	Boston	Connecticut	Bridgeport	Portland,*Manchester,* Burlington, Bridgeport	Red
		Maine	Portland		
		New Hampshire	*Manchester*		
		Rhode Island	Providence	Providence, Worcester	Blue
		Vermont	Burlington		
		Massachusetts	Worcester		

The requirement of minus seventy Celsius storage and the ultra cold chain for Covid-19 vaccine in the United States is the essential infrastructure. It is controlled by applying a dry ice approach within transshipment in the predetermined locations. Carriers such as refrigerated trucks that are equipped with systems of controlling the temperature range and GPS trackers are used. Figure 4 illustrates the schematic of the proposed Covid-19 vaccine distribution in the U.S. from the arrival stage to cover the whole U.S. in detail. As shown, to the best of the authors' knowledge this is the best approach for Covid-19 vaccine distribution. The proposed model may not reflect some other requirement that can be configured and extended as follows.

Figure 4: Schematic of proposed Covid-19 vaccine distribution in the U.S.



Covid-19 vaccines arrive at the US central distribution center	Covid-19 vaccines are distributed to the HHS regional offices as local distribution centers	Covid-19 vaccines are transported to the capital city of states as local server centers by equipped carriers with GPS and ultra-cold storage that can be recharged by the dry ice in the predetermined locations to preserve the temperature range.

CONCLUSION

The uncertainty created by the pandemic in demands and disruptions of vaccines is the motivation behind this paper. The paper has attempted to develop a mathematical model for vaccine delivery. The model explains the distribution network of vaccine at two decision levels. The decision levels are influenced by the distribution of Covid-19 vaccine in the U.S. The vaccine delivery system has to revolve around the management of specific requirements such as ultra-cold chain mechanisms while maintaining multi-dose vaccine systems and develop a well-coordinated approach to leverage the existing resources. Due to the unexplored after-effects of the vaccine, the system has to be coupled with rapid monitoring on a real time basis. The integration of data regarding vaccine providers and vaccine takers has to be collated to ease the tracking of individuals with the symptoms of the virus. This information in a surveillance system can identify the gaps, both existing and new, and will ensure proper vaccine allocation. This study can be done by the logistic organizations, as they will be traveling to different places to deliver vaccines. The staff of the logistics and transportation organizations can be trained to conduct this survey as well as even a virus test.

There are some limitations in the proposed models that can be revised and developed in the next stage of this research due to the availability of more relevant data. The theoretical model can be extended by considering the location of new facilities for faraway areas to support all people even in the rural. Vaccine server centers should be located separately from the hospitals and clinics providing service to corona patients. This omits the disease contacts chain. The operating costs related to locating the distribution centers and the server centers are the other features that can be added to the model. The proposed model can be extended to support the whole individual demands and minimize the gap between vaccine supply and demand when there are sufficient vaccine supplies. Consideration of safety stock to satisfy unexpected demands is a good approach.

These prevent the shortages of this critical medicine due to unpredicted demands. In order to prevent the spread of Covid-19 effectively as a new way in mass vaccination and the growth of e-commerce and IT, the care delivery model can be developed to apply for all individuals to service them at their locations by use of the mobile application to send the request online. And also, vaccine servicing in the workers' facilities for their own personnel is a practical idea in this direction.

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A Text Mining Analysis of First-Generation College Students' Persistence and Retention

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ABSTRACT

Retention measures how many students remain at an institution from one period to the next. Typically, it is measured on a yearly basis. Persistence has a similar definition but with a different connotation. Persistence is the more individual view of the issues – how a student was able to "persist". We used a text mining approach to identify themes from papers published in the past few years on retention and persistence for first-generation college students. Our results show researchers have addressed academic, support, and programs with surveys, interviews, and focus group interviews being the most commonly-used study methods.

KEYWORDS: Student retention, persistence, first-generation college students, text analysis, under-served population

INTRODUCTION

Retention is a topic of great interest to academic institutions. Retention is simply a measure of how many students remain at an institution from one period to the next. Typically, it is measured on a yearly basis. Persistence has a similar definition but with a different connotation. Persistence is the more individual view of the issues – how one student was able to "persist". A student persists, while an institution is the one who retains students. Conventional views of retention have evolved greatly over the past century, aligning with a shift on whom the responsibility for a failure to educate an individual should lie with. It is no longer the conventional view that a student fails out of an academic curriculum purely due to a lack of academic skills (Tinto, 2005). Instead, the blame is shifted to lie more with the systems in place at the academic institution itself. Programs and departments have been introduced across the country in order to increase the rates of retention in higher education. The goal of retention programs is to reduce the rates of students who leave the institution before completing a degree.

In 2014 and 2015, retention rates at 4-year colleges averaged 81%. The type of college did matter. For example, at open admissions schools the average was 62% while at schools with the harshest admission standards (<25% applicants accepted), the retention rate was 96% (U.S. Department of Education, National Center for Education Statistics, 2017). The type of student matters as well. Statistics show that only 11% of first-generation college students earn a bachelor's degree in six years compared to 55% of non-first-generation college students (The Pell Institute, 2008). Moreover, first-generation college students are 71% more likely to leave college in their first year than non- first-generation (Pratt, Harwood, Cavazos, & Ditzfeld, 2017). Given that 56% of undergraduate students nationally were first-generation college students in 2015 (RTI International, 2019), improving retention is of great interest to the academy.

The purpose of this study is to review the literature and to perform text analytics on published papers on first-generation college student retention. By identifying the recent evidence, we want to suggest strategies to improve first-generation students' persistence.

LITERATURE REVIEW

In Vincent Tinto's 2006 paper "Research and Practice of Student Retention: What Next?", Tinto lays out an excellent and slightly pessimistic overview of the evolution of retention in secondary education across the course of his career, dating from the 60s until the time he wrote the paper. He points out that our understanding of retention and its causes advanced heavily from a somewhat flawed, "lens of psychology" (Tinto, 2006, p.2) model in the 60s, where lack of retention was viewed as a failure on the individual student's part rather than on the part of the institutions. This change is presented as categorically good, with one caveat. Despite this change in viewpoint and various additional retention programs, "the national rate of student persistence and graduation has shown disappointingly little change over the past decade. The fact is that despite our many years of work on this issue, there is still much we do not know and have yet to explore" (Tinto, 2006, p. 2). While the phrase and acronym, "Dimensions of institutional action" is not used in his paper, the theory outlined in it is referred to by this name in later papers (Harrell, 2018). Understanding of specific risk factors for retention has advanced greatly since Tinto's paper due to the advent of analytics, but counter-acting these identified risk factors has remained difficult (Harrell, 2018).

Historical Statistics

Retention and graduation statistics have remained relatively stable for some time now. "As many as 41% of college students leave higher education without obtaining their degree. Of these students, 75% leave within the first two years, and freshman attrition rates are commonly as high as 20-30%. While many theories exist that attempt to explain retention, retention rates have remained steady over the decades and institutions have yet to find a way to effectively operationalize theory" (Barclay, 2018). This is not necessarily a wholly negative statistic, however, as retention rates have not universally risen either. Many scholars and institutions remain heavily focused on first-year college students, as "in recent years, one-fifth of all first-time, first-year students who started at a four-year institution was not expected to return for a second year at that same institution, an attrition rate that has held steady for many years now" (Feldham, 2017, p. 187). Graduation rates remain similar. "Yet most four-year colleges and universities only graduate 59% of each entering class, and nearly 20% of first-year students drop out of college before the start of their second year" (Feldham, 2017, p. 309).

Risk Factors

There are a number of specific risk factors for retention for both individual students and schools as a whole. Private, for-profit colleges have an abysmal overall retention rate of 56% while highly exclusive public universities and private non-profits are at 81-82%. More to the point, highly exclusive schools (accepting less than 25% of students) have an average retention rate of >95% in all cases. Open admissions colleges hover around a 60% retention rate. While retention rate and graduation rate are not the same issues, they are highly correlated and both of concern to universities. "About 60 percent of students who began seeking a bachelor's degree at a 4-year institution in fall 2010 completed that degree within 6 years; the 6-year graduation rate was higher for females than for males" (nces.ed.gov). Whether this is an institutional risk presented by the structure of the institution or by the types of students the institution accepts is difficult to say.

Some of the various individual risk factors identified from the literature include whether students were from rural areas, LSEO (low socio-economic background), members of a minority group, first-gen college, academic background, & gender. Milea (2018) did an exhaustive study of 7 years of data from a public university and developed some regression models for which variables effected retention rates the most. By far, the highest variables were all economic - scholarships and grants had the highest positive correlation (sports scholarships as well as academic) (p 317), while loans were negatively correlated. An increase in class size was correlated with a decrease in retention as well.

In a similar vein, Chan (2015) examined the factors that determined GPA at a two-year technical college. Chan focused on different types of social interaction and attempted to determine what correlation (if any) these types of interactions had with GPA and retention. They categorized the interactions by the student's motivations: curricular demand, diversity-related, and broader educational purpose. Chan's study helped prove that different types of interactions had different effects on GPA. Curriculum enforced was negatively correlated, broader education was positively correlated, and diversity-related was slightly negative.

Barclay and Barclay (2018) argue that self-efficacy and self-discipline are the most important traits. By self-efficacy, they mean that "[how] one view themselves and the narratives they hold in relation to their academic success can predict their success academically". They added this to the idea that "ego strength" was particularly predictive (p. 67). Ego strength was essentially the level of self-confidence that the individual had, but with consideration given to resilience of their self-identity as well.

Feldman (2017) argues that "fixed" vs "growth" mindsets are what separate some of those who fail from others, with all other factors being even. The fixed mindset means that a person believes that work is beyond them, while a growth mindset means they believe they can grow to accomplish it. While not quite as psychologically focused as the theories from the 60s that Tinto disdained, psychology still factors in for many retention risks.

Both Travers (2016) and Hlinka focused on a particular type of at-risk student: rural students. They were more likely to engage in online courses, and as Hlinka (2017) says, "This study revealed three major factors affecting traditional-age, rural Appalachian community college students' decision-making processes that affect retention: (a) community's and family's values of education provide the essential push to attend and complete college, (b) students are challenged with possessing cultural capital that enables them to overcome the pull of family obligations, and (c) students struggle to collect the academic capital to master college-level coursework."

Gender is an area where the risk factors cut both ways when combined with other factors. D'Lima (2014) found that African American and Hispanic men were more at risk than their female counterparts for graduation (36% /41% of all degrees earned were by men respectively) and that men of all ethnicities were under-represented in graduate studies. Men also experienced a greater decrease in intrinsic motivation as the semester went on than women did. Conversely, specific programs of study are correlated negatively with retention for gender, of which the most research, by far, has been on women in STEM fields. It is suggested that this is a result of societal expectations and pressure, and this is at least somewhat borne out due to the fact that women at all-women's colleges perform better in STEM classes than do their co-ed counterparts (Feldman ch. 10, 2017).

Practice and Implementation

Retention programs fall into roughly four categories as to what they're trying to improve: academic, interpersonal skills, social situation, and financial situation. Universities have tried a wide variety of types of programs: University Wide, First Year Seminars, advising alteration, Mentor/Role Model programs, and altering gateway courses. Gateway courses are the ones that are required to progress further into a program of study that has to be taken early on by all students of that major.

University-wide programs are by far the most effective but also by far the riskiest and costliest. For example, the University of Kentucky's 15-year program to improve retention, starting in 1999, had essentially no effect on their retention while costing massive amounts of money (Johnson 2017), while the University of Texas at Austin had great success (Feldman 2017), improving their graduation rate from 51% to 66% across 6 years. First-year seminars have been in place in some form for over a hundred years (Bigger, 2005), and over 90% of all universities have them, though implementation varies wildly, with no standard format existing (some prefer year-long seminars, some prefer 1 credit hour orientations). While they have existed in a credited form since 1911, their most modern incarnation took place in 1972, in response to riots at the University of South Carolina (Bigger, 2005).

The cheapest options that still have some effect appear to be the Mentor/Role model and advising programs. UT Austin's program was incredibly ambitious, and it came close to meeting its goals for such a large institution (it has 40,000 undergrads) is notable. They attempted to change the culture, by redesigning freshman orientation, appointing a Graduation Champion (an individual solely responsible for increasing grad rates), and creating a regression model to determine at-risk students before matriculation, along with various academic success programs. They also put considerable effort into making sure that the faculty was on-board with all changes before they were made. The variables they used "related to student demographics and past academic performance include state and national residency status, first-generation in college status, self-reported parent income, SAT equivalent score, high school class rank, high school credits by subject area, the student's academic college and whether it was the student's first choice, and whether the student was admitted automatically based on high school class rank as part of Texas' "Top 10% Rule" (Feldham 2017, p. 163).

The most impressive advising alteration was examined by Harrell (2018), who examined a two-year nursing program that raised its retention rate from 49% to 57% over the course of three years with changes to their advising program. The program added a face-to-face meeting within the first two weeks of the semester as a part of their advising duties (p 38), maintained and documented contact at least once every 16 weeks, and responded within 72 hours to any referral of concern from faculty. Before the first session, students were also asked to complete a curriculum assessment (to track their progress to graduation), and a study skills self-assessment (Student Study Skills Self-Assessment).

Mangan (2015) wrote about a program called Connect2Complete, implemented for low-income students who were in remedial classes. The students were assigned peer tutors who had graduated from the class, and the retention for the program was 32% instead of 26% for the control group. The theory behind the program was to improve the self-confidence of the students.

The most effective programs generally focus on specific groups of at-risk students, tailoring the program to their specific needs. Programs frequently only increase the retention rate of at-risk students, while having a less noticeable effect on the groups who are already generally well retained (Feldman 2017). UT Austin's persistence rate increased by 7% for the bottom SAT quartile, compared to 2% for the top quartile, for example. Likely for this reason, some universities chose to have programs that focus more specifically on the at-risk groups. Hernandez (2018), Becker (2018), and Brooks (2012) focused on these types of programs.

Gateway courses are somewhere in between the FYS and the campus-wide initiatives. As Feldham (2017) puts it, "We find that students who are in otherwise good academic standing but take and earn a D, F, W, or I grade in a gateway course simply elect not to return to the institution at which they took the course" (p. 134). This means that if a student fails any gateway class, they generally never graduate at all (let alone at the institution they were at). Both Feldham (2017) and Tinto (2006) argued that the method of teaching these classes, in general, should be rethought. Tinto (2006) pointed out that the only educators in the country not trained in education are college professors, while Feldham (2017) argued that lectures are an ineffective method of imparting knowledge.

METHODS

We conducted a text analysis on the abstract of papers published using the keywords search of the first-generation college student, persistence, and retention. After a screening of recent publications, 29 abstracts of papers published between 2017-2021 were used to perform text analytics to identify themes. Several Python NLTK packages were used to identify and count keywords, produce visuals, and create topics/themes.

RESULTS

As shown in Figure 1, highly occurred words are academic, support, experience, social, education, belongings, etc. These words indicate researchers have addressed academic performance, programs offered to first-generation students, various support mechanisms, and social/belonging aspects.

Figure 1: Word cloud of abstracts

Figure 2 depicts the 20 most common words. These are academic, support, program, self, experience, education, belonging, etc.

Figure 2: 20 Most Common Words

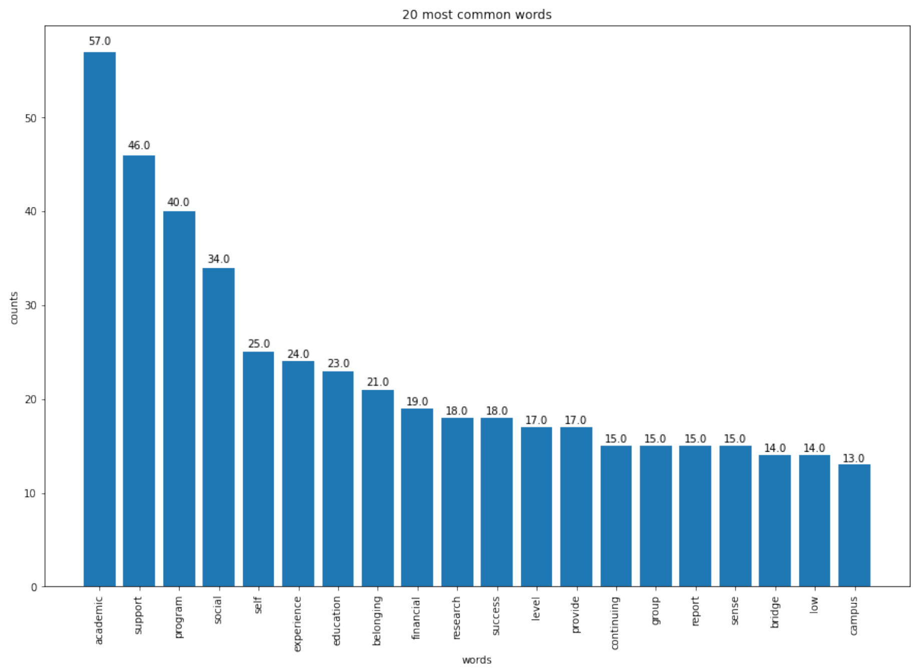

Figure 3 shows the number of topics produced by the 39 abstracts.

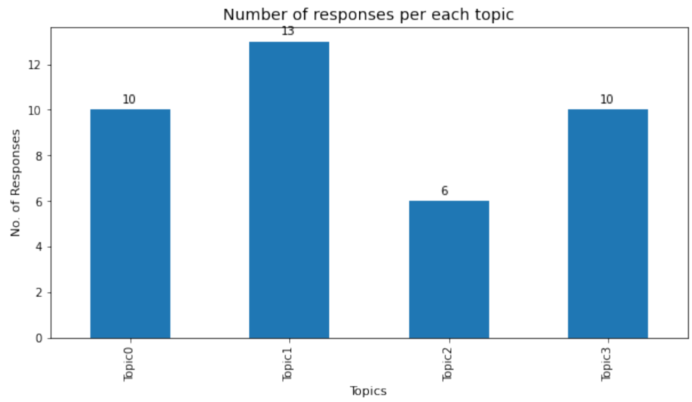

Table 1 contains keywords for each topic. Topic 0 focuses on academic performance, belonging, self-identify, and relationship with parents for low-income first-generation students; Topic 1 addresses academic support, student groups, experience, and financial aspects of the first-generation students; Topic 2 explores how different programs can help with the retention of first-generation students; Topic 3 emphasizes various supports: financial, social, emotional support.

Table 1: Keywords in Each Topic	
Topic #0	academic, belonging, self, parent, sense, report, low
Topic #1	academic, support, program, group, experience, self, financial
Topic #2	program, bridge, support, social, aca demic, summer, education
Topic #3	support, social, program, education, financial, experience, emotional

DISCUSSION AND CONCLUSIONS

The literature examined provides fruitful results on the retention of first-generation students. With regards to research methods, 2 used mixed methods, 14 used qualitative, 11 used quantitative, and 2 used secondary data analysis. Studies have focused on academic support, financial support, mentoring, summer programs, bridge programs, academic enrichment programs, social support, etc. More recently, mental, and emotional support have become available on many campuses. Campuses have offered training classes for instructors to do early detection of emotional/mental distressed students. As the retention of first-generation students continues to be of concern, university administrators need to leverage their institution’s data to find patterns and trends. At the same time, administrators need to motivate faculty members to engage students more and report early warning signs. Advisors and counselors also play critical roles in helping first-generation students. New and innovative interventions are to be developed based on students' needs and challenges. Getting to know students at a personal level will facilitate the better design of interventions.

In the future, we will build on what we have and expand the literature reviews. We'd also explore how institution types affect students' retention.

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A White Box Perspective on Supply Chain Delivery Performance Improvement

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ABSTRACT

This paper proposes a delivery performance improvement technique using the Graphical Evaluation and Review Technique based on the characteristic function (CF-GERT). It addresses a critical disadvantage of supply chain delivery performance models, namely considering a delivery process as a whole and ignoring characteristics and relationships between activities in the delivery process. Based on the CF-GERT model, an approach for applying managerial effort to improve overall delivery performance is proposed. Then, particle swarm optimization (PSO) is used to identify an optimal decision.

KEYWORDS: Supply chain management, Delivery performance, Delivery window, Graphical Evaluation and Review Technique, Particle swarm optimization

INTRODUCTION

In today's highly competitive global business environment, meeting customer needs in a timely and reliable manner is of great importance for companies to enhance market competitiveness (Tracey et al., 2005). To increase market competition, many organizations adopt supply chain management as the basis of their competitive strategies (Kouvelis et al., 2006). With the support of supply chain management techniques, competition among companies has changed into competition among supply chains, and effective supply chain management has become a tool to enhance the overall competitive advantage (Tracey et al., 2005). Supply chain performance evaluation and improvement play an important role in pursuing a high competitive advantage. Many researchers have pointed out the importance of performance evaluation in supply chain management (Gopal & Thakkar, 2012, Ellinger et al., 2012). Within the hierarchy of supply chain performance indicators, delivery performance is considered to be one of the key indicators driving supply chain excellence (Guiffrida & Nagi, 2006; Guiffrida & Jaber, 2008; Hsu et al., 2013).

Many researchers have studied the problem of delivery performance improvement. Although these papers provide several insightful and useful management methods, they do have a significant limitation: the delivery process is considered a black box. Most of the existing studies assume a predetermined lead time distribution type and then explore how changes in distribution parameters influence the delivery performance. This perspective regards the supply chain as an overall system, neglecting all sub-activities that constitute the supply chain delivery process. Hence, we define this perspective as a black-box perspective which may provide fewer management insights in reality. Because supply chain managers have no clear idea of which supply chain activity to improve, and how to allocate the investment.

In reality, a supply chain delivery process consists of several related activities aimed to fulfill the customer needs. Therefore, supply chain delivery performance improvement should rely on the improvements in each of the activities, e.g., duration reduction and variance reduction. Also, due to the uncertainty associated with some complex elements of a delivery process, there might be probability branches and rework required in the process. Therefore, an appropriate tool is needed for the description of a complex supply chain delivery process. In this study, the supply chain delivery process will be portrayed as a network of related activities, which remain to be improved. So, we call this perspective a white box perspective.

The current study aims to build a white-box approach to improve supply chain delivery performance based on the concept of delivery window and the Graphical Evaluation and Review Technique based on the characteristic function (CF-GERT) model. The research herein allows determining whether it is beneficial to invest in delivery performance improvement and the amount of resources (or applied effort) that should be allocated to each activity. Particularly, the resources (i.e., managerial efforts and monetary assets) will be applied to reduce the variance of supply chain activities. To achieve this goal, the delivery time distribution is deduced by the analysis algorithm of the CF-GERT model. Then, considering the relationship between the applied effort and reduced uncertainty, the expected cost model is established. Finally, the optimal solution is found by finding the optimal position of the delivery window and the percentage of applied effort of each activity that minimizes the expected cost.

The contribution of the paper is twofold. First, a general approach to portray a complex supply chain delivery process using CF-GERT is proposed. It allows to derive a delivery time distribution in form of probability density function (PDF) and cumulative distribution function (CDF) and analyze the effect of each activity in the delivery process on the delivery time distribution. Thus, the proposed white-box perspective of supply chain delivery performance improvement takes all related activities within the supply chain and their relationships into full consideration. Second, a particle swarm algorithm-based solution procedure is proposed to allocate additional investment and managerial efforts. The procedure uses a resource allocation model developed in the paper herein. The procedure minimizes the delivery-related costs in the resource allocation model.

The rest of this paper is organized as follows. Section 2 provides a literature review. On this basis, section 3 constructs a cost-based supply chain delivery performance improvement model with a white-box perspective. Following this, the model solution based on the particle swarm algorithm (PSO) is developed in section 4. Finally, section 6 gives the conclusion and future research directions.

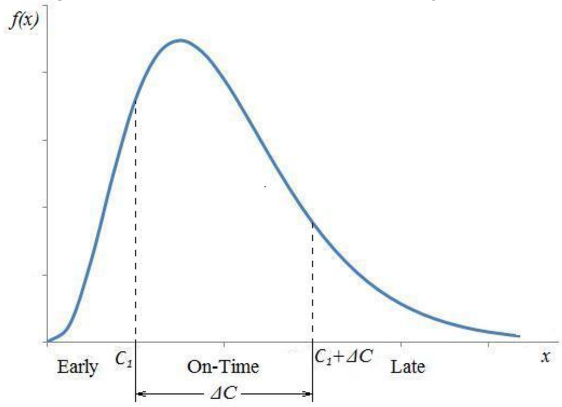
LITERATURE REVIEW

Supply Chain Delivery Performance Improvement

The delivery window concept used in supply chain delivery performance models evolved from the general class of time interval constrained models for vehicle routing and scheduling found in the operations research and operations management literature. Supply chain delivery performance models that use delivery windows can be categorized into two groups (Bushuev and Guiffrida 2012): (i) index-based measures that convert the probability of on-time delivery into a delivery capability index, and (ii) cost-based measures that utilize costs incurred by untimely delivery to reveal delivery performance. The present paper extends research in the area of delivery performance improvement. For delivery performance improvement, cost-based models have a huge advantage over index-based models because improvement is easier to understand in cost values than in index values. Moreover, a decision can be easily made if the monetary advantage of the decision is known (Bushuev, 2018). Therefore, this study adopts the cost-based delivery performance expression to analyze the delivery optimization of the supply chain.

The concept of the delivery window was introduced by Guiffrida & Nagi (2006), which is defined as the difference between the earliest acceptable delivery date and the latest acceptable delivery date (Figure 1). Thus, the delivery may be classified as early, on-time, or late. When the delivery is completed within a given delivery time window, the delivery is regarded as on time. Otherwise, the delivery will be early or late, which will result in additional costs for a buyer which will pass the costs to the supplier in form of penalties for untimely delivery. For delivery performance evaluation using a delivery window, Guiffrida & Nagi (2006) developed a model that incorporates the variability found in the individual stages of the supply chain into a financial measure. They discussed the effect of the reduction of delivery variance and delivery window on the improvement of the overall system performance, financially justifying investments for delivery performance improvement.

Figure 1: Illustration of a Delivery Window



Legend: f(x) is the probability density function (PDF) of delivery time, c1 is the beginning of on-time delivery, Δc is the width of the delivery window.

Based on the cost-based model, Bushuev and Guiffrida (2012) introduced the concept of the optimal position of the delivery window (OPDW) which defines a time when the delivery process should begin to minimize the expected penalties paid for untimely delivery by the supplier. Further, Guiffrida & Jaber (2008) and Guiffrida, Jaber, & Rzepka (2008) developed cost-based models based on the concept of the delivery window and financially quantified the benefit of reducing delivery variance. Hsu et al. (2013) investigated the effect of further reduction of lead time variability on delivery performance. Ngniatedema et al. (2016) developed a variance reduction modeling approach. Bhattacharyya and Guiffrida (2015) demonstrated an optimization framework for improving supplier delivery performance. The influences of different delivery time distributions and other model parameters were investigated by several researchers (Tanai and Guiffrida, 2015; Bushuev, Brown, and Rudchenko, 2018; Bushuev, 2018). Madadi & Iranmanesh (2012) proposed an indicator and a method to identify important activities and the amount of effort that should be assigned to them. Tao et al. (2021) proposed a Conditional Value-at-Risk (CVaR) measure of the penalty for untimely delivery.

All previous research mostly focused on 2-stage supply chains where the delivery process is considered whole and not divided into activities (black-box models). White-box models separate a delivery process into activities which provides a significant advantage for delivery performance improvement. At the same time, the previous research with a white-box perspective has several limitations that are addressed in the paper herein:

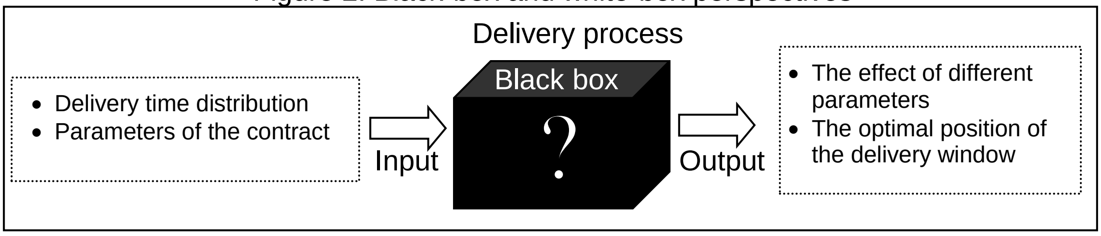
1. All previous research uses the normal distribution to describe the duration of each activity. The paper herein is using a general form of delivery time distribution.
2. All previous research focuses on a serial supply chain and as a result, assumes a serial form of relationship between activities within the delivery process. The paper herein assumes a general form of a network of delivery process activities that might include parallel, serial, and loop forms of connections.
3. All previous research assumes that the position of the delivery window is fixed or in other words, the time when the product should be shipped is predefined which leads to non-optimal decisions. The paper herein exploits the optimal position of the delivery window (OPDW) concept to find an optimal time to ship the product and minimize the penalty costs.

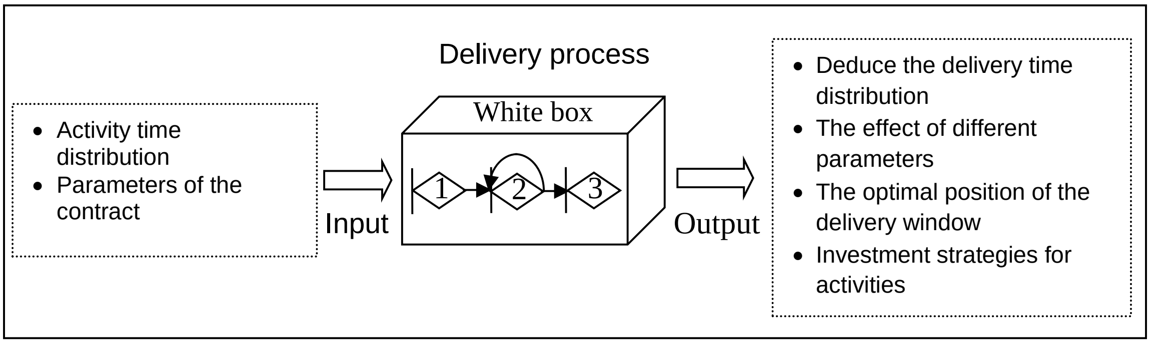
Graphical Evaluation and Review Technique

The Graphical Evaluation and Review Technique (GERT), proposed by Pritsker (1966) is suitable for use in this case, because of its capability of handling probabilistic activity duration, and probabilistic representation of network logic, and rework (Tao et al., 2017). The main differences between the black-box perspective and the white-box perspective are presented in Figure 2.

Both black-box and white box perspectives have similar inputs, the only difference is that delivery time distribution is provided for the whole delivery process (black-box) or for each activity individually (white-box). Also, the white-box perspective breaks down a delivery process into activities and provides the relationship between the activities in form of a network. In addition to the same outputs (the effect of different parameters and the OPDW), the white-box perspective provides several more outputs. First, the delivery time distribution for the whole process should be deduced based on the delivery time distributions of all activities. Second, an analysis should define what activities should be improved and what amount should be invested into the improvement of each activity.

Figure 2: Black-box and white-box perspectives





GERT has been widely used in the fields of supply chain management (Wang et al., 2020; Zhou et al., 2016). However, GERT can only provide the mean and the variance of several network parameters. To obtain the PDF and CDF of the delivery time, a characteristic function based on GERT (i.e., CF-GERT), proposed by Tao et al. (2017), will be employed to portray the delivery process. It can not only describe the relationship between activities time and completion time but also deduce the distribution of the whole delivery process.

MODELLING SUPPLY CHAIN DELIVERY PROCESS

For the sake of convenience, the notations used in the study are provided in Table 1.

Table 1: Notation list

x_{ij}	The stochastic duration of activity (i, j)
$\hat{x}_{ij}$	The stochastic duration of activity (i, j) after management efforts are applied
u_{ij}	The mean duration of activity (i, j)
x	A random delivery time
$\hat{x}$	A random delivery time after management efforts are applied
W_{ij}	A transfer function concerning activity *(i,j)*
c_1	Beginning of the on-time portion of the delivery window / difference between the time the delivery process is initiated and the earliest acceptable delivery time
c_1^*	The optimal position of the delivery window
$\hat{c}_1^*$	The optimal position of the delivery window after management efforts are applied
Δc	The width of the on-time portion of the delivery window
C_{ij}	The planned cost of the activity (i, j)
$\hat{C}_{ij}$	The cost of the activity (i, j) after management efforts are applied
C	The expected costs for the delivery
$\hat{C}$	The expected costs after management efforts are applied
χ	The maximum additional investment
σ_{ij}	The original uncertainty of activity (i, j)
$\sigma_{ij}^{'}$	The reduced uncertainty of activity (i, j)
ε_{ij}	The theoretical minimal activity uncertainty as a percentage of the original variance of the duration of activity (i, j)
τ_{ij}	The distance from ∂_{ij} when 100% effort is applied to the activity (i, j)
γ_{ij}	The applied effort as a percentage of the planned cost of the activity (i, j)
$\hat{\gamma}_{ij}$	The upper limit of applied effort allocated to the activity (i, j)
QH	Penalty cost per time unit early (levied by the buyer)
K	Penalty cost per time unit late (levied by the buyer)
$E(\cdot)$	The expectation operator
$f(\cdot)$	The probability density function

Optimal Position of the Delivery Window

Guiffrida and Nagi (2006) proposed the following expected penalty cost per period when deliveries are classified as early and late according to a delivery window.

$$Y = Y_{early} + Y_{late} = QH\int_{0}^{c_1}(c_1 - x)f(x)dx + K\int_{c_1+\Delta c}^{\infty}(x-(c_1+\Delta c))f(x)dx\,, \tag{1}$$

where Y = expected penalty cost of untimely delivery,

$Y_{early} = QH\int_{0}^{c_1}(c_1 - x)f(x)dx$ is the expected penalty cost of early delivery,

$Y_{late} = K\int_{c_1+\Delta c}^{\infty}(x-(c_1+\Delta c))f(x)dx$ is the expected penalty cost of late delivery.

Although the earliest acceptable delivery time is predefined by the contract, the supplier can define the time when delivery begins, therefore changing the value of c_1. For example, if the supplier decides to ship the product 10 hours before the earliest accepted delivery time, c_1 is equal to 10 hours.

As demonstrated in Bushuev and Guiffrida (2012), Y is a convex function of c_1 and the optimal value of c_1 (which is defined as c_1*) that minimizes Y can be determined by evaluating

$$K \cdot P_{late} = QH \cdot P_{early}\,, \tag{2}$$

where $P_{late} = \int_{c_1+\Delta c}^{\infty} f(x)dx$ and $P_{early} = \int_{0}^{c_1} f(x)dx$ are the probabilities of late and early deliveries.

GERT and CF-GERT Models

The delivery time is closely related to the activity duration of different stages, so the uncertainty of each activity will affect the whole delivery process. Therefore, we need a tool to derive the distribution function of the delivery time. To this end, this paper reviews the GERT model and its extension, the CF-GERT model, which is extensively adopted to portray complex processes, such as supply chain processes (Wang et al., 2020; Li, 2014; Zhou et al., 2016), product development processes (Nelson et al., 2016; Tao et al., 2017).

The GERT network (Pritsker, 1966) belongs to the *Activity on Arc (AOA)* type. Nodes represent the system status, and arrows between nodes represent the activity or transfer relationship. Therefore, the GERT network can be represented by *G=(N, A)*, where *N* is the set of network nodes indicating the states, and *A* is the set of network arrows indicating the activity. The GERT method is used to describe a delivery process represented as a set of activities. Using the required parameters for each activity, the analysis of the GERT network can be used to calculate the expected delivery time and variance.

CF-GERT is an extension of the typical GERT network model. The core idea of CF-GERT (Tao *et al.*, 2017) is to replace the moment generating function (MGF) of GERT with a characteristic function. Then the expected delivery time, variance, etc. are obtained by using the properties of the characteristic function. More importantly, the Cumulative Distribution Function (CDF) and the Probability Density Function (PDF) can be obtained via the inverse Fourier transform of the characteristic function. The following are some key definitions and theorems of CF-GERT, please refer to Tao *et al.* (2017) for more information.

Definition 1: Characteristic function. Given that the PDF of supply chain activity duration x_{ij} is $f\left(x_{ij}\right)$, then its characteristic function $\varphi\left(x_{ij}\right)$ is

$$\varphi_{x_{ij}} = E\left[e^{\sqrt{-1}tx_{ij}}\right] = \begin{cases} \int_{-\infty}^{\infty} e^{\sqrt{-1}tx_{ij}} f\left(x_{ij}\right)dx_{ij}, x_{ij} \text{is a continuous random variable} \\ \sum e^{\sqrt{-1}tx_{ij}} p\left(x_{ij}\right), x_{ij} \text{is a discrete random variable} \end{cases}, \tag{3}$$

where $t \in R$ is a real number.

Combining the characteristic function and the occurring probability p_{ij} of activity (i, j), we define the transfer function W_{ij} in the CF-GERT network.

Definition 2: Transfer function W_{ij}. Given the characteristic function $\varphi\left(x_{ij}\right)$ of the stochastic duration x_{ij} and the occurring probability p_{ij}, the transfer function W_{ij} is defined as $W_{ij} = p_{ij}\varphi_{x_{ij}}$. Using the transfer function W_{ij}, Mason's formula can be utilized to obtain the equivalent transfer function $W_E(t)$ of a GERT network. The related network performance measure can be obtained by the following theorem.

Theorem 1. If the equivalent transfer function of the CF-GERT network is $W_E(t)$, then the equivalent probability P_E is $P_E = W_E(0)$, and the equivalent characteristic function of the CF-GERT network is $\varphi_E(t) = \frac{W_E(t)}{W_E(0)}$. ■

See Tao *et al*. (2017) for the proof of Theorem 1.

Last, we present the method to derive the PDF from the equivalent characteristic function of the CF-GERT network. We use the Fourier-cosine series expansion method, proposed by Fang and Oosterlee (2009), to obtain the probability density function. Furthermore, the PDF $f_E(x)$ between the interval $[a,b]$ is

$$f_E(x) = {\sum_{k=0}^{N-1}}' F_k \cos(k\pi \frac{x-a}{b-a}), \tag{4}$$

where $F_k = \frac{2}{b-a}\mathrm{Re}\{\varphi_E\left(\frac{k\pi}{b-a}\right)\exp(-i\frac{ka\pi}{b-a})\}$;

a and *b* are the smallest and largest duration of the delivery process, respectively;

$\mathrm{Re}\{\cdot\}$ is the operation of taking the real part of a complex number;

$\sum'$ operation means that the weight of the first item is 0.5;

N is a positive integer.

The PDF and CDF of the delivery time can be obtained at the hand of the CF-GERT. Consequently, we can explore the optimal delivery window.

Relation between Applied Effort and Uncertainty Reduction

To improve delivery performance, the manager has to reduce the uncertainty of supply chain activities, which means that additional investments are needed. The relation between applied effort and uncertainty reduction needs to be quantified. According to Martens & Vanhoucke (2019), the relationship between applied effort and uncertainty reduction is defined as

$$\frac{\sigma'}{\sigma} = (1-\grave{o}) \times \left(\frac{1-\grave{o}}{\tau}\right)^{-\gamma} + \grave{o}, \tag{5}$$

where σ' is the reduced uncertainty, σ is the original activity uncertainty, γ is the percentage of applied effort.

That is to say γ reflects the applied effort as a percentage of the planned activity cost, $\eth$ ($\eth \in [0,1]$) reflects the theoretical minimal activity uncertainty as a percentage of the original variability, and τ ($\tau \in [0,1-\eth]$) is the distance from the theoretical minimum $\eth$ as a percentage point when 100% effort is applied. Accordingly, τ reflects how difficult it is (e.g. how much effort is required) to reduce the activity variability. Since $\eth$ reflects the theoretical minimal activity uncertainty that can be reached, $\eth$ indicates the capability to reduce activity uncertainty.

According to Eq. (5), we can quantify the relationship between applied effort and uncertainty reduction and quantify the expected penalty cost after applying effort. Inspired by this method, we can further study the improvement of delivery performance in a supply chain.

Delivery performance improvement without Management Efforts

The incorporation of GERT in the supply chain delivery process evaluation sheds light on the improvement of delivery process activities. Based on Eq. (4), the probability density function of the delivery time is derived as $f(x) = \sum_{k=0}^{N-1}{}' F_k \cos(k\pi \frac{x-a}{b-a})$. Accordingly, combined with Eq. (1), the expected penalty cost is defined as

$$C = \sum_{(i,j\in A)} C_{ij} + E\left[V\left(c_1, x\right)\right] = \sum_{(i,j\in A)} C_{ij} + QH\int_a^{c_1}\left(c_1 - x\right) f\left(x\right)dx + K\int_{c_1+\Delta c}^{b}\left(x - c_1 - \Delta c\right) f\left(x\right)dx \quad (6)$$

In this set, the effort for uncertainty reduction is not considered and the total cost is composed of two parts. The first part is the overall fixed costs of each activity, while the second part is the penalty for untimely delivery. Consequently, we can achieve the lowest total cost by determining the optimal value c_1^*, in the sense that

Model I $c_1^* = arg\min_{c_1} C = arg\min_{c_1}\left(\sum_{(i,j\in A)} C_{ij} + E\left[V\left(c_1, x\right)\right]\right)$

$$= arg\min_{c_1}\left(\sum_{(i,j\in A)} C_{ij} + QH\int_a^{c_1}\left(c_1 - x\right) f\left(x\right)dx + K\int_{c_1+\Delta c}^{b}\left(x - c_1 - \Delta c\right) f\left(x\right)dx\right) \quad (7)$$

Delivery Performance Improvement with Management Efforts

To decrease the uncertainty of a supply chain delivery process and optimize the delivery performance of the supply chain, management efforts can be applied to reduce the variance of activities within CF-GERT network. Specifically, the adopted relation (see Eq. (5)) between applied efforts and uncertainty reduction for each activity (i, j) is $\frac{\sigma_{ij}'}{\sigma_{ij}} = \left(1-\eth_{ij}\right)\times\left(\frac{1-\eth_{ij}}{\tau_{ij}}\right)^{-\gamma_{ij}} + \eth_{ij}$.

Different levels of effort will be applied to each activity to reduce their variances and thus changing the PDF of each activity. Accordingly, the delivery time distribution $f(x)$ and the total expected cost C will also be changed. Concerning the effort, the total expected cost is defined as follows

$$\hat{C} = \sum_{(i,j\in A)} \hat{C}_{ij} + E\left[V\left(\hat{c}_1, \hat{x}\right)\right] = \hat{C}_{ij} + QH\int_0^{\hat{c}_1}\left(\hat{c}_1 - \hat{x}\right) f\left(\hat{x}\right) d\hat{x} + K\int_{\hat{c}_1+\Delta c}^{\infty}\left(\hat{x} - \hat{c}_1 - \Delta c\right) f\left(\hat{x}\right) d\hat{x}\ , \tag{8}$$

where $\hat{C}_{ij} = C_{ij} + \gamma_{ij} C_{ij}$ represents the sum of fixed activity cost and the applied effort, the new delivery time PDF with applied efforts is $f\left(\hat{x}\right)$, and $\hat{c}_1$ is the changed optimal position of the delivery window.

To improve delivery performance, we need to minimize the total cost $\hat{C}$ by determining the optimal value of $\hat{c}_1^*$ and the applied efforts γ_{ij}^*. That can be defined as

Model II $\hat{c}_1^*, \gamma_{ij}^* = \arg\min_{c_1,\gamma_{ij}} \hat{C} = \arg\min_{c_1,\gamma_{ij}} \left(\sum_{(i,j\in A)} \hat{C}_{ij} + E[V(\hat{c}_1, \hat{x})] \right)$

$$= arg \min_{c_1,\gamma_{ij}} \left(\sum_{i,j\in A} (C_{ij} + \gamma_{ij} C_{ij}) + QH\int_0^{\hat{c}_1}\left(\hat{c}_1 - \hat{x}\right) f_E\left(\hat{x}\right) d\hat{x} + K\int_{\hat{c}_1+\Delta c}^{\infty}\left(\hat{x} - \hat{c}_1 - \Delta c\right) f_E\left(\hat{x}\right) d\hat{x} \right) \tag{9}$$

Moreover, the total budget is limited, thus the budget constraint is added as

$$s.t. \sum_{(i,j\in A)} \hat{C}_{ij} < \chi \tag{10}$$

OPTIMAL SOLUTION

Delivery performance improvement can be completed in 3 steps.

Step 1. The probability density function *f(x)* of delivery time is derived by using the CF-GERT model. The complex and concrete supply chain delivery process is decomposed into activities, which are described by a GERT network. Then the delivery time pdf *f(x)* is found using Eq. (4).

Step 2. Assuming that no effort is applied to improve delivery performance, the optimal position of the delivery window c_1^* and the related expected total cost C^* are calculated based on Model I.

Step 3. When management efforts are applied, a delivery performance improvement model is proposed to minimize the total cost $\hat{C}$ under the limited budgets (see Model II). The decision variables of this model are the position of the delivery window $\hat{c}_1^*$, and the applied effort γ_{ij}^* (the solution is discussed in the next section).

A solution to Model II is more complicated. The delivery time distribution *f(x)* obtained by the analytical method of the CF-GERT network has a complex expression, it is difficult to analyze the formula of the expected cost, thus c_1 and γ_{ij} cannot be solved by analytical derivation. Therefore, a heuristic algorithm is required to solve Model II. The solution algorithm adopted in this paper is the particle swarm optimization (PSO) algorithm.

PSO (Coath & Halgamuge, 2003; Bonyadi & Michalewicz, 2017; Houssein *et al.*, 2021) is easy to implement. In PSO, every particle in the search space is regarded as the potential solution to the problem to be optimized. In the optimization problem proposed in this paper, the particles are the applied effort γ_{ij} and the delivery position c_1.

The PSO only needs to handle two equations when updating the position and velocity in each generation. Particularly, the velocity and position of each particle *i* can be expressed as v_i^{k+1} and x_i^{k+1} , respectively, the formulas are as follows:

$$v_i^{k+1} = wv_i^k + c_1 r_1 (\text{pbest}_i^k - x_i^k) + c_2 r_2 (\text{gbest}^k - x_i^k) \tag{11}$$

$$x_i^{k+1} = x_i^k + v_i^{k+1}\ , \tag{12}$$

where x_i^k represents the current position of the particle i in the *k*th iteration, v_i^k represents the velocity, $pbest_i^k$ represents the optimal value searched by the particle i, and $gbest^k$ represents the optimal value searched by the entire cluster. In addition, w refers to the inertia weight, r_1, r_2 are the random numbers of the uniform distribution within the range of $[0,1]$, and c_1, c_2 represents learning factors used to control the significance of the best solution.

Since Model II is a constrained multivariable nonlinear optimization, classical PSO fails to handle the constraint. Therefore, the particle swarm algorithm based on the penalty function (Coath & Halgamuge, 2003) is adopted to solve the optimal window position $\hat{c}_1^*$ and the percentage applied effort γ_{ij}^*. The algorithm flow is

Algorithm 1: Penalty Function PSO algorithm solving $\hat{c}_1^*$ and γ_{ij}^*

Input: Population size NP, characteristic function $\hat{\varphi}_E$, the maximum number of iterations G, the constrain function h derived from Eq. (10)
the upper bound of variables $U = \{c_1, \gamma_{ij}\} = \{u(1), u(2), ..., u(n)\}$
and lower bound of variables $L = \{c_1, \gamma_{ij}\} = \{l(1), l(2), ..., l(n)\}$
the parameters N, a, b in Eq. (4)
Output: $\hat{c}_1^*$ γ_{ij}^* $F_{best} = \hat{C}^*$
for k=1: N **do**
  calculate $f(x)$ using Eq. (4)
  calculate $\hat{C}$ using Eq. (8) based on $f(x)$
Return the penalty function-based cost function $F = \hat{C} + 1000\max(0, h)$
Create and initialize an *N* D-dimensional swarm.
Repeat
  for each particle $i = 1, 2, ..., N$ **do**
    if $h(X_i) \le 0$ **then**
      if $F(X_i) < F(P_{best_i})$ **then**
        $P_{best_i} = X_i$;
      end
      if $F(P_{best_i}) < F(G_{best})$ **then**
        $G_{best} = P_{best_i}$;
      end
    end
  end
  for each particle $i = 1, 2, ..., N$ **do**
    Update particle's velocity using Eq. (11).
    Update particle's position using Eq. (12).
  end
Until maximum iteration is reached;
Return F_{best}

CONCLUSION

For any enterprise, the supply chain delivery process is one of the core processes that deserves an attention. A timely delivery can not only allow to avoid extra penalty costs but also build a good reputation for the enterprise and provide competitive advantage. Enterprises need to evaluate and improve their supply chain delivery processes to achieve the goal of on-time delivery. For any enterprise eager to improve its delivery performance, it is inevitable to optimize the supply chain delivery process.

For supply chain management, time and cost are two important factors that are closely watched. Therefore, this paper adopts a cost-based delivery performance model and proposes a three-step approach for evaluation and improvement of supply chain delivery performance. On the first step, a delivery process is divided into various activities, the CF-GERT model is used to describe the whole process, and the distribution of the delivery time is derived from the delivery time distributions of all activities. On the second step, an optimal position of the delivery window which defines when the product should be shipped is calculated for the initial (not-improved) delivery process. The information derived in steps 1 and 2 is used in the third step for delivery performance improvement. Step 3 uses the particle swarm algorithm to obtain the optimal amount of applied effort adopted for each activity and the optimal position of the supply chain delivery window.

Compared to the black-box models, the proposed approach breaks down delivery process into activities and provides a detailed analysis of an effect of each activity on the delivery performance and the related costs.

The proposed approach for improving delivery performance provides with managerial insights for delivery performance improvement. The approach defines what activities are the most critical in the delivery process in terms of their effect on the delivery related costs. Moreover, the approach determines specific amounts of effort that should be applied to each activity to minimize the cost. It provides managers a specific plan on delivery performance improvement and help them to formulate effective strategies to improve supply chain delivery performance.

From the present research, we can draw several research directions. Firstly, besides paying attention to the activity time variances, we should also study the influence of the expected values of the activity times on the delivery performance. Second, a more robust algorithm for solving this multivariable nonlinear optimization problem should be considered.

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DECISION SCIENCES INSTITUTE

Abandoning social accountability: exit strategies and motivations for SA8000 cancellation

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ABSTRACT

We introduce our research analysis on 15 multi-country/industry companies. Our study investigates those motivations that may push companies to abandon their engagement with the main auditable corporate social responsibility standard: Social Accountability 8000 (SA8000). We also consider which exit strategies firms initiate as a consequence of the abandonment. Our study identifies previously classified abandoning motivations - which are also common in other standards - and novel ones that are unique to SA8000. With regard to exit strategies that firms pursue after decertification, we identify three different ones.

KEYWORDS: Social Accountability, Sustainability, Standard, and Decertification

INTRODUCTION

Over the last decades, concerns related to social and environmental issues have grown steadily (de Bakker et al., 2019). Expectations about the role of companies in society have evolved to include a wide range of collective interests: firms are now invited to consider the accountability requests of several stakeholders such as customers, employees, governments, NGOs, and media. As a result, organizations have become interested in legitimizing their activities and testifying their sustainability efforts (Jastram & Klingenberg, 2018).

Corporate Social Responsibility (CSR) standards are a useful tool to achieve such purposes: they reflect voluntary predefined rules to guide, assess, verify, and communicate firms' practices (Llach et al., 2015; Fransen & Kolk, 2007). Among them, Social Accountability 8000 (SA8000) emerges for several reasons (Koster et al., 2019). It is the most widely adopted social standard; it is characterized by a third-party certification process carried out by independent bodies; it is non-industry specific; it acts on the whole supply chain of the certified organizations (El Abboubi et al., 2022; Gilbert et al., 2011; McIntosh et al., 2003).

When looking at the literature on SA8000 (for a review see Sartor et al., 2016), extant research has mainly shed light on aspects related to the benefits and obstacles of the adoption. Surprisingly scholars are almost silent as regards the reasons why some firms decide to leave the standard (i.e., the decertification drivers) and how it occurs (i.e., the decertification paths). The only partial exception is the study by Podrecca et al. (2021) which investigates the financial effects of SA8000 decertification and the differences between still certified and decertified firms.

Developing in-depth knowledge of SA8000 decertification is relevant for several reasons. First, according to the data provided by the regulatory body in charge of monitoring SA8000 (Social Accountability Accreditation Services – SAAS, 2021), an increasing number of firms are leaving it: 2020 has registered 788 new certifications and 592 cancellations/expirations, while data up to the third quarter of 2021 exhibit 681 new adherents and 819 cancellations/expirations. These numbers put the future of the standard into question. Second, as argued by Rasche et al. (2022) and Knudsen (2011), decertification from CSR standards could represent an alarming signal of potential social disengagement. Shedding light on the phenomenon could, therefore, lead relevant stakeholders to develop potential strategies to overcome it. Lastly, as Podrecca et al. (2021) point out, several aspects related to the decertification decision (e.g., the link between (ex-ante) motivations to adopt, and the (ex-post) reasons to leave SA8000) are still far from being clear.

Starting from this background, we formulate the following research questions: RQ1) What are the drivers that lead companies to abandon SA8000? And RQ2) Which alternative paths do firms select once they abandon SA8000?

To provide answers, this study adopts a multiple case study approach on a sample composed of 15 multi-country/industry firms. Our results show that companies abandon the standard for many reasons (e.g., the reduction of commercial benefits, paperwork overload, complexities in orders and supplier management). Decertified firms follow three distinct paths: 1) embrace an alternative social standard/initiative, 2) do not adopt any alternative social standard/initiative but continue respecting some SA8000 requirements, 3) do not adopt any alternative social standard/initiative and stop taking care of SA8000 requirements.

Our investigation provides theoretical and practical contributions. From a theoretical point of view, we advance knowledge on SA8000 decertification by identifying the drivers for abandonment, comparing them with the previous reasons for membership, and pointing out exit paths. In doing this we show how the theories previously used to investigate certification-related aspects (i.e., Transaction Cost Economics, Stakeholder, and Institutional Theory), are also useful to explain decertification choices. From a managerial point of view, we offer relevant insights to companies on the upholding of the standard and possible exit strategies.

The paper is structured as follows. The next section provides a literature background on decertification studies and on the potential benefits and obstacles associated with SA8000 adoption. Thereafter, we introduce the adopted methodological approach. Next, we illustrate and discuss the findings. We conclude outlining the contributions and the main limitations of our study.

LITERATURE REVIEW

In order to uncover previous studies on SA8000 decertification, we conducted a search on Scopus and Web of Science with the following keywords: “decert*”, “delist*”, “discontinu*”, “end*”, “withdraw*”, “termin*”, “cancel*”, together with “Social Accountability 8000”, “SA8000, “SA 8000”. Only the contribution by Podrecca et al. (2021) emerged. We, therefore, adopted a broader perspective and considered papers concerning decertification from the most popular CSR initiatives (i.e., EMAS, ISO 14001, UNGC) and from ISO 9001 (i.e., the most widely adopted standard) (see Podrecca et al., 2022; Ociepa-Kubicka, 2021; Sfreddo et al., 2019; Orzes et al., 2018; Sartor et al., 2016, 2019 for a detailed description of the characteristics of each standard/initiative); the following keywords were added to the search string: “Eco-Management and Audit Scheme”, “EMAS”, “ISO 1400*”, “ISO1400*”, “United Nations Global Compact”, “UN Global Compact”, “UNGC”, “ISO 900*”, and “ISO900*”. The review was conducted to understand if similarities and recurring patterns about decertification exist among these standards.

The review highlighted that decertification might also depend on unfulfilled expectations or unforeseen obstacles associated with the certification adoption (Cândido & Ferreira, 2021a; Ferreira & Cândido, 2021). For this reason, the following sub-sections will introduce: a) the decertification literature and b) the potential benefits and obstacles of SA8000 (based on the systematic review of Sartor et al., 2016, complemented with the most recent papers on the topic). In doing this, the theoretical lenses underpinning the studies will be also presented and discussed.

Decertification

The literature analysis unveiled three main research topics: decertification drivers, contingency factors, and post-decertification paths. The main findings are presented in Table 1 and summarized below.

As for the decertification drivers, the literature highlights that companies decertify when they do not achieve expected benefits (e.g., limited operational benefits) and/or when they face unexpected obstacles (e.g., financial burden) in the management of the standard. Sometimes this choice comes from motivations unrelated to the standard itself (e.g., company restructuring). Extant research also shows that, although some decertification reasons are common to many of the analyzed standards (e.g., the absence of commercial benefits/disadvantages – Mastrogiacomo et al., 2021; Daddi et al., 2018), others are certification-specific and based on their unique characteristics (e.g., absence of recognition by policymakers – Heras-Saizarbitoia et al., 2016; Ferreira & Candido, 2021).

For what concerns contingency factors, the implementation timing (early or late adopters), and the ownership status (public or private) only affect UNGC maintenance (Rasche et al., 2022). The size of the company turns out to be critical for UNGC, EMAS, ISO 14001, and ISO 9001 (e.g., Knudsen, 2011; Merli et al., 2018), yet not for SA8000; the latter is influenced by factors such as the region of the decertifying company (i.e., firms from developing countries perceive higher need to achieve and retain SA8000 to legitimize their activities – Podrecca et al., 2021).

As for the alternative paths, there are no studies on SA8000 and UNGC. Instead, Merli & Preziosi (2018) show how the proliferation of initiatives (such as ISO 14001, the Product Environmental Footprint) offered alternative solutions to EMAS. Moving to ISO 14001, Mosgaard & Kristensen (2020) identify two distinct alternative paths after decertification: a) adoption of a company-specific system or b) no formal recertification. Regarding the latter outcome, Kafel & Nowicki (2014) notice that many organizations maintain their environmental-related practices yet not the accreditation. Lastly, Simon & Kafel (2018) note that companies exiting ISO 9001 may decide to move to industry- or company-specific management systems.

To investigate the above aspects, scholars have resorted to some theoretical lenses. However, their application remains scattered and isolated. In our analysis we identified and analyzed those available in the literature: the (Neo)-Institutional Theory applied to explain how firms operating in the same competitive environment face analogous pressures, making, therefore, similar decisions with respect to decertification (from SA8000 – Podrecca et al., 2021 and EMAS - Heras-Saizarbitoria et al., 2016); the Contingency Theory, used to show that - after decertification - companies tend to retain only those (ISO 9001 - Zimon & Dellana, 2019) practices that are instrumental to their context; and the Resource Based View availed to analyze how companies renew their certified status as long as the (ISO 9001 - Cândido et al., 2016, 2021) certification remains a valuable, rare, and inimitable resource.

SA8000 benefits and obstacles

Extant research has shed light on several potential benefits and obstacles of SA8000 adoption (see Sartor et al., 2016 for a more detailed review on the topic).

Starting with the positive externalities, some authors highlight that the company’s work environment might benefit from SA8000 adoption (e.g., Murmura & Bravi, 2020; Tencati & Zsolnai, 2009); the enhancement of working conditions that usually results from the implementation of SA8000 dictates is expected to generate enthusiasm among employees (e.g., Jamali et al., 2020; Henkle, 2005). This, in turn, might strengthen the labor productivity and upgrade company performance (e.g., Battaglia et al., 2014; Rohitratana, 2002). Similar effects may result from the need to review labor practices and operational activities (e.g., Testa et al., 2018; Ruževičius & Serafinas, 2007): SA8000 requires firms to detect potential sources of danger and to proactively face the risks before accidents occur, this way helping companies to identify areas of improvement and increase internal process efficiency (e.g., Murmura et al., 2017; Stigzelius & Mark-Herbert, 2009). On the reputational side, authors argue that the particular attention to ethical issues and workers' rights testified by SA8000 certification, could help companies in enhancing corporate image (e.g., Santos et al., 2018; Orzes et al., 2017); firms usually enact SA8000 aiming at commercial benefits such as new customers attraction and revenues' boost (e.g., Battaglia et al., 2014). Moreover, SA8000 might help organizations in imposing premium prices for their products (De Magistris et al., 2015). As a side note, it is worth mentioning that the positive aspects highlighted so far are supposed to be more pronounced for firms coming from developing countries. For instance, the initial working conditions in these contexts are generally worse than those of developed regions thus offering higher room for improvement (Ikram et al., 2020). At the same time, in terms of commercial/reputational aspects, organizations from developing countries usually present a greater need to signal their social responsibility efforts than their developed counterparts; in such contexts, SA8000 allows to cope with pressures that may originate from clients that are concerned with CSR practices or pose specific requirements to conduct business (Podrecca et al., 2021). To conclude on the benefits, several scholars underline that the potential positive effects of SA8000 extend beyond the unit of the firm and affect the whole supply chain (e.g., El Abboubi et al., 2022; Leipziger, 2009). In particular, SA8000 second-party audits are expected to help organizations in identifying non-compliances and ease communication with business partners thus improving supply chain coordination and performance (e.g., Sartor & Orzes, 2019; Kortelainen, 2008).

Conversely, SA8000-certified companies may incur several obstacles. The most recurring one regards maintenance costs (Koster et al., 2019). Increased labor costs might result from higher wages and stricter working hours regulation (e.g., limited overtime). Additional issues may stem from coordination expenses (e.g., Ciliberti et al., 2011; Rohitratana, 2002); SA8000 requirements usually result in limitations to the sourcing base, forcing companies to devote additional resources to find complying suppliers. Moreover, larger delivery time lags and reduced flexibility have been reported (e.g., Merli et al., 2015; Christmann & Taylor 2006). Lastly, SA8000 requires to store and manage a relevant number of documents, resulting in complex and costly data management (Leipziger 2009, 2010).

As for the theoretical underpinnings adopted by extant research, the Stakeholder Theory has been applied (Battaglia et al., 2014) to understand how firms have improved their competitive edge with SA8000 implementation. Furthermore, the (Neo-) Institutional Theory (Behnam & Maclean, 2011) discloses SA8000 adoption outcomes as shaped upon different coercive pressures, normative expectations, or to imitate competitor's CSR efforts. Also, Transaction Cost Economics (Christmann & Taylor, 2006) unveil potential certification-related economic benefits - such as the reduction of transaction costs in the search for socially responsible partners - may depend on the adoption purpose (either symbolic or substantial), while the Contingency Theory (Orzes et al., 2017) underlines the relevance of the specific context of the certified company. Finally, the application of the Agency Theory (Ciliberti et al., 2011; Orzes et al., 2017) has shown that SA8000 may reduce adverse selection and asymmetries between the agents (employees) and the principal (manager).

To sum up, the analysis of the literature seems to highlight the existence of intersections between decertification drivers and the potential benefits and obstacles associated with the certification. For instance, SA8000 adoption might result in a minor market recognition than expected thus inducing firms to decertify (e.g., absence of commercial benefits/advantages). Similarly, SA8000 maintenance costs might be larger than predicted and force firms to decertify due to financial burden. In light of these issues, we will seek not only to shed light on the drivers of SA8000 decertification, but also to highlight their potential connection with benefits and obstacles (expected and actual) of SA8000 adoption.

Table 1: Overview of decertification literature

	SA8000	EMAS	ISO 14001	UNGC	ISO 9001
Absence of commercial benefits / advantages		Von Ahsen et al. (2004); Preziosi et al. (2016); Daddi et al. (2018); Merli et al. (2018)	Marimon et al. (2009); Alič (2012); Kafel & Nowicki (2014); Mosgaard & Kristensen (2020)		Lo & Chang (2007); Kafel & Nowicki (2014); Kafel & Simon (2017); Simon & Kafel (2018); Chiarini (2019); Cândido et al. (2021) (RBV***); Ferreira & Cândido (2021); Cândido & Ferreira (2021a); Cândido & Ferreira (2021b)
Financial burden		Von Ahsen et al. (2004); Preziosi et al. (2016); Daddi et al. (2018); Merli et al. (2018)	Marimon et al. (2009); Alič (2012); Kafel & Nowicki (2014); Mosgaard & Kristensen (2020); Lira et al. (2021)		Lo & Chang (2007); Alič (2014); Kafel & Nowicki (2014); Sansalvador & Brotons (2015); Cândido et al. (2016) (RBV***); Zimon & Dellana (2019) (CT**); Chiarini (2019); Mastrogiacomo et al. (2021); Ferreira & Cândido (2021)
Paperwork load and documental management		Von Ahsen et al. (2004); Daddi et al. (2018); Merli et al. (2018)	Moosgard & Kirstensen (2020)		Lo & Chang (2007); Kafel & Nowicki (2014); Mastrogiacomo et al. (2021); Ferreira & Cândido (2021)
Limited sphere of influence		Von Ahsen et al. (2004); Preziosi et al. (2016); Heras-Saizarbitoria et al. (2016) (N-IT*); Daddi et al. (2018); Merli & Preziosi	Moosgard & Kirstensen (2020)		Kafel & Nowicki (2014); Simon & Kafel (2018); Ferreira & Cândido (2021); Cândido & Ferreira (2021a)

		(2018); Merli et al. (2018)			
Limited top management engagement			Moosgard & Kirstensen (2020)		Chiarini (2019); Zimon & Dellana (2019) (CT**)
Company restructuring			Marimon et. al. (2009); Alič (2012); Kafel & Nowicki (2014); Mosgaard & Kristensen (2020)		Simon & Kafel (2018)
Limited operational benefits		Von Ahsen et al. (2004); Daddi et al. (2018)	Alič (2012); Kafel & Nowicki (2014); Moosgard & Kirstensen (2020)		Lo & Chang (2007); Alič (2012); Alič (2014); Kafel & Nowicki (2014); Sansalvador & Brotons (2015); Cândido et al. (2016) (RBV***); Simon & Kafel (2018); Chiarini (2019); Zimon & Dellana (2019) (CT**); Cândido et al. (2021) (RBV***); Mastrogiacomo et al. (2021); Ferreira & Cândido (2021)
Macroeconomic shocks			Alič (2012)		Alič (2012); Simon & Kafel (2018)
Absence of recognition from policymakers		Von Ahsen et al. (2004); Heras-Saizarbitoria et al. (2016) (N-IT*); Daddi et al. (2018); Merli et al. (2018)			Kafel & Simon (2017); Ferreira & Cândido (2021)
Size		Preziosi et al. (2016);	Alič (2012); Mosgaard &	Knudsen (2011); Rasche	Alič (2012)

		Merli et al. (2018)	Kristensen (2020)	et al. (2022)	
Region/Country	Podrecca et al. (2021) (N-IT*)		Lira et al. (2019); Lira et al. (2021)	Knudsen (2011)	Marimon et al. (2009)
Industry/Sector	Podrecca et al. (2021) (N-IT*)		Alič (2012); Lira et al. (2019); Lira et al. (2021)	Knudsen (2011)	Alič (2014)
Implementation timing (early VS late adopters)				Rasche et al. (2022)	
Ownership status (private VS public)				Rasche et al. (2022)	

Note: N-IT* ((Neo)-Institutional Theory), CT** (Contingency Theory), RBV*** (Resource-Based View Theory)

METHODS

SA8000 abandonment is a contemporary phenomenon that is rapidly evolving, with a dearth of available research. For such circumstances, Yin (2017) recommends the use of multiple case studies as this approach “allows for an in-depth investigation” of the topic. Accordingly, we used semi-structured interviews (Burnard, 1994; Ryan et al., 2009) and content analysis (Weber, 1990). Other studies on decertification that have adopted this methodology are, among others, Mosgaard & Kristensen, (2020), Daddi et al. (2018), and Kafel & Nowicki (2014).

To safeguard rigor, relevance, and accuracy the following protocol has been implemented:

- Development of a checklist of open-ended questions based on the findings emerging from the literature review. Semi-structured interviews constituted the basis for experience sharing and fostered an open dialogue that allowed for engaging conversations and broader descriptions of the investigated topic (Brinkmann & Kvale, 2015; Yin, 2017).
- Selection of a sample composed of companies located in different regions (Asia, South America, Europe); operating in various sectors (manufacturing, services, utilities); diverse in size (small, medium, and large). These segmentation variables were defined considering previous studies on decertification issues (e.g., Mosgaard & Kristensen, 2020; Daddi et al., 2018), and the characteristics of the population of SA8000 decertified firms (SAAS, 2021). Moreover, in line with Daddi et al. (2018), and Mosgaard & Kristensen (2020), we decided to include only companies that had been certified with SA8000 for at least 5 years. This aspect was critical to ensure that the case companies had adequate experience with SA8000 and were committed to it (i.e., they did not join SA8000 due to a temporary fad or a transitory requirement).

Based on these criteria, we identified 15 firms (see Table 2 for a detailed description of the companies). For each interview, the person in charge of SA8000 was consulted. 5 companies authorized us to interact with an alternative respondent who was also informed over SA8000-related choices. Conversations lasted an average of 60 minutes. To generate trust and minimize social desirability bias, we ensured the interviewee that the results of the study would have been disclosed in an aggregate form and presented in an anonymous way (Wilhelm et al., 2016). Two authors transcribed the tape, analyzed, and classified the evidence. Once the interviewing process ended, the researchers exchanged remarks and notes to compare and integrate them.

The interview protocol (reported in full in Appendix – Table A1) touched on aspects related to (de)certification drivers and post-decertification paths (i.e., changes to processes/internal practices and potential replacement of SA8000 with other CSR initiatives/standards).
For each case, we sought permission to record the interview; ten companies authorized us. Whenever the participants did not agree to the recording, both researchers handwrote the interviewee's answers and highlighted the most relevant sentences of the respondent. At the end of each non-recorded interview, the interviewers compared their notes and created a structured summary of the case.
The research team constructed a database containing the interview recordings, notes, and transcripts. Consistently with Voss et al. (2002) and Eisenhardt (1989), we first considered the gathered data in terms of within-case analysis and then we performed the cross-case analysis.
For what concerns the within analysis, building on the write-ups of the cases, we resorted to the data coding procedure recommended by Yin (2017): a multiple iteration approach based on a combination of both deductive and inductive qualitative content analysis was adopted, followed by a pattern matching process (Eisenhardt 1989; Voss et al., 2002). This activity was carried out separately by two different researchers to enable inter-coder reliability (Miles & Huberman, 1994). Consistently with the suggestions of Mayring (2004), the coding units ranged from a single sentence to whole paragraphs (if they relate to the same concept). This categorization was done manually (i.e., no automatic analysis or categorization was adopted) with the support of the software NVivo which allows the association of categories and text passages, as well as their storage and retrieval.
The independently coded data were then compared to ensure consistency: emerging findings were reviewed with the rest of the research team and with an additional (external) researcher taking the role of the "devil's advocate". The resulting codes are reported in Table A2 (Appendix).
To encourage both within and cross-case comparison data were organized in charts (Miles & Huberman, 1994).
To conclude, the cross-case analysis was performed to identify differences and recurring patterns among the cases.

Table 2: Case companies

	Region	Sector	Employees	Interviewee(s) role(s)	Interview duration (min)
Company A	Asia	Manufacturing	1,000 – 5,000	Social Compliance Manager + Vice President HR	61
Company B	Asia	Manufacturing	>10,000	Operations Director	57
Company C	Asia	Manufacturing	1,000 – 5,000	Quality Manager + Vice President HR	66
Company D	Asia	Manufacturing	>10,000	Social Compliance Manager	48
Company E	Asia	Manufacturing	1,000 – 5,000	Quality Manager + Vice Manager HR	62
Company F	Asia	Manufacturing	>10,000	GM Operations	49

Company G	Europe	Manufacturing	<1,000	HR Manager	56
Company H	Europe	Manufacturing	1,000 – 5,000	Social Compliance Manager + HR Manager	69
Company I	Europe	Service	1,000 – 5,000	Quality Manager	55
Company L	Europe	Manufacturing	1,000 – 5,000	Quality Manager	42
Company M	Europe	Service	<1,000	Certifications Manager	59
Company N	South America	Manufacturing	>10,000	Sustainability Manager + Quality Manager	63
Company O	South America	Manufacturing	>10,000	Operations Director	71
Company P	South America	Utilities	<1,000	Quality Manager	58
Company Q	South America	Service	>10,000	Corporate Social Responsibility Manager	64

RESULTS

Through the investigation of (de)certification drivers our research questions aimed at 1) understanding the reasons that led companies in abandoning SA8000; 2) identifying the alternative paths. In the next subsection we therefore present: the decertification drivers, the initial certification drivers, and the post-decertification paths (see Tables 3, 4, 5 for an overview of the findings).

Decertification Drivers

In terms of abandoning reasons, the absence of commercial benefits/advantages is the most recurring one in our sample (14 cases). Companies disclose that, with time, SA8000 becomes "*inessential"* (Company D) for business partnerships: as the firm develops a trustworthy relationship with the client, the certification "*is no longer necessary"* (Company Q). In other cases, the public agency "*omits SA8000*" from the bid (Company M). Sometimes clients become "*uninterested"* (Company F) in rewarding certified companies' efforts with a premium price this way eroding certification benefits. Furthermore, competitors often react by adopting SA8000 (or similar standards/initiatives) thus "*deteriorating the company's initial competitive advantage*" (Company O).

The financial burden (12 companies) is the second most cited reason: companies underline that SA8000 costs are *"disproportionately high"* (Company E). For instance, the increase in the hourly wage that the company must guarantee to be compliant with SA8000 constitutes a "*major financial burden*" (Company P). Additionally - with time - auditors "*request everlasting updates*" (Company N) to adjust to the standard's requirements resulting in increased expenditures.

Moreover, additional costs stem from the *"very onerous"* (Company H) paperwork load and documental management (7 cases) required by the standard which accrues to an accumulating number of working hours.
Five companies claim that SA8000 is too limited in its sphere of influence, therefore they prefer alternatives with "*broader targets*" (Company O) that are more "*in line with the company's needs*" (Company N).
Five companies also underline growing complexities in orders and suppliers' management because of the *"stringent requirements"* (Company O) that SA8000 imposes. Firms that mainly deal with small-sized partners - that do not have the means to be compliant with the standard's requisites - struggle to "*find, handle, and monitor"* (Company Q) their suppliers. Often, the complexity has generated "*additional dissipation, both in terms of finances and man-hours*" (Company O): conducting supplier's inspections over time has become an issue, as companies need to devote "*considerable resources*" to this task (Company G).
With time, a lack of available auditors has emerged, forcing companies (3 cases) to hire foreign auditors with an overall increase in the audit costs. Moreover, available auditors often lack *"sector-specific skills"* (Company E) thus generating further frustration. Several companies have attempted to signal auditor's scarcity and inadequacy to the certifying body, but with *"insignificant results"* (Company E). These firms also complain about a miscommunication with the certifying body that is perceived as *"hard to interact with"* (Company N).
Also, on mimicking behavior (2 cases): as some companies witness similar firms abandoning SA8000, they drop out too with a consequent domino effect.
Two case companies emphasize employees' discomfort that results in reactions, strikes, and backlash from the protections guaranteed by the standard. This happens because some employees are disturbed by the working hour limit imposed by SA8000. Hence, they are more interested in "*capitalize on working hours"* (Company F) by extending their overtime, rather than establishing better working conditions.
Furthermore, at times, firms experience a difficult integration of local laws and SA8000 requirements (2 cases). Often, the national law has similar, yet different requirements; this duality can make the integration between the local regulations and SA8000 difficult. Companies stress how SA8000 is "sometimes *redundant"* (Company N) for some of those aspects that are already covered by the national legislation (e.g., overtime restrictions).
Another identified decertification reason is the limited top management engagement (1 case). When managers do not value SA8000, the implementation of the standard is not only uncommitted but even counterproductive as it generates distress during and after the audits.
To conclude, it is worth underlining that, in general, SA8000 evaluation changed over the years: companies highlighted that "*over time the effort to keep the certification became heavier and the benefits registered a deterioration*" (Company G).

Table 3: Illustrative incidents of decertification reasons in the case studies

Decertification Reason for SA8000	Previously identified in EMAS, ISO14001, UNGC, ISO9001 (Literature)	Occurrence in SA8000 Case Studies	SA8000 Illustrative Incidents
Absence of commercial benefits/advantages	✓	A, B, C, D, F, G, H, I, L, M, N, O, P, Q	*"In the beginning SA8000 allowed us to capitalize our CSR efforts by charging premium prices and attracting new clients that were attentive to these topics.*

			Over the years though SA8000 allure faded" (Company C) *"Initially, SA8000 represented a means to communicate our values and efforts. Over time our competitors certified too thus weakening SA8000 differentiation effect" (Company A).*
Financial burden	✓	A, D, E, F, G, H, I, L, M, N, O, P	*"SA8000 implicates additional work, and this means additional cost" (Company I)* *"After some years the effort became too high, too expensive. Audits made the process too rigid" (Company N)*
Paperwork load and documental management	✓	A, E, H, I, M, N, O	*"The paperwork load and, in general, the imposed procedures were very onerous" (Company H)* *"SA8000 requires too much bureaucracy" (Company M)*
Limited sphere of influence	✓	H, M, N, O, Q	*"SA8000 scope was too narrow. Now we follow SMETA that is in line with all the pillars of UN Guiding Principles" (Company O)* *"SA8000 despite the name has a small social accountability target" (Company H)*
Complexity in orders and suppliers' management	✗	B, G, M, O, Q	*"It has stringent requirements, especially with the management of suppliers both in terms of orders, and inspections" (Company G)* *"Managing orders involved continuous monitoring. Smaller suppliers were struggling with the requirements" (Company B)*
Lack of auditors	✗	E, N, O	*"Local auditors became scarce" (Company O)*
Mimicking behavior	✗	H, O	*"Many companies were giving up SA8000" (Company H)*
Employees' discomfort	✗	F, O	*"Some employees wanted to work beyond 48 hours per week to maximize their income" (Company O)*
Difficult integration of local laws and SA8000 requirements	✗	L, N	*"In case of emergency, our national regulation allows for overtime flexibility. With SA8000 it was only 2 hours per day" (Company N)*

Limited top management engagement	✓	L	*"Managers did not value SA8000" (Company L)*

Certification Drivers

Concerning certification drivers (Table 4), the most recurring one in our sample is Commercial purposes (11 cases). According to the respondents, firms enacted SA8000 expecting it to "vouche for our CSR efforts in a concrete and visible way" (Company E). The goal was to "improve company's image" (Company I) and "create value" (Company O), this way building a "competitive advantage" (Company F). Along the same lines, other companies were hoping to "reach new clients" (Company A) and "increase orders" (Company C).

Financial savings (7 cases) is the second most frequent certification driver. It originates from expectations of reducing costs and improving the efficiency of internal processes. On the one hand, companies wanted to "optimize shop-floor management" (Company N) and reduce those negative aspects related to more labor-intensive tasks. Also, SA8000 was supposed to aid the coordination of the supply chain by building trust and "facilitating contract stipulation" (Company D), thus making client's audits "unnecessary" (Case H) and "granting important man-hour savings" (Company P).

Improve social performance (6 cases) is another important certification driver: several respondents underlined company's aim to "set clear guidelines" (Company F) in the context of CSR protocols to "foster management-employee relationships" (Company O), or to "enhance work environment safety" (Company H). Other organizations perceived SA8000 as a necessary tool to "identify more clearly strengths and weaknesses on labor issues" (Company P).

Client's request (5 cases) follows as clients pressured suppliers by "demanding SA8000" (Company D). In some cases, SA8000 served as a "minimum pre-requisite" (Company L) to obtain orders or initiate business relationships. Often, it was the "larger multinational customers that pushed for SA8000" (Company C) since it was the "most adopted CSR certification, an industry standard" (Company Q). Also, SA8000 was a "mandatory asset to compete in certain bids" (Company M).

Lastly, one case (Company G) revealed an Ethical choice: for this company SA8000 represented "nothing but a flagship, a statement to showcase our values" (Company G) driven by moral principles rather than marketing purposes or client's requests.

Table 4: Illustrative incidents of certification drivers in the case studies

Certification drivers for SA8000	Occurrence in SA8000 case studies	*SA8000 illustrative incidents*
Commercial purposes	A, B, C, D, E, F, H, I, N, O, P	*"With better social performance we wanted to differentiate ourselves and reach new markets" (I)* *"It was our way of demonstrating to the customers that we respect worker's rights" (O)*
Financial savings	C, D, F, H, N, P, Q	*"It was a matter of assessment, development of better working routines, and trainings" (H)* *"SA8000 was expected to reduce inefficiencies and minimize monitoring costs over the supply chain" (C)*
Improve social performance	B, F, H, N, O, P	*"We wanted to engage with human resources and fine-tune our work environment" (P)*

		"Our aim was to become closer to our employees, and address those obstacles that were preventing us from achieving our CSR goals" (O)
Client's request	C, D, L, M, Q	*"SA8000 was mandatory to access public bids" (M)* *"It was a requirement to get orders" (L)*
Ethical choice	G	*"It reflected our company's values" (G)*

Alternative Paths

In our sample, SA8000 decertification leads to three scenarios: 1) implement an alternative social standard/initiative, 2) do not adopt any alternative social standard/initiative, but continue respecting some of SA8000 requirements, 3) do not adopt any alternative social standard/initiative and stop taking care of SA8000 requirements.

Regarding scenario A (adoption of an alternative initiative/standard), our interviews unveil several outcomes. According to the respondents, after some time from the abandonment - e.g., 4 years (Case M) and 5 years (Case Q) - companies have decided to embrace another CSR standard. The motivation is twofold: on the one hand, these firms have recognized the need to signal their CSR commitment; on the other hand, they have become aware of the dissipation of part of the positive CSR practices introduced with SA8000 (and that the management believed to be internalized).

As for the adopted standards, Company H selects the Global Reporting Initiative – GRI (i.e., a standard for sustainability reporting), judging it as the ideal alternative because of its "*less strict requirements*" (e.g., no formal audits required) and "*wider scope*"; "*GRI not only covers SA8000 principles, but it also focuses on governance, climate change, and social wellbeing*".

Company N embraces ABNT NBR ISO 16001 (i.e., a country-specific norm that aids organizations in operating in a socially responsible way) because it is a local certification standard considered "*much closer to the company's reality"* and *"it allows for flexibility and customization*".

Company O and Q adopt SMETA (i.e., an ethical trade social audit) issued by Sedex. They consider this initiative well-balanced: it imposes lower obligations and is characterized by broader boundaries (including also ethical trading and environmental issues); moreover "*clients are more reassured by SMETA's company-wide audits rather than SA8000's that are instead plant-wide*" (O). In addition, respondents explain that SMETA allows for "*increased transparency*" (Q) and "*cost reduction*" (O).

Company M implements an "*unlicensed*" certification (obtained through a body that is not accredited by SAI but officially recognized in public bids), that has "*some of the SA8000 contents but allows cost savings*" (M) (thanks to less expensive audits and fewer CSR compliance requests). This certification represents a "*good compromise*" (M) between not having SA8000 at all – a sort of "*Wild West, where everyone does as they please, as they are not accountable",* and SA8000 official version *"where the company has to be compliant with every detail*" (M). This solution allows the company to maintain some of the benefits of SA8000, reduce costs (as a result of more lenient requirements) and receive less complicated audits (that resulted in leaner documental obligations thus unburdening the company from large data management).

Five companies opt for scenario B (no adoption of any alternative social standard/initiative, but still respect some SA8000 requirements).

All the companies (B, D, E, G, P) have relaxed some aspects associated with the most stringent (and costly) requirements of SA8000: the proactive approach to the prevention and elimination of possible social criticalities and risks, supplier monitoring, working hours limits, the continuous improvement that often proceeded from the audits, or the presence of a "social performance team" inside the firm.

As for retained practices, Company B maintains the use of advanced solutions for the communication between the top management and the employees.

Company G continues to share with its stakeholders a self-declaration "*to prove social sustainability diligence*". The company claims to use it as a tool that ensures stakeholder engagement and monitors social performance. Accordingly, the stakeholders can verify the company's compliance with the declaration through audits.

In scenario C (no adoption of any alternative social standard/initiative and stop taking care of SA8000 requirements), selected by five companies in our sample, SA8000 processes do not survive the abandonment.

SA8000 requirements "*aggravated*" (Case A) the company's spending and resource dispersion (e.g., large data management and man-hours). Furthermore, "*all the SA8000 source of costs were removed*" (Case L). Rather, SA8000 is regarded as a "*sinker*" (Case A) whose processes impede some company's activities or the ability to stay in line with market requirements. Consequently, all the SA8000 limitations have been lifted as the certification is no longer in place. In particular, companies have reduced the workers' committees (solely to the ones required by domestic regulations) and have eliminated all the SA8000 procedures connected to salaries management, additional compliance with health and safety requirements, and diversity management plans.

Table 5: Illustrative incidents of post-decertification paths in the case studies

Post-decertification path	Occurrence in SA8000 case studies	SA8000 illustrative incidents
Implementation of an alternative initiative	H, M, N, O, Q	*"Yes, our company has moved to a different standard" (H)* *"We became aware of an alternative initiative and resolved to use that one" (Q)*
No alternative initiative, but still respect some of SA8000 requirements	B, D, E, G, P	*"Although we did not continue with SA8000, we do still observe some of its good practices" (E)* *"We do keep some processes that can be implemented even without the certification" (D)*
No alternative initiative, and stop taking care of SA8000 requirements	A, C, F, I, L	*"SA8000 has been totally abandoned" (C)* *"We were not motivated to maintain SA8000 nor other initiatives" (A)*

DISCUSSION

This section is structured in two parts. The first will present the SA8000 decertification drivers (RQ1) emerging from our cases using three theoretical lenses and compare them with the initial reasons leading companies to adopt SA8000. The second will discuss SA8000 post-decertification paths (RQ2) also considering those already observed for other standards.

As for RQ1), the decertification drivers outlined in Table 3 can be traced back to three categories: a) cost; b) loss of certification value over time; and c) weakening of "institutional" pressures towards certification. Each of these categories, in turn, can be framed through a theoretical perspective: a) the Transaction Cost Theory (TCT); b) the Stakeholder Theory (ST); and c) the Institutional Theory (IT). As previously seen in the literature review section, these theories exhibit proven usefulness in explaining decertification issues (e.g., Podrecca et al., 2021) and a firm's choices related to SA8000 (e.g., Sartor et al., 2016).

Cost. Three factors in Table 3 directly relate to the costs of certification: "financial burden", "complexities in orders and suppliers' management", and "paperwork load and documental management". Based on our evidence, certification entails several expenses: higher procurement costs (to find and monitor compliant suppliers), higher human resources costs (to ensure better wages and working conditions), and higher administrative costs (to manage the bureaucratic and documentary aspects imposed by the standard). Furthermore, according to the case companies, such costs tend to rise over the years.

The Transaction Cost Theory offers arguments to explain such decertification drivers. The unit of analysis of the TCT, as is well known, is the transaction (such as a commercial exchange) (Coase, 1937; Williamson, 1979) and its costs (of negotiation, monitoring, validation, registration, and enforcement of contracts). Since transaction costs impact economic performance, firms try to minimize them. Certification, in general, reduces transaction costs in trading relations by testifying a firm's superior performance. Through CSR standards, companies prove their social commitment to customers and are, therefore, relieved of many burdens (and costs/efforts) associated with negotiating and monitoring (Gunasekaran & Spalanzani, 2012; Ciliberti et al., 2008). This advantage is particularly relevant for those certifications, such as SA8000, that are extended to the whole supply chain of adopting companies (O'Rourke, 2006; Sartor et al., 2016).

In the case of the interviewed firms, however, over the years compliance with SA8000 dictates has led to more expensive transactions due to the additional expenses highlighted above. If the transaction costs with SA8000 become higher than those without it, the adoption of social practices can be inhibited (Christmann & Taylor, 2006). This is even more relevant if the market value of certification (next category) does not compensate for these additional costs.

Loss of certification value over time. Two factors in Table 3 directly relate to this category: "absence of commercial benefits/advantages" and "limited sphere of influence". Two other factors can be indirectly associated: "limited top management engagement" and "employees' discomfort". The usefulness of certification is ultimately decided by the market: according to our evidence, the perception of the commercial benefits of SA8000 has declined over time. This was also due to the effect of competing certifications, whose scope ("sphere of influence") was perceived to be wider. The reduction of the SA8000 reputational effect, therefore, resulted in lower managerial commitment.

This evidence could be understood through the Stakeholder Theory (Kujala et al., 2022). Managers operate "under fire" (Freeman, 2010) in an environment dominated by cooperative and competing interests that require continuous management of the company's stakeholders (Donaldson & Preston 1995). To achieve superior performance organizations are required to understand stakeholders needs and requests (Battaglia et al., 2014; Laplume et al., 2008); certifications are usually considered a useful tool to take into account these aspects as they provide a widely accepted moral base to justify firm actions (Zhao et al., 2012). In this perspective, customers are focal external stakeholders, and their lack of recognition (of SA8000) influences the managers towards decertification and sometimes towards the adoption of "less narrow" alternatives. Employees are another key stakeholder category that SA8000 prioritizes (Merli et al., 2015). In the context of developing countries, some studies highlight the beneficial role of CSR standards for the human resources of the firm (Beschorner & Muller, 2007; Stigzelius & Mark-Herbert, 2009). On the contrary, the analyzed cases show that employees - to increase their gross income - may sometimes prefer working conditions that are less regulated. The "employees' discomfort" may also be influenced by the "institutional" context in which the companies operate (next category).

Weakening of "institutional" pressures towards certification. Three factors in Table 3 directly relate to this category: "mimicking behavior", "difficult integration of local laws and SA8000 requirements", and "lack of auditors".

Institutional Theory states that a company's choices are driven by the aspiration to be socially validated and accepted (Yang et al., 2021). According to this perspective, the business environment is subject to normative (e.g., context-specific practices), coercive (e.g., governmental requirements), and mimetic (e.g., peer imitation) pressures. In looking for the required legitimacy to operate in the market, organizations must be able to answer these pressures and align their strategies and actions with what is considered “desirable, proper or appropriate” (Koster et al., 2019, p. 538) in their specific context. This leads firms competing in similar settings (and therefore subject to the same pressures) to embrace similar practices thus resulting in isomorphic (imitative) behaviors (DiMaggio & Powell, 1983).

In the context of SA8000, companies may follow an SA8000 decertification trend due to mimetic pressures: as already pointed out, the number of companies that have opted for decertification is now significant and its imitative “persuasion” has become relevant. Similarly, the "lack of auditors" and "difficult integration of local laws and SA8000 requirements" can be interpreted as a weakening of normative and coercive pressures respectively.

Turning to the “employees' discomfort” factor, we believe that here too “institutions” may play a role. Extant literature underlines how factors associated with the institutional environment (e.g., income inequality and country development) may shape the behavior of human resources (Josifidis & Supic, 2019; Bagdadli et al., 2021). More specifically, workers in less developed countries may be exposed to a restricted variety of development opportunities (Leana & Meuris, 2015; Jia et al., 2014). Therefore, they may prefer to work for companies that are not SA8000 certified in order to increase their income (for example, through the use of unregulated overtime).

If we compare the reasons for decertification illustrated above with the reasons that had motivated certification, we find that they can be traced to a) unfulfilled market benefits; b) obstacles that emerged during implementation. As for the unfulfilled benefits, firms often anticipate positive sales-related externalities; however, as clients cease to request SA8000, or the absence of commercial benefits becomes evident, firms decertify. Similarly, unexpected obstacles (such as the ones related to SA8000 ongoing management or contextual factors) may evolve into a troublesome implementation thus enabling decertification. Lastly, a decertification driver stands on its own (i.e., “mimicking behavior”) and does not exhibit any relationship with the initial reasons leading firms to join SA8000.

As for the comparison among the decertification reason emerging for SA8000 and those already identified for other standards some relevant aspects emerge. As already mentioned, some drivers are common (“absence of commercial benefits/advantages”; “financial burden”; “paperwork load and documental management”; “limited sphere of influence”; “limited top management engagement”), others apply only to the SA80000 (“complexity in orders and supplier’ management”; “lack of auditors”; “mimicking behavior”; “employees’ discomfort”; “difficult integration of local laws”). The peculiarity of most of these drivers can probably be explained by the fact that SA8000 involves not only the company but its whole (upstream) supply chain (Ciliberti et al., 2009). Inter-organizational procurement processes, especially on an international scale, entail greater management difficulty (complexity in order and supplier management), attention to regulatory diversity (difficult interpretation of local laws to be combined to SA8000 requirements), and intense network dynamics (mimicking behavior) (Stigzelius & Mark-Herbert, 2009). The "employees' discomfort" can probably be traced back to the specific nature of this certification, whose focus is on the working conditions (Sartor et al., 2016; Sartor & Orzes, 2019). The “lack of auditors” is also standard-specific: as many firms are leaving SA8000, it’s becoming difficult to find (independent) auditing organizations in some areas.

As for the RQ2), our findings highlight that all the case companies have pursued less expensive decertification pathways. In particular, some firms (scenario A) moved to less stringent, less costly, and more flexible initiatives; others (scenario B) dismissed some of the most costly and stringent practices; the remaining (scenario C) stopped taking care of all the SA8000 requirements.

This behavior is different from the ones detected in the literature for other (environmental) standards. Previous studies on ISO 14001 and EMAS show that most of the companies maintain their environmental practices after decertification (Kafel & Nowicki, 2014; Daddi et al., 2018). A possible explanation can be found by considering the contribution of Koster et al. (2019). The authors highlight that poor environmental performance is usually difficult to hide; on the opposite, "much of the exploitation is invisible" for social behaviors (Koster et al., 2019, p. 544). As such, SA8000 decertified companies experience less pressures to maintain socially acceptable practices: they can freely decide to reduce costs by decreasing their social efforts (scenario B, C) or reduce costs by adopting less expensive (but broader or more context-specific) standards (scenario A).

CONCLUSIONS

By providing evidence of the reasons driving firms to leave SA8000 and the alternative paths that companies select after the abandonment, we offer relevant contributions to theory and practice. This section presents these contributions together with the limitations of the study and avenues for future research.

Contributions to Theory

This paper furthers CSR knowledge in at least four ways.

Our research answers previous calls for more specific studies on the topic of SA8000 decertification (Podrecca et al., 2021) by proposing the first analysis of the drivers leading firms to abandon the norm. Some drivers have never emerged in other standards; others have already been found in ISO 9001, ISO 14001, EMAS, and UNGC. This enriches the literature by showing that decertification drivers are at least partially standard specific.

Second, our findings underline that companies may decertify because of some unexpected obstacles associated with the certification decision. This highlights that CSR standards (and in particular SA8000) are not beneficial for all the organizations and calls for additional investigations on the SA8000 implementation process and certification outcomes.

Third, our research is the first to unveil the existence of three exit strategies that firms undertake upon the decision of leaving SA8000: 1) some companies implement an alternative social standard/initiative, 2) others do not adopt any alternative social standard/initiative, but continue respecting some SA8000 requirements, 3) others do not adopt any alternative social standard/initiative and stop taking care of SA8000 requirements. Previous studies on ISO 14001 and EMAS show that most companies follow a single common path after decertification: maintain their environmental practices (Kafel & Nowicki, 2014; Daddi et al., 2018). This enriches the literature by revealing that the decertification paths are also, at least partially, standard specific.

Lastly, this study is the first to show how some theoretical lenses usually used to read the certification, can also be used for the decertification. In particular, our paper refers to the Transaction Cost Theory, the Stakeholder Theory, and the Institutional Theory to explain SA8000 abandonment.

Contribution to Practice

Our research at first contributes to practice by providing evidence of the SA8000 decertification drivers. Managers can refer to our findings to promptly perceive the early signs of the emergence of any of these abandoning reasons, address them, and implement corrective measures. On the other hand, organizations that are about to initiate their certification process can have a structured overview of the critical issues they may face; this can help them to take more informed and conscious decisions.

Second, by highlighting the potential links between the potential benefits and obstacles of the certification and the decertification drivers, our study warns companies on the need to carefully consider the motivations leading them to join SA8000. Overly high expectations or underestimated obstacles associated with SA8000 adoption (in particular the economic effort required to maintain it) can lead to decertification, thus resulting in wasted time and resources.

Third, our research shows the evidence of three exit strategies that cases implement. Managers could evaluate these alternative paths in order to understand the one that better fits their company's profiles.

Fourth, while CSR is increasingly becoming a core aspect of a firm's strategies (Bartolacci et al., 2020; Orzes et al., 2020), data show an alarming number of companies that abandon SA8000. This phenomenon should be carefully recognized, monitored, and addressed by SAI (i.e., the regulatory body) that can utilize this study to consider a revision of SA8000: by addressing these challenges, SAI could contain and even reverse the decertification phenomenon.

To conclude, we hope that putting the spotlight on CSR decertification could lead all the relevant stakeholders to increase their awareness of the issue and to carefully reflect on the potential strategies to overcome it. This could contribute to a more sustainable society in which firms consider people's needs as a top priority along with economic interests.

Limitations and Future Research

Our study has two main limitations. First, a reduced sample size (15 companies). Second, this sample includes only one company belonging to the "Utilities" sector. As qualitative research doesn't have inferential aims (Stuart et al., 2002), we believe that these issues do not represent critical shortcomings. Nonetheless, further contributions could address such aspects by performing a survey on wider and more structured samples.

To conclude, decertification literature is still poor on most of the international management standards/initiatives, despite the surging number of cases. Possible future studies could explore a wider range of CSR initiatives thus performing a comparative analysis.

Appendix:

Table A1: Interview protocol

1) Introduction	Presentation of the interviewers and the research team, description of the study (motivations, aims/objectives). Discussion of issues related to confidentiality, research consent, and permission for recording.
2) General information on the company and the interviewee	The interviewee was asked to describe: Its role, responsibilities, and years of experience within the organization. Company profile, product/service offer, size, number and location of plants, and the geographical distribution of the customers/suppliers. The industry the firm competes in and its main characteristics.

3) (De)Certification	The interviewee was asked to describe: The drivers leading the firm to adopt SA8000, whether there was any specific objective related to SA8000 adoption and if these goals have been met. The effects (positive and negative) of the adoption of SA8000 and whether they have remained stable or have changed over time. The reasons leading to the decision to abandon SA8000 and whether at the time of the initial certification the firm considered these potential issues. The origin of the decision to decertify (e.g., the employees explicitly requested it, the management realized that SA8000 was not useful/posed some problems). Whether in his/her view the SA8000 was more useful in some contexts (e.g., specific countries/industries) rather than in others.
4) Post-decertification	The interviewee was asked to describe: Potential changes to firm practices following the decertification (e.g., which practices have been dismissed/maintained) and effects of the abandonment. Main challenges of not being certified anymore and whether the firm believes that the decision to decertify was correct. Whether the firm replaced SA80000 with another CSR initiative.
5) Further comments	The interviewee was asked if he/she would like to add anything to the themes touched upon during the interview and if he/she had any additional comments.

Table A2: Categorization codes			
Topic	Description	Categories	Description
Certification drivers	The motivations leading firms to adopt SA8000	Client's request	Need to accommodate the requirement of a client that mandates SA8000 or to acquire SA8000 to participate in public bids
		Commercial purposes	Willingness to improve company reputation and commercial performance

		Financial savings	Desire to strengthen supply chain management efficiency and identify improvement areas in shop-floor activities
		Ethical choice	Desire to testify the core values of the implementing company
		Improve social performance	Willingness to improve working conditions and settle labor issues
Decertification drivers	The motivations leading firms to leave SA8000	Absence of commercial benefits/advantages	Lack of competitive advantage related to SA8000
		Financial burden	High cost of SA8000 maintenance
		Paperwork load and documental management	High bureaucracy imposed by SA8000
		Limited sphere of influence	SA8000 scope was too specific/narrow
		Complexity in orders and suppliers' management	SA8000 posed difficulties in finding (and dealing with) suppliers
		Lack of auditors	Difficulty to find local auditors to perform the SA8000 renewal audits
		Mimicking behavior	Firms followed the decision of similar companies to leave the SA8000
		Employees' discomfort	Employees were unsatisfied with the restrictions imposed by SA8000
		Difficult integration of local laws and SA8000 requirements	Some requirements of SA8000 were in contrast with local regulations
		Limited top management engagement	Top managers did not believe in the SA8000
Post-decertification paths	The alternative paths firms undertake after abandoning SA8000	Implementation of an alternative initiative	Embracement of a different

			CSR/sustainability initiative
		No alternative initiative, but still respect some of SA8000 requirements	Maintenance of some of the practices introduced with SA8000
		No alternative initiative, and stop taking care of SA8000 requirements	Dismissal of all the practices related to SA8000

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DECISION SCIENCE INSTITUTE

An Econometric Model of the US Government Yield Curve Levels and Dynamics

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ABSTRACT

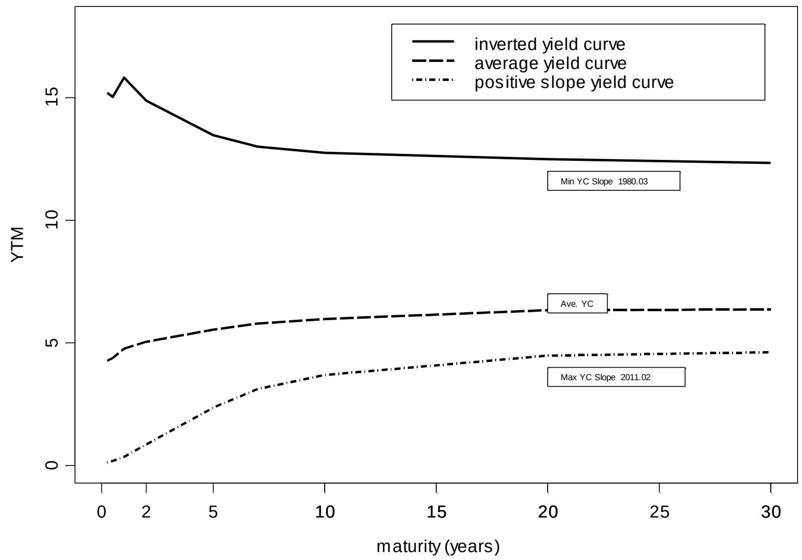
This research uses five mathematical algorithms, three money supply measures, as well as multiple linear and nonlinear regression to model each yield to maturity (ytm) of nine treasury bills, notes, and bonds along the US Government bond maturity spectrum. The result is a system of equations that explains and predicts the US Government yield curve levels, slopes and dynamics, a phenomenon largely responsible for driving the value of US$273 Trillion of global debt. The research results are highly relevant to institutional and retail investors, borrowers, and lenders, as well as academics and policy makers.

I. INTRODUCTION

The yield curve is the graph of the relationship of the nominal yield to maturity (ytm) on bonds of a similar asset class with different bond maturities at a point in time. Yield curves exist for every sector of the fixed income asset class, e.g., government, corporate, municipal, emerging markets, high yield, etc. for all bond markets worldwide.

Fig.1 displays three yield curve shapes that occur in the government sector, the inverted yield curve, average yield curve and positive slope yield curve. The average yield curve and positive slope yield curve have a positive slope whereas the inverted yield curve has a negative slope. The yield curves become flatter as the maturity increases. The yield curve is constantly shifting and pivoting.

Fig.1 Three Yield Curves



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The purpose of this research is to model the slope and shape of the US Government Sector Yield Curve and to identify the factors which cause the Yield Curve to shift or pivot.

Five multiple linear and nonlinear regression specifications are used to model the yield to maturity of nine treasury bills, notes, and bonds along the US Government bond maturity spectrum using three alternative money supply measures, inflation, and price level. The optimal modelling methodology, i.e., mathematical specification and Money Supply alternative, is selected based on model percentage error. The result is a system of nine equations that explains and predicts each of nine US Government yield to maturity. In concert, the nine equations allow prediction of the US Government Yield Curve position and slope.

Four outcomes of this research are:

1. Identification of the superior math specification and money supply definition which will best model the US Yield Curve levels.
2. Estimation of the sensitivity of each ytm to inflation and both real and nominal money supply.
3. Infer the "Real" Yield Curve i.e., the existence of the Yield Curve where inflation is equal to zero.
4. Produce evidence in support of (or against):
   - Liquidity Preference Theory
   - Fisher Equation Theory
   - Demand curve for money

The research results are highly relevant to institutional and retail investors, borrowers, and lenders, as well as academics and policy makers and other individuals interested in macroeconomics and finance. The research is important, as the value of US Government Bond sector is over $80US Trillion.

II. METHODOLOGY

Eqn. 6 displays the functional specification. It is hypothesised that as the inflation or cpi increases, each ytm will increase and as money supply increases each ytm will decrease.

$$ytm_i = f(\overset{-}{ms}, \overset{+}{cpi}, \overset{+}{infla}) \qquad (6)$$

where:
ytm_i = yield to maturity, tb3, tb6, us1, us2, us5, us7, us10, us20, us30
infla = inflation, % change in consumer price index last 12 mth. as a proxy for inflation expectations
ms = US Money Supply.

The three alternative measures of money supply are:

- AMB (Adjusted Monetary Base) = Currency and Coin
- M1 = AMB + Checking Accounts
- M2 = M1 + Saving Accounts

This research estimates one of five mathematical specifications and one of three measures of money supply that will best model the US Yield Curve levels and dynamics.

Five mathematical specifications to model ytms are:

linear: $\text{ytm} = \text{a} + \text{b}_{\text{ms}} * \text{ms} + \text{b}_{\text{infla}} * \text{infla}$ (1)

logMS: $\text{ytm} = \text{a} + \text{b}_{\text{ms}} * \ln(\text{ms}) + \text{b}_{\text{infla}} * \text{infla} + \text{b}_{\text{cpi}} * \text{cpi}$ (2)

emsNExp: $\text{ytm} = \text{a} + \text{b}_{\text{ms}} * \exp(\text{e}_{\text{ms}} * \text{ms}) + \text{b}_{\text{infla}} * \text{infla} + \text{b}_{\text{cpi}} * \text{cpi}$ (3)

sLog: $\ln(\text{ytm}) = \text{a} + \text{b}_{\text{ms}} * \text{ms} + \text{b}_{\text{cpi}} * \text{cpi} + \text{b}_{\text{infla}} * \text{infla}$ (4)

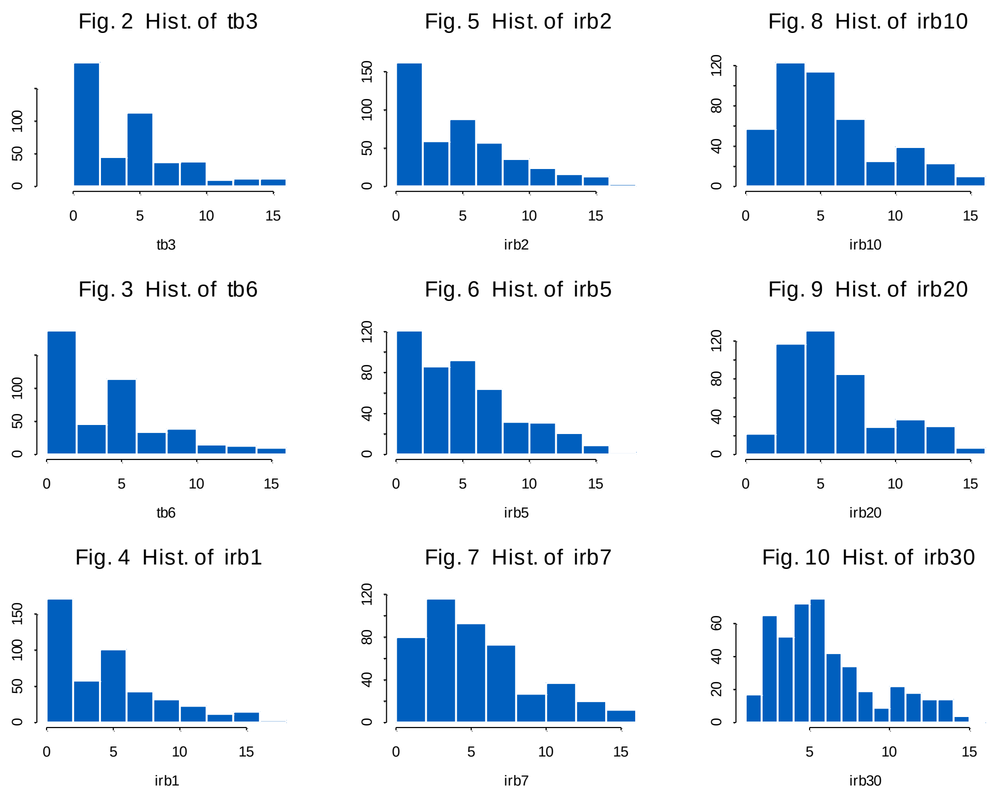
dLog: $\ln(\text{ytm}) = \text{a} + \text{b}_{\text{ms}} * \ln(\text{ms}) + \text{b}_{\text{cpi}} * \ln(\text{cpi}) + \text{b}_{\text{infla}} * \ln(1 + \text{infla})$ (5)

For this research 539 monthly observations were gathered from Federal Reserve Bank of St. Louis. Graphical techniques (Histograms, Time-series plots, Scatterplots), descriptive statistics, correlation, as well as multiple linear and nonlinear regression analysis were executed, and the statistical and computing program used was S+ to analyse the data.

III. RESULTS

Graphical Results

Figs. 2-10 display the histograms of each debt instrument. The histograms of the interest rates skew to the right but less so as the maturity increases.



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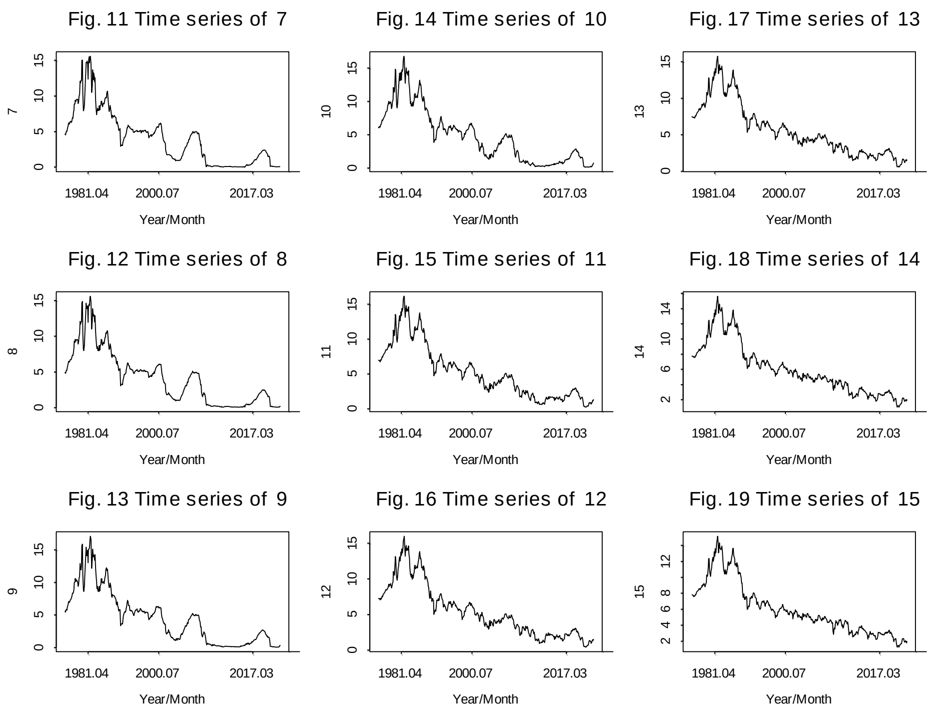
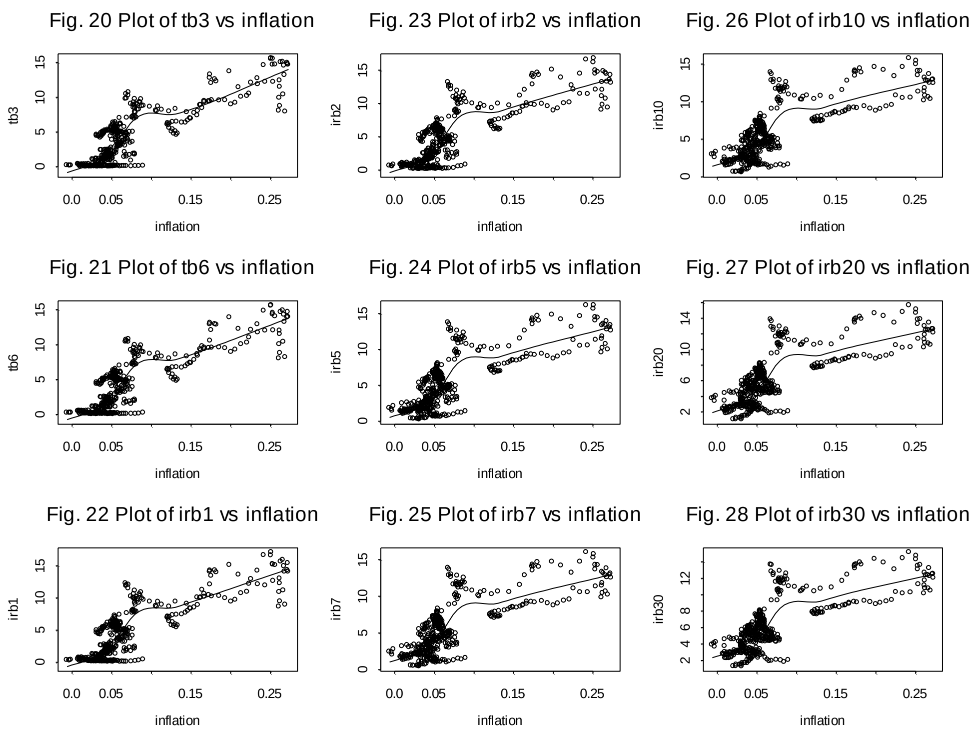
Figs 11-19 display the time series plots of each debt instrument. All the time series plots peak in 1980, then gradually decrease.



Figs 20-28 display the scatterplots between inflation and each debt instrument. All scatterplots are positive, resemble an S function.



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Figs. 29-37 displays the scatterplots between amb and ytm for each debt instrument.

Fig. 29 Plot of tb3 vs amb

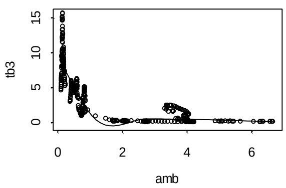


Fig. 32 Plot of irb2 vs amb

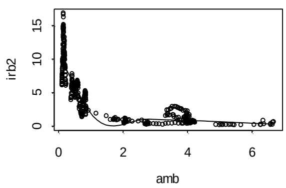


Fig. 35 Plot of irb10 vs amb

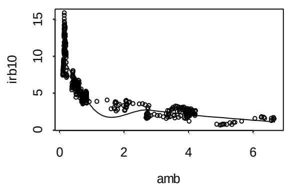


Fig. 30 Plot of tb6 vs amb

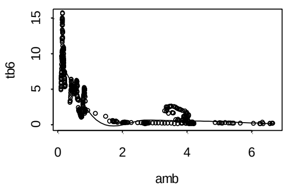


Fig. 33 Plot of irb5 vs amb

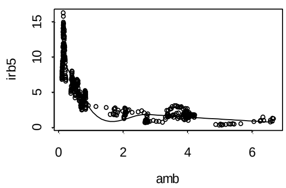


Fig. 36 Plot of irb20 vs amb

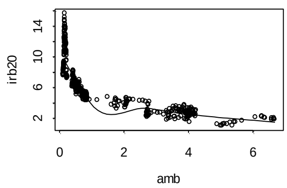


Fig. 31 Plot of irb1 vs amb

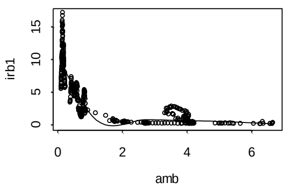


Fig. 34 Plot of irb7 vs amb

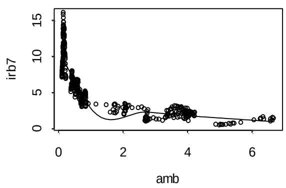
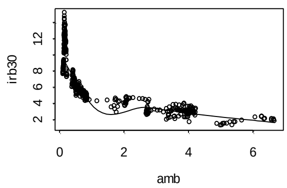


Fig. 37 Plot of irb30 vs amb



The yields to maturity are negative, and asymptotic to amb.

Figs 38-46 display the scatterplots between M1 and the ytm of each debt instrument.

Fig. 38 Plot of tb3 vs m1

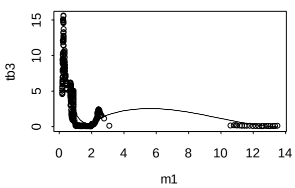


Fig. 41 Plot of irb2 vs m1

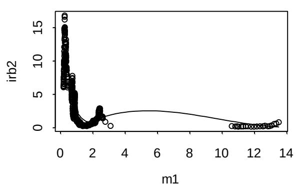


Fig. 44 Plot of irb10 vs m1

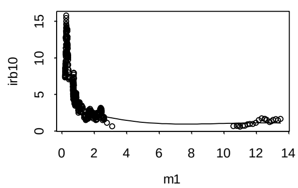


Fig. 39 Plot of tb6 vs m1

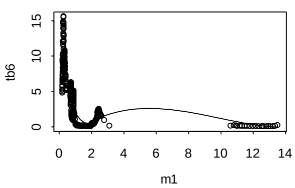


Fig. 42 Plot of irb5 vs m1

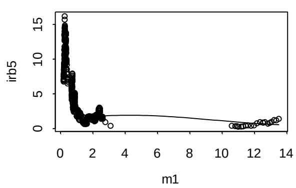


Fig. 45 Plot of irb20 vs m1

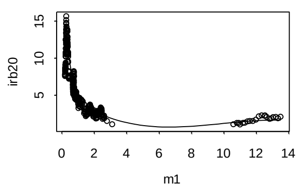


Fig. 40 Plot of irb1 vs m1

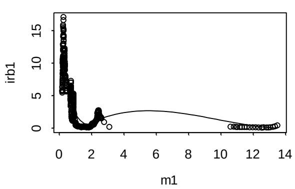


Fig. 43 Plot of irb7 vs m1

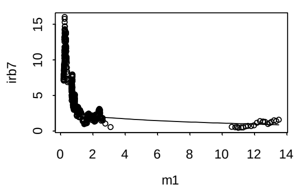
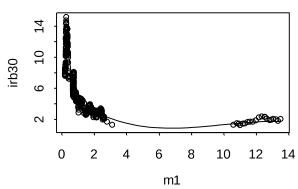


Fig. 46 Plot of irb30 vs m1



The yields to maturity are negative, and asymptotic to m1.

Figs 47-55 display the scatterplots between M2 and the ytm of each debt instrument.

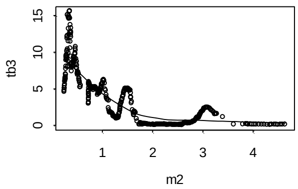


Fig. 47 Plot of tb3 vs m2

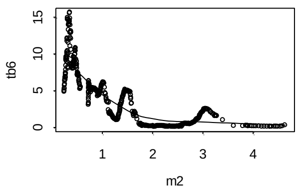


Fig. 48 Plot of tb6 vs m2

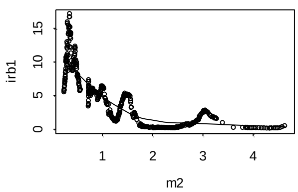


Fig. 49 Plot of irb1 vs m2

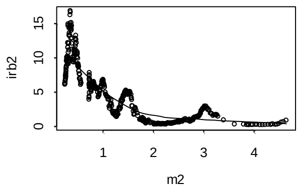


Fig. 50 Plot of irb2 vs m2

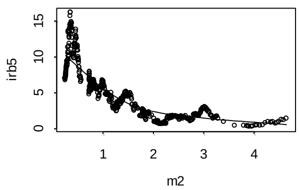


Fig. 51 Plot of irb5 vs m2

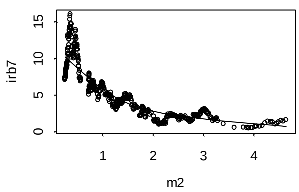


Fig. 52 Plot of irb7 vs m2

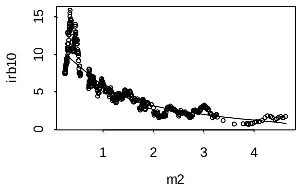


Fig. 53 Plot of irb10 vs m2

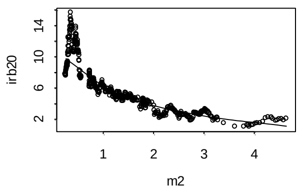


Fig. 54 Plot of irb20 vs m2

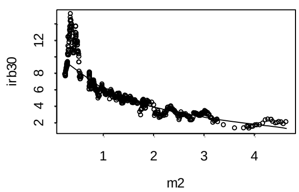


Fig. 55 Plot of irb30 vs m2

The yields to maturity are negative, and asymptotic to m2.

Statistical Analysis

Table 1 displays Descriptive Statistics. Notice that the mean and median of the debt instrument ytm's increase monotonically with maturity.

Table 1 Descriptive Statistics

	min	*q1*	*mean*	*med*	*q3*	*max*	*stdev*	*skew*	*kurt*	*n*
tb3	-0.02	0.33	4.01	3.62	5.74	15.59	3.80	0.96	0.41	458
tb6	0.04	0.48	4.11	3.80	5.95	15.61	3.79	0.90	0.18	458
irb1	0.04	0.67	4.47	4.00	6.29	17.06	4.08	0.91	0.15	458
irb2	0.11	1.03	4.71	4.21	6.62	16.78	4.04	0.84	-0.10	458
irb5	0.22	1.91	5.18	4.52	7.00	16.13	3.79	0.85	-0.10	458
irb7	0.40	2.31	5.43	4.63	7.24	15.97	3.66	0.86	-0.10	458
irb10	0.56	2.73	5.62	4.72	7.38	15.75	3.52	0.88	-0.06	458
irb20	1.01	3.20	6.01	5.32	7.61	15.62	3.33	0.83	-0.08	458
irb30	1.23	3.40	6.02	5.25	7.60	15.14	3.20	0.89	-0.02	458
amb	0.12	0.24	1.56	0.73	2.76	6.68	1.67	1.16	0.23	458
m1	0.20	0.45	1.49	0.80	1.51	13.51	2.43	3.91	14.74	458
m2	0.25	0.57	1.48	1.23	2.14	4.65	1.05	0.95	0.25	458
cpi	59.60	110.05	176.17	182.20	229.10	281.93	60.55	-0.36	-1.04	458
infla24X	-0.01	0.04	0.07	0.05	0.07	0.27	0.06	2.02	3.50	458

Table 2 displays Correlation Matrix. The debt instruments are highly correlated with cpi, inflation and the measures money supply.

Table 2 Correlation Matrix

	amb	m1	m2	m3	cpi	infla24	tb3	tb6	irb1	irb2	irb5	irb7	irb10	irb20	irb30	syc
amb	1	0.76	0.962	0.962	0.824	-0.453	-0.682	-0.689	-0.691	-0.706	-0.723	-0.728	-0.731	-0.749	-0.736	0.294
m1	0.76	1	0.772	0.772	0.543	-0.228	-0.405	-0.411	-0.413	-0.426	-0.449	-0.458	-0.467	-0.48	-0.48	0.079
m2	0.962	0.772	1	1	0.91	-0.532	-0.741	-0.749	-0.754	-0.771	-0.794	-0.803	-0.809	-0.825	-0.818	0.283
m3	0.962	0.772	1	1	0.91	-0.532	-0.741	-0.749	-0.754	-0.771	-0.794	-0.803	-0.809	-0.825	-0.818	0.283
cpi	0.824	0.543	0.91	0.91	1	-0.714	-0.851	-0.859	-0.866	-0.878	-0.891	-0.895	-0.898	-0.901	-0.9	0.41
infla24	-0.453	-0.228	-0.532	-0.532	-0.714	1	0.82	0.817	0.812	0.787	0.766	0.757	0.757	0.742	0.746	-0.55
tb3	-0.682	-0.405	-0.741	-0.741	-0.851	0.82	1	0.999	0.995	0.986	0.966	0.956	0.946	0.929	0.925	-0.703
tb6	-0.689	-0.411	-0.749	-0.749	-0.859	0.817	0.999	1	0.999	0.992	0.973	0.963	0.954	0.937	0.933	-0.697
irb1	-0.691	-0.413	-0.754	-0.754	-0.866	0.812	0.995	0.999	1	0.996	0.981	0.973	0.964	0.948	0.944	-0.677
irb2	-0.706	-0.426	-0.771	-0.771	-0.878	0.787	0.986	0.992	0.996	1	0.993	0.987	0.979	0.966	0.962	-0.634
irb5	-0.723	-0.449	-0.794	-0.794	-0.891	0.766	0.966	0.973	0.981	0.993	1	0.999	0.995	0.988	0.985	-0.542
irb7	-0.728	-0.458	-0.803	-0.803	-0.895	0.757	0.956	0.963	0.973	0.987	0.999	1	0.999	0.994	0.992	-0.502
irb10	-0.731	-0.467	-0.809	-0.809	-0.898	0.757	0.946	0.954	0.964	0.979	0.995	0.999	1	0.998	0.996	-0.465
irb20	-0.749	-0.48	-0.825	-0.825	-0.901	0.742	0.929	0.937	0.948	0.966	0.988	0.994	0.998	1	0.999	-0.417
irb30	-0.736	-0.48	-0.818	-0.818	-0.9	0.746	0.925	0.933	0.944	0.962	0.985	0.992	0.996	0.999	1	-0.404
syc	0.294	0.079	0.283	0.283	0.41	-0.55	-0.703	-0.697	-0.677	-0.634	-0.542	-0.502	-0.465	-0.417	-0.404	1

Model Comparison and Evaluation

Each element of Tables 4, 5 and 6 show the average R^2, Median and Mean Absolute Error, respectively, of the nine debt instruments for each model using each money supply. Importantly, the double log linear model using amb as measure of money supply, as shown in Eqn. 7 and 8, is the optimal model because it has the highest average R^2 and the minimum Median and Mean Abs Error.

$$\ln(ytm) = \alpha + \beta_{amb} * \ln(amb) + \beta_{cpi} * \ln(cpi) + \beta_{infla} * \ln(1 + infla) + \varepsilon \qquad (7)$$

$$\ln(ytm) = a + b_{amb} * \ln(amb) + b_{cpi} * \ln(cpi) + b_{infla} * \ln(1 + infla) + e \qquad (8)$$

Table 3 Ave R^2

	amb	m1	m2
basic	0.834	0.831	0.834
logMS	0.842	0.832	0.832
emsNExp	0.86	0.836	0.854
sLog	0.839	0.813	0.828
dLog	0.862	0.792	0.842

Table 4 Min Median Abs Error

	amb	m1	m2
basic	0.702	0.704	0.706
logMS	0.764	0.714	0.714
emsNExp	0.704	0.755	0.818
sLog	0.184	0.211	0.182
dLog	0.157	0.252	0.181

Table 5 Min Mean Abs Error

	amb	m1	m2
basic	1.09	1.084	1.091
logMS	0.823	0.83	0.826
emsNExp	0.976	1.097	1.054
sLog	0.358	0.408	0.385
dLog	0.312	0.439	0.369

Analytical Results

Table 6 displays the Regression Results of the optimal model i.e., dlog on AMB for all instruments. Note the following:

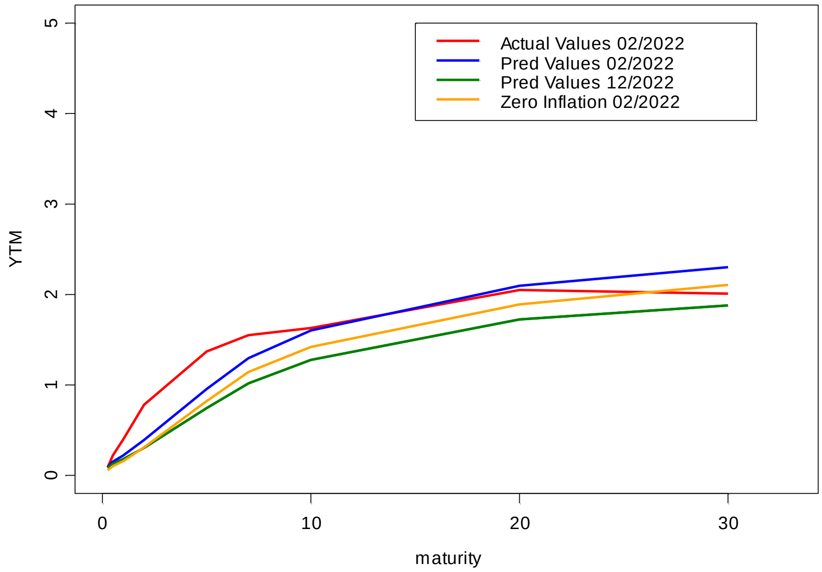
1. The R^2 is high for all nine models and increases with maturity.
2. The coefficients of the amb are all negative and become less negative with maturity.
3. The coefficients of cpi are all positive and increase with maturity.
4. The coefficients of the inflation are all positive and decrease as the maturity increases.
5. All independent variables: cpi, inflation and amb are very significant for all nine equations as all t-statistics are very high (99% level of significance).
6. The predicted values of each ytm for 02/2022 are very close to the actual values of 02/2022.
7. The predicted values for each ytm for 12/2022 are significantly lower that the values of each ytm for 02/2022.

Fig. 56 shows the Actual Yield Curve of 02/2022, the Predicted Yield Curve of 02/2022, the Predicted Yield Curve of 12/2022, and the Zero Inflation Yield Curve of 02/2022.

Table 6 Regression Results

Instrument	*n*	*Actual Val 02/22*	*Pred Val 02/22*	*Pred Val 12/22*	*rpct*	*R^2*	*Zero Infla*	*int*	*b_{MS}*	*b_{cpi}*	*b_{Inlfa}*	*t_{int}*	*t_{MS}*	*t_{cpi}*	*t_{Inlfa}*
tb3	541	0.09	0.09	0.08	0.23	0.77	0.06	-18.11	-2.31	3.46	11.41	-11.03	-25.01	11.15	4.65
tb6	541	0.22	0.15	0.13	0.20	0.79	0.10	-14.20	-1.96	2.75	9.28	-10.51	-25.83	10.79	4.60
irb1	541	0.40	0.22	0.18	0.18	0.81	0.16	-11.44	-1.73	2.27	7.77	-9.73	-26.24	10.22	4.43
irb2	541	0.78	0.39	0.31	0.15	0.83	0.31	-7.62	-1.38	1.60	5.40	-8.29	-26.69	9.19	3.93
irb5	541	1.37	0.96	0.74	0.09	0.86	0.82	-3.22	-0.90	0.83	3.51	-5.50	-27.41	7.52	4.01
irb7	541	1.55	1.30	1.02	0.08	0.88	1.14	-1.83	-0.75	0.59	2.93	-3.90	-28.20	6.67	4.17
irb10	541	1.63	1.60	1.28	0.08	0.89	1.42	-1.07	-0.65	0.46	2.80	-2.69	-28.81	6.15	4.68
irb20	541	2.05	2.10	1.73	0.08	0.90	1.89	-0.58	-0.55	0.40	2.39	-1.64	-27.53	5.94	4.47
irb30	541	2.01	2.30	1.88	0.06	0.90	2.11	0.33	-0.47	0.23	2.07	1.08	-27.32	3.92	4.49

Fig.56 Yield Curves



IV. DISCUSSION

The real Yield Curve, where inflation is equal to zero, was identified. The values of the real interest rates are all positive and increase with maturity. This phenomenon supports the Liquidity Preference Theory as short-term interest rates are predicted to be lower than the long-term interest rates.

Interest rates are a positive function of inflation something that supports the Fisher Effect Theory. However, the coefficient decreases with maturity.

The coefficients of cpi are all positive. This indicates that the real money supply affects the interest rate and not the nominal money supply.

The coefficients of money supply are all negative, evidence in support of the negative "demand for money" hypothesis. Importantly, the coefficients become less negative with maturity.

V. CONCLUSIONS

This research estimated nine equations, one for each instrument of the yield curve. Short term interest rates are identified to be more sensitive to money supply, inflation and cpi than the long-term interest rates. Additionally, the model of this research predicts that the values of the interest rates will fall in 12/2022, something that will result to the rise of the bond prices. The results of this research will interest institutional and retail investors, borrowers, and lenders, as well as academics and policy makers.

VI. REFERENCES (BIBLIOGRAPHY)

Federal Reserve Bank of St. Louis.

DECISION SCIENCES INSTITUTE

Analysis on the dominant choice of toxic outcomes in the closed-loop shipbuilding supply chain

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ABSTRACT

The survival of shipbuilding business relies heavily on recycling the end-of-life ships. However, in 2021, nearly 100% of the world's retired vessels were sent to weakly regulated shipyards and broken down manually, which caused detrimental environmental impact and many deaths and injuries. To understand why the choice of such toxic outcomes dominates this industry and the regulations that forbid unethical ship recycling were ineffective, we develop an equilibrium framework to analyze the end-of-life recycling decisions. We show that the end-of-life recycling decisions tend to fall in irresponsible shipowners' hands and responsible shipowners also benefit financially from irresponsible shipowners' unethical choice.

KEYWORDS: Closed-loop supply chains, Demand chains, Equilibrium problems, Circular economy, Shipping policies

INTRODUCTION

The survival of the shipbuilding business relies heavily on recycling end-of-life ships. However, in the recent ten years, more than two-thirds of the world's retired vessels, instead of being recycled at industrial sites such as dry docks and quaysides with the capacity to store and treat oily and hazardous wastes, are recycled in South Asia, where the end-of-life vessels are dismantled manually on tidal beaches by low-paid workers with little training and personal protective equipment under lax regulations.

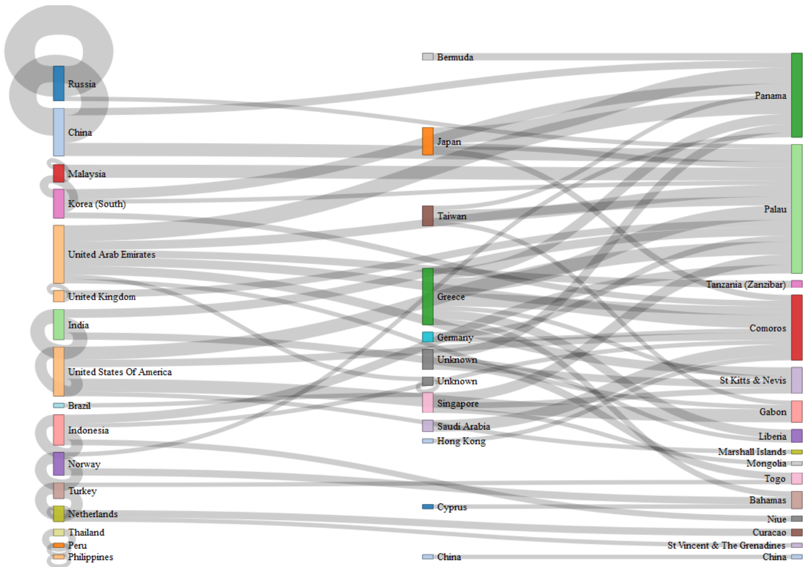
Since 2009, 398 fatalities and 251 injuries have occurred from the manual recycling of 6430 ships in the South Asian ship recycling facilities located in Bangladesh, India, and Pakistan (NGO Shipbreaking Platform 2020). The International Labour Offce (ILO) describes shipbreaking as the most dangerous occupation." In addition to occupational health and child labor issues, pollution is another primary concern about ship recycling. End-of-life vessels contain various hazardous materials within their structure and may carry hazardous materials as cargo, such as asbestos, heavy metals, mineral oil, and ozone-depleting substances.

With the ever-increasing criticism of the scandals in the vessel recycling business, the International Maritime Organization (IMO), the United Nations specialized agency responsible for curbing shipping pollution and ensuring safety, adopted the Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships (HKC) at a Diplomatic Conference held in Hong Kong in 2009. HKC requires every ship over 500 gross tonnage to maintain an Inventory of Hazardous Materials (IHM), which identifies the amount and location of hazardous materials onboard the ship. Meanwhile, ship recycling yards will be required to provide a Ship Recycling

Plan, which specifies how each ship will be recycled, depending on its particulars and inventory. However, in the first four years, only six countries ratified, accepted, or approved the HKC, far below the enter-into-force requirement of fifteen.

To bring forward the requirements of HKC and to make ship-recycling greener and safer, the European Parliament and the Council of the European Union adopted the Ship Recycling Regulation (EU SRR) on 20 November 2013. Under EU SRR, every EU-flagged ship must carry IHM on board. From 31 December 2018, all commercial vessels above 500 GT must be recycled in safe and environmentally sound ship-recycling facilities that are included in the European List of approved ship-recycling facilities. Although EU SRR will also require all vessels calling at an EU port or anchorage to carry an IHM from 31 December 2020, it has little control over non-EU-flagged vessels on how they are recycled. EU aims to make ship-recycling greener and safer by regulating the vessels under its flag. However, the effectiveness of these regulations is hindered by "flag hopping" - shipowners can easily swap the flag of a ship to avoid regulations. According to the statistics published by the United Nations Conference on Trade and Development (UNCTAD), around 76.9% (in terms of deadweight tonnage) of commercial ships are registered under a flag that differs from the flag of the country of ownership. The leading flags of registration, namely Panama, the Marshall Islands, and Liberia, are not major ship-owning countries. For end-of-life vessels, the discrepancy between the countries of beneficial ownership and the ships' flags is even higher than during the operational life of a ship - many vessels convert the flag of the vessel just before vessel disposal and sell her to the unethical recycling yard. Figure 1 shows the transitions from the Ship Owning States to the End-of-Life flag state, based on the statistics compiled by the NGO Shipbreaking Platform in 2019. States like Palau, Comoros, St Kitts, and Navis are not ship-owning states but are typical end-of-life flag states.

Figure 1: Shipbreaking Platform 2019 Statistics: Transition from Ship Owning State to End-of-Life Flag State. The figure shows only transition paths with at least 3 vessels.



With more than ten years of waiting time and under the persistent effort of the EU, the HKC is still in its pending status. EU SRR managed to expedite the enter-into-force of HKC as seven more EU countries ratified the HKC. However, this enter-into-force requirement of HKC will only be satisfied if all EU countries ratify the convention. Up to January 2020, 15 countries have ratified, accepted, or approved HKC, representing 30.21% of world merchant shipping by gross tonnage.

Why the ratification of HKC takes such a long time? What and who makes HKC hard to enter into force? Are there so many irresponsible stakeholders in the industry who shut their eyes to the deaths and pollution? In this paper, we develop models to understand the reasons behind these questions.

LITERATURE REVIEW

An extensive literature on ship recycling has provided overviews for the ship recycling market (e.g., Knapp et al, 2008; Mikelis, 2008; Hossain, 2015; Gourdon, 2019), explored how ship-breaking activities affect the adjacent environment and the health and safety of workers (e.g., Carvalho et al, 2011; Deshpande et al, 2013; Sivaprasad & Nandakumar, 2013; and Hossain et al, 2016), and discussed the related regulatory regime (e.g., Bhattacharjee, 2009). There are also papers (e.g., Alcaidea et al, 2016; and Gourdon, 2019) providing empirical evidence on the end-of-life reflagging before vessel scrapping and analyzing the most common flags selected for scrapping. However, all these papers study the ship recycling market alone as an independent market. Little work can be found in the literature on how the shipowner's recycling decision interferes with a vessel's life cycle. Kalouptsidi (2014) is an exception, which constructs a dynamic model of ship entry and exit and studies the impact of time-to-build on investment and prices. However, the focus of Kalouptsidi (2014) is not on the ship recycling decisions but on new building investments, so the study does not differentiate between ethical and unethical recycling.

Methodology-wise, our model shares some similarities with the model for durable products and the closed-loop supply chain (CLSC), e.g., Desai & Purohit, 1998; Hendel & Lizzeri, 1999; Agrawal et al, 2015; and Huang et al, 2019. We elaborate on this in the next section.

THE MODEL

Consider a set of potential shipowners that wish to invest in a given type of vessel. These shipowners differ in profit-generating ability, captured by the parameter $\theta,$ which is distributed under a cumulative distribution function θ. Let $\mu := E(\theta)$ denote the expected value of customer's profitability and assume that F is continuous and strictly increasing in an interval $[\underline{\theta}, \bar{\theta}]$, where $\underline{\theta} \geq 0$, and the buyer's type θ is independent of his or her choice of where to scrap the vessel (at ethical yards or unethical yards) in the future.

A potential buyer of type θ enjoys utility θ to own a newly-built vessel and $\delta\theta$ to obtain a second-hand vessel, where $\delta \in [0,1]$ captures the vessel durability. A shipowner who owns a second-hand vessel will receive a scrap revenue r from recyclers for disposing of the vessel. Each buyer in the population has essentially three options: to buy the vessel (“NEW”) to be resold to the secondary market later, or to buy a vessel in the secondary market (“2ND”), or not to invest (“NI”). We assume a common discount factor μ for all potential buyers.

We characterize a buyer of type θ’s demand for the three options according to the discounted profit. The net discounted profit for the NEW option is $\Pi_1 := \theta - p + \gamma p^s$, for the 2ND option is $\Pi_2 := \delta\,\theta - p^s + \gamma\, r$ and for NI option is $\Pi_3 = 0$. Note that the buyers are assumed to form rational expectations of the prices in the secondary market (p^s), and the scrap price r in making their decisions. These modeling assumptions provide an analytically tractable framework that has become almost standard in modeling the demand for durable products (see, Desai & Purohit, 1998; Hendel & Lizzeri, 1999; Agrawal et al, 2015; Huang et al, 2019).

We define the equilibrium so that the fraction of 2ND vessels and the fraction of NEW vessels are balanced out.

RESULTS

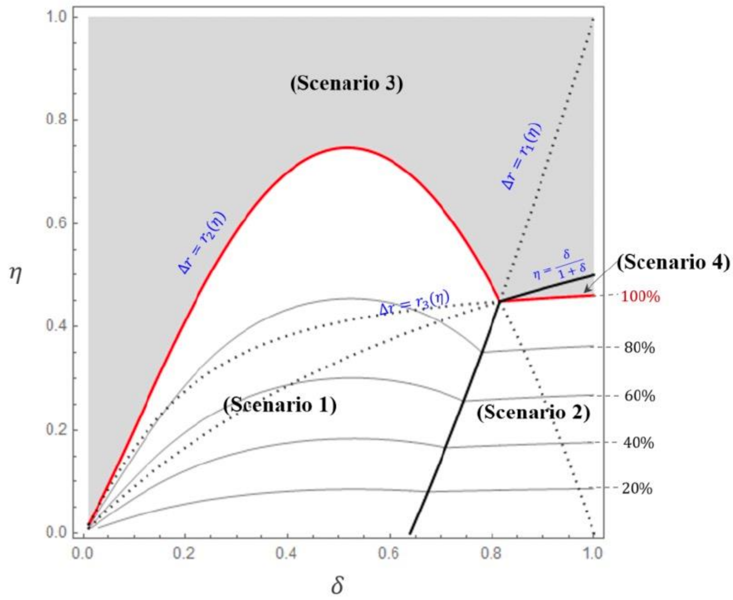
Case Study: Suezmax Tankers

In this section, we use our model to study the secondary market of ten-year-old Suezmax tankers. Suezmax is a naval architecture term for the largest size of ships that can sail through the Suez Canal fully laden. On average, a Suezmax has a light displacement (ldt) of 25,000 tonnes, a deadweight (dwt) of 160,000 tonnes, and an overall internal volume of 80,000 gross tonnage (gt). In the eleventh week of year 2020, the current value of a ten-year-old Suezmax vessel is around 35 million USD. The current recycling price for tanker is around 380 USD/ldt in South Asia, and around 240 USD/ldt in Turkey. Accordingly, we set r^{b} and r^{w} as 9.5 million USD and 6 million USD, respectively. We consider the proportion of irresponsible shipowner and the fraction of owners who buy secondary vessels as visualized in Figure 2.

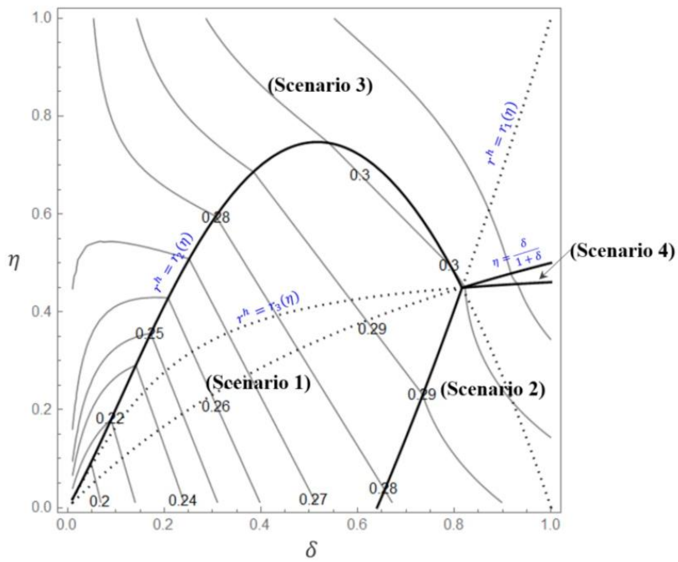
In Figure 2-(a), the isoquant curves in light grey indicate the fraction of irresponsible shipowners in the secondary market, the solid lines represent the thresholds for the transitions among different scenarios, and the grey shaded region shows the situations under which all the shipowners who buy secondary vessels are irresponsible shipowners, with the frontier highlighted in red. We found that, regardless of the level of performance deterioration, at most 50% of irresponsible shipowners among all shipowners will be amplified to at least 80% in the EOL secondary market. These irresponsible shipowners make ship recycling decisions, including where to scrap the EOL vessel. As a result of the amplification of irresponsible behavior, most of the ship recycling decisions are made by the irresponsible shipowners.

Similarly, in Figure 2-(b), the isoquant curves in light gray indicate the fraction of potential owners who invest in secondary vessels. At any given performance deterioration level, the higher the percentage of irresponsible shipowners among all potential owners (η), the greater the fraction of owners who buy secondary vessels.

Figure 2: Contour plot of Suezmax recycling market gray-scale (τ) for sensitivity analysis



(a) Fraction of irresponsible owners in scrap market (τ)



(b) Fraction of owners who buy secondary vessels (y)

CONCLUSIONS

The traditional research in the OM field has focused on the role of Extended Producer Responsibility, since the CLSCs in many sectors such as electronic goods are relatively short and largely driven by producers. In the ship recycling business, the CLSC is long and complicated, exacerbated by the fact that the residual value of a vessel is huge.

In this paper, we conduct a multi-stakeholder analysis to identify the existing problems in ship recycling business. We model the game between two types of shipowners and find that, when the unethical ship recycling yards are willing to provide a higher price than the ethical ship recycling yards, there will be more irresponsible shipowners in the secondary markets, in which EOL vessel owners make decisions on where to recycle the vessel. The responsible shipowners will avoid buying a EOL vessel. These responsible shipowners are the hidden beneficiaries of unethical ship recycling operations through the higher price in the secondary market. This finding has several implications. First, general regulation to enforce industry wide ethical behaviour, by forbidding the unethical option, is not likely to bear fruit, in part because majority of the players in the industry are already responsible operators. A more promising approach is to address directly the (misaligned) incentive of selling to the irresponsible players in the secondary market for EOL vessels. The approach adopted by Shipping Lines like Evergreen - adding a liquidated damage clause into the memorandum of agreement (MOA) to ensure that its buyers will dispose of the vessels in a responsible manner - may be more effective, provided the regulatory framework can be strengthened and the rule of the law can be applied worldwide. At the same time, better communication and monitoring of the situation in hot spots (beaching locations), using remote sensing (e.g., satellite imageries, GIS software), may be effective in deterring the small number of rogue agents from the ecosystem. In this regard, work from NGOs like the Shipbreaking platform and news agency like BBC (see https://www.bbc.co.uk/news/extra/ao726ind7u/shipbreaking) have certainly helped raise the awareness of the severity of the problems. This problem can only be exterminated however when the rest of the shipping community, the responsible shipowners who benefited indirectly from the activities of these rogue agents, start to pay heeds to the long-term consequences of their inaction, and participate aggressively to ensure that their vessels be disposed of by the buyers in an environmentally friendly manner.

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DECISION SCIENCES INSTITUTE
Antecedents and Impact of Business Data Analytics Capability

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ABSTRACT

This study explores possible factors facilitating development of data analytics capability and examines its impact on new product development. Using survey data, this study has tested the validity of the business-organization-technology ecosystem framework for data analytics capability development, and some associated hypotheses. Findings are discussed with respect to theory and practice.

KEYWORDS: Data analytics capability, Data management, Data-oriented business strategy, Open systems culture, and New product development

INTRODUCTION

Research has emphasized the importance of developing a data analytics related capability and demonstrated its positive impact on firm performance (Kamble & Gunasekaran, 2020). But little attention has been directed on exploring factors that lead to the development of such a capability (Jha, Agi, & Ngai, 2020; Sena, Bhaumik, Sengupta, & Demirbag, 2019). Exploring such factors is no less important than showing the impact of data analytics capability, as it will inform firms of how to develop this capability. To address this research exigency, recently Jha et al. (2020), and Vidgen, Shaw, and Grant (2017) collected qualitative data to identify possible factors that may contribute to the development of business data analytics capability (DAC). On the basis of analyzing such qualitative data, Vidgen et al. (2017) proposed a functional model of how firms can promote the development of DAC, which remains to be empirically tested.

The purpose of this study is to test validity of this proposed model by seeking empirical evidence that shows the contribution of data management, data-oriented business strategy, and open systems culture to DAC and then its positive impact on new product development (NPD). We choose to examine DAC' impact on NPD, not just because it is a strong indicator of product performance, but it also showcases the overall competitiveness of a firm, as it involves strategic planning, innovation management, as well as operations and supply chain management. While accomplishing its research objective, this study attempts to make two contributions to the literature: extending data analytics research from examining its impact on firm performance to identifying its antecedents. Thus, in the remainder of this paper, we will first review the relevant literature, then propose some hypotheses, introduce the research methodology, present the data analysis results, and finally discuss the findings.

LITERATURE REVIEW

Two recent studies (Jha et al., 2020; Vidgen et al., 2017) took the inductive approach to explore organizational factors that could possibly facilitate the development of DAC. The use of this approach resulted in emergence of a series of such contributing factors in the two qualitative studies. After several rounds of categorization of these factors and further abstraction, Vidgen et al. (2017) found that these factors reflect and represent three major themes: data/technology, business, and organization, and thereafter developed a framework of coevolving ecosystem in which success in business analytics depends on the interaction and coevolution of these three organizational themes. More specifically, while the data/technology component mainly refers to technology use for data management, the business and organization components can be characterized as data-oriented business strategy and organizational culture respectively. Supporting and enhancing the validity of this framework, Gust et al. (2017) showed that a bottom-up project in a traditional Swiss company, benefiting from transformational changes in and interactions of data/technology, data-oriented business strategy, and organizational culture, successfully seeded data analytics capabilities in their firm. Integrating Vidgen et al. (2017) and Gust et al. (2017), we name the framework for this study as business-organization-technology ecosystem (BOTE) for DAC development.

Conceptual model

In this study we draw on the business-organization-technology ecosystem perspective to propose a conceptual model that consists of five constructs: data management, data-oriented business strategy, open systems culture, DAC, and NPD. The argument inherent in this model is that development of DAC depends on the nourishment of data management, data-oriented business strategy, and open systems culture and DAC plays an important role in NPD. While data management represents the technology component of the BOTE, data-oriented business strategy is the essence of its business part. Open systems culture is then the backbone of BOTE's organization component. Figure 1 below shows the conceptual model. Definitions of these constructs are presented in Table 1.

Figure 1: Conceptual Model

Data management Data-oriented business strategy Open systems culture		DAC		NPD

Table 1: Constructs and Definitions

Concepts	**Definitions**
Data management	Process and capability of building an IT platform and using technologies to access, collect, store, clean, and secure data, as well as to ensure its quality, before it is further processed
Data-oriented business strategy	Organizational guidance for how to use data and analytics to create value
Open systems culture	Organizational culture that emphasizes flexibility and external orientation and therefore promotes values of exploration and creativity, learning and knowledge creation
Data analytics capability	Organizational ability and competence to process various types of data for the purpose of creating value for the organization

New product development	Ability as well as a process of innovatively translating a business idea into a manufacturable product that will generate business value, involving a series of activities such as assessing market opportunities and technical possibilities, building and testing a prototype, and launching it at the market

HYPOTHESES

As defined above, data management is about using technology to ensure data availability, quality, and security. There would be no analytics without data. The case organizations in Jha et al.'s (2020) study reported that a missing of desired results in their analytics projects was due to lack of organized data. Similarly, if data is lost or stolen, either no analysis will ensue, or the value hidden in the data is also stolen even if an analysis can still be performed after the data is stolen. In this sense, data security is an important condition for analytics. Additionally, data quality is critical to success of analytics projects (Kwon, Lee, & Shin, 2014). Further, IT infrastructure, an integral part of data management, is ranked as most important resource to DAC development (Yasmin et al., 2020). More specifically, IT infrastructure enables the application of the mathematical models, statistical methods, and optimization that constitute analytics (Bamel & Bamel, 2021). Thus, data management is a prerequisite to DAC. With this reasoning, we propose the following hypothesis:

H1: Data management is positively associated with development of DAC.

Data-oriented business strategy is one that emphasizes the role of data and analytics in business value creation by the firm. When big data projects are well aligned with business strategy, it facilitates the integration, deployment, and utilization of the soft resources/capabilities (employee big data and analytics skills and knowledge) in the firm, and then benefits firm performance (Akter, Wamba, Narrett, & Biswas, 2019). The data-oriented business strategy enables the firm to align their overall capabilities with their strategic plan. Successful incorporation of this strategy into the organizational routines enhances their DAC in leading companies including Amazon, Dell, Netflix, and Tesco, making it hard for competitors to copy (Akter et al., 2016). Some case studies showed that big data capability is inherently strategic, allowing firms to achieve predetermined goals as well as develop new directions, consistent with the dynamic capabilities theory. Similarly, Grover et al. (2018) conceptualized big data DAC as to create strategic value for firms. This is in alignment with the definition of data-oriented business strategy. Thus, we hypothesize:

H2: Data-oriented business strategy is positively associated with development of DAC.

The analytics literature has already articulated a strong point that in general, organizational culture is important in the process of developing DAC. For example, Dubey et al. (2019) showed that organizational culture shapes how big data analytics influences a firm's supply chain performance. Similarly, Zheng (2005) showed that organizational culture is a key driver in executing organizational capabilities. Likewise, Upadhyay and Kumar (2020) indicated that organizational culture positively influences big data DAC. Ross et al. (2013) argues that success of big data initiatives depends on a data culture, a culture that highly endorses the value of data in the firm. LaValle et al. (2011) attributes failure of big data projects more to organizational culture than data and technology characteristics. Gupta and George (2016) argued that data-driven culture is critical to big DAC.

As specifically for open systems culture, some studies suggested a possible link between it and DAC development. For example, Srinivasan and Swink (2017) found that organizational flexibility worked effectively with DAC in influencing operational performance. Additionally, Dubey et al. (2019) also showed that organizational flexibility, aligned with DAC, enhanced supply chain performance. As shown above, flexibility is a key attribute of open systems culture. Thus, the findings from these two studies at least suggested that open systems culture and DAC are compatible with each other. Given the role of organizational culture in general in shaping DAC discussed above, we could reason that open systems culture may do so as well. This discussion of the literature leads to our next hypothesis:

H3: Open systems culture is positively associated with development of DAC.

The analytics literature has provided enough theoretical explication of why DAC benefits firm performance. According to Kamble and Gunasekaran (2020), theories widely used in the big data analytics literature mainly include the RBV, dynamic capabilities, knowledge-based view, organizational information processing theory, information success theory, among others. The RBV and its extension, theory of dynamic capabilities, have been cited to present the argument that analytics are important resources or capabilities that organizations need in firm performance to keep their competitive advantage. Similarly, the knowledge-based view, organizational information processing theory, and information success theory strongly suggest that data analytics help to produce and process information and knowledge, two types of resources critical to organizational success. Along this same line of reasoning, all these theories point to the possibility that DAC facilitates NPD, a specific indicator of a firm’s operations and supply chain performance.

The relationship between DAC and NPD is not just theoretically made possible. There has been some accumulation of empirical evidence supporting the view that this relationship is likely to happen. First, analytics can be used to collect and analyze customer data to produce customer demand knowledge that is a requirement for NPD. For example, text analytics produces such knowledge through handling online customer reviews (Zhou et al., 2018). Similarly, text analytics and natural language processing can be used to collect and analyze unstructured data to support managerial decision of whether the firm should develop a new product for a new market (Markham, Kowolenki, & Michaelis, 2015). On a more sophisticated level, an analytics infrastructure built on the basis of integrating data collection from a variety of sources and use of advanced analytics techniques helped a leading international Chinese sports equipment manufacturer to identify the best product development processes (Zhan & Tan, 2020). Given such indirect theoretical and empirical support, we here pose our last hypothesis:

H4: DAC is positively associated with NPD.

In addition to these four hypotheses, our literature review also leads to another three hypotheses regarding the mediated relationships between each of the three antecedents and NPD via DAC. Among these three antecedents, data management is a resource that can be directly used in the production process, and therefore can impact performance. However, NPD, even though it is a performance indicator, is a epitome of organizational uniqueness, highly showcasing its differentiation from other firms. Based on the dynamic capabilities theory, dynamic capabilities are firm specific. In light of this, only when data management is fully integrated with other resources and become an integral part of DAC, it will contribute to NPD. This suggests that DAC's role in the relationship between data management and NPD is a full mediation. As for the other two antecedents, they are not operational resources that can be directly used in production. Therefore, DAC fully mediates the relationship between data-oriented business strategy and NPD, and the one between open systems culture and NPD. Thus, the following three hypotheses are proposed:

H5a: The relationship between data management and NPD is positively mediated by DAC.

H5b: The relationship between data-oriented business strategy and NPD is positively mediated by DAC.

H5c: The relationship between open systems culture and NPD is positively mediated by DAC.

METHODOLOGY

A survey was designed to collect data for this study. The measurement scales for the two constructs were adapted from previous studies, with NPD from Swink and Song (2007), Song et al. (1997), and Schoenherr et al. (2014), and open systems culture from Quinn and Spreitzer (1991). We developed the scales measuring data management, data-oriented business strategy, and DAC. The survey questionnaire is presented in the Appendix. Detailed description of the scale development process and that of data collection is provided in the longer version of this paper, but omitted here as the conference paper acceptance policy discourages submission of long papers. For the same reason, we just present the tables here showing the results of validity and reliability tests but not the word description of the test processes.

Table 2: Descriptive Statistics, Loading, Composite Reliability, and Cronbach's Alpha

Latent Construct	Item	Mean	Standard Deviation	Loading	Composite Reliability	Cronbach's Alpha
Data Management	DM1	5.38	0.66	0.55	0.76	0.72
	DM2	5.23	0.78	0.60		
	DM3	4.32	0.81	0.58		
	DM4	5.21	0.87	0.62		
Data-Oriented Business Strategy	DOBS1	5.14	0.97	0.72	0.81	0.81
	DOBS2	5.09	1.02	0.73		
	DOBS3	4.89	0.94	0.73		
	DOBS4	5.05	0.90	0.72		
Open Systems Culture	OSC1	5.50	0.70	0.70	0.77	0.75
	OSC2	4.68	0.85	0.64		
	OSC3	4.89	1.0	0.68		
	OSC4	5.32	0.78	0.67		
Analytics Capability	AC1	5.12	0.92	0.73	0.72	0.82
	AC2	4.99	1.01	0.71		
	AC3	5.06	0.99	0.76		
	AC4	4.94	1.09	0.69		

New Product Development	NPD1 NPD2 NPD3 NPD4 NPD5	5.09 5.18 6.05 4.89 5.19	0.89 0.93 0.91 0.83 0.90	0.63 0.58 0.68 0.72 0.76	0.81	0.80

TABLE 3: Correlations and Average Variance Extracted

	DM	DOBS	OSC	AC	NPD
DM	0.33				
DOBS	0.64**	0.52			
OSC	0.41**	0.49**	0.44		
AC	0.66**	0.66**	0.43**	0.39	
NPD	0.66**	0.64**	0.44**	0.61**	0.39

**: Correlation is significant at the 0.001 level (2-tailed).
Average variance extracted values are printed in diagonal.

Besides those tests whose results are shown in Tables 2 and 3, we also ran a heterotrait-monotrait ratio (HTMT) test (Hensler, Ringle, & Sarstedt, 2015) and found that the HTMT values for all the five constructs were all below 0.85. These results further support discriminant validity of the constructs. Additionally, we used conventionally used methods (Swafford, Ghosh, & Murthy, 2006 for non-response bias test, and Schwarz et al., 2017, and Williams, Hartman, & Cavazotte, 2010 for common-method bias) to address non-response bias and common-method bias concerns and did not find evidence of such bias in our dataset.

RESULTS

We used the structural equation modeling method to test hypotheses of 1, 2, 3, and 4. The structural model test results show that the model has a good fit. The CMIN/DF ratio (=1.96) shows superior model fit. Both the CFI (= 0.92) and TLI (=0.92) values indicate strong goodness-of-fit. The NFI (= 0.85) value is a little bit lower, suggesting acceptable model fit. The RMSEA (= 0.04) suggests superior model fit. Thus, overall, these indicators show a good model fit. Hypothesis 1 indicates that data management positively contributes to DAC. The results show support to this hypothesis ($\beta = 0.67$, $p < 0.0001$). Hypothesis 2 posits that data-oriented business strategy is positively related to DAC. The test results indicate that data-oriented business strategy has a strong positive relationship with DAC. Thus, H2 ($\beta = 0.53$, $p < 0.0001$) is supported. Similarly, hypothesis 3 suggests that open systems culture is positively related to DAC. The results ($\beta = 0.18$, $p < 0.0001$) show that H3 is supported. Further, hypothesis 4 posits that DAC is positively related to NPD. The test results ($\beta = 0.95$, $p < 0.0001$) show that H4 is strongly supported.

The mediation test results are shown in Table 4. Hypothesis 5a states that DAC fully mediates the effect of data management on NPD. The results show that the mediation effect is significant, as 0 does not fall between the lower bound of 0.15 and upper bound of 0.52. Thus, hypothesis 5a is supported. Additionally, the results show that this is a full mediation effect, as data management does not have a significant direct effect on NPD. Hypothesis 5b indicates that DAC fully mediates the effect of data-oriented business strategy on NPD. The bootstrapping mediation test results indicate that this mediation effect is significant, as 0 does not fall between the lower bound of 0.12 and the upper bound of 0.38. Therefore, hypothesis 5b is supported. Further, the results show that this is a full mediation effect. Finally, hypothesis 5c states that DAC fully mediates the relationship between open systems culture and NPD. The bootstrapping test results provide support for this hypothesis, as 0 does not fall between the lower bound of 0.16 and upper bound of 0.49. As hypothesized and confirmed by the results, this is also a full mediation.

TABLE 4: Results of Bootstrapped CI Tests for Mediation Hypotheses

X variable	Mediator	Y variable	Mediation Test (*ab*)			Type of mediation
			Lower bound	Upper bound	Zero included?	
DM	AC	NPD	0.15	0.52	No	Full
DOBS	AC	NPD	0.12	0.38	No	Full
OSC	AC	NPD	0.16	0.49	No	Full

DISCUSSION AND CONCLUSION

The hypothesis testing results indicate that these three antecedents, i.e., data management, data-oriented business strategy, and open systems culture, all positively contribute to the development of DAC. Further, this study also found that DAC then positively influences NPD. Prior research (e.g., Zhan & Tan, 2020; Zhan, Tan, Li, & Tsey, 2018; Zhang & Xiao, 2020) mainly relied on case studies to articulate and support this point of view. This study supplies empirical evidence supporting the positive relationship between DAC and NPD. With these findings, this study made two major contributions to the literature of data analytics research.

The first contribution this study made to the literature is that in joined effort with Jha et al. (2020) and Vidgen et al. (2017), this study helped to broaden the horizon of data analytics research. Prior and current research is still focused on identifying benefits of DAC to the firm. Yet, little is known about how this capability can be developed in firms. Thus, in responding to the call for inquiry into what firms need to do in the development of DAC, this study has helped to fill a research gap in this area. To start with, this study has explored three organizational factors with respect to whether they are conducive to developing DAC. The finding that data management, data-oriented business strategy, and open systems culture, all help to foster the growth of DAC encourages continuous research to reveal other factors that may serve this purpose.

Secondly, and most importantly, this study contributed to theoretical development in data analytics research. The inquiry into what helps the development of DAC is in an initial stage and therefore badly in need of theoretical input. In light of Vidgen et al.'s (2017) business-organization-technology ecosystem perspective, this study theorized that materializing the three components of the ecosystem in that order, data management, data-oriented business strategy, and open systems culture constitute an ecosystem that would favor the growth of DAC. The findings of this study that all these three factors positively contribute to the development of DAC provided empirical support to this newly proposed theory. Thus, this study can be viewed as an encouragement to continuous theory development that will enable deductive or empirical research in this area, which is currently mostly inductive.

Besides these theoretical contributions, this study also generates important implications for practice. First, this study informs organizations of the power of DAC in NPD. Besides using big data as inputs for NPD ideas, organizations can further explore how DAC will benefit their NPD process, as this developed dynamics capability is more powerful and comprehensive than simply one resource, i.e., big data. Second, the findings of this study can guide organizations in developing their own DAC. Specifically, they should develop and implement a data-oriented strategy, foster growth of an open systems culture, and invest in data management technology. With an open systems culture, organizations would encourage organizational learning, promote exploration activities, and then emphasize the role of knowledge making in business value creation. Doing that, they are more likely to formulate a data-oriented business strategy, which then requires them to invest enough in data management technology. It can then be expected that a DAC will spiral up from efforts in these three directions.

Despite these theoretical and practical contributions, this study has some limitations inherent in its design, which may dampen the generalizability of its findings. The survey method enabled us to collect data from a wide variety of firms, but it was just cross-sectional. The findings only captured a snapshot of the development of DAC in these firms. Future research should collect time-series data which will make the findings more valid as such data are more appropriate for showing the process of developing DAC in firms. Additionally, the theoretical model adopted in this study could have been constructed with a stronger foundation. This line of inquiry into how organizations can develop a DAC was still at the initial stage when this study was performed. Thus, it relied on a limited number of inductive studies for its theoretical inspiration and development. Future research should examine more such studies that will emerge in the literature so as to enrich and solidify the concepts constituting the theoretical model.

Appendix: Survey Instrument

Codes	*Questionnaire Items*
	Data Management (DM)
DM1	We are able to identify sources of data that meet our needs.
DM2	We are able to collect data that meet our needs.
DM3	We are able to store large volumes of data.
DM4	We are able to process data with a fast speed.
	Data-Oriented Business Strategy (DOBS)
DOBS1	We rely on data to identify new business opportunities.
DOBS2	We rely on data to develop new products.
DOBS3	We rely on data to enhance our innovativeness.
DOBS4	We rely on data to formulate our business strategy.
	Open Systems Culture (OSC)
	Please assess each of the following items with regard to how they are valued in your organizational culture:
OSC1	Innovation and change
OSC2	Creativity
OSC3	Flexibility, decentralization
OSC4	Expansion, growth, and development
	Data Analytics Capability (DAC)
AC1	We are good at data analytics which is mainly data mining and statistical analysis.

AC2	We are good at text analytics that deals with unstructured textual format data.
AC3	We are good at web analytics that deals with web sites.
AC4	We are good at mobile analytics that deals with mobile computing.
	New Product Development (NPD)
NPD1	We have developed new products that offer some unique features to the customer.
NPD2	We have developed new products that superbly meet customers' needs.
NPD3	We have developed new products that are of high quality.
NPD4	We have developed new products that have superior technical performance.
NPD5	We have developed highly innovative new products.
	Control Variables
Industry	Your company is ______________________ industry.
Organization size	How many employees does your company have? __________________

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Applying Group Concept Mapping to Determine Leading Management Practices Enhancing Sustainability in Industrial Supply Chains

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ABSTRACT

Supply Chain leaders and experts in various industrial supply chains operating within different segments of the end-to-end industrial supply chain are asked about their observations of specific management practices across the supply chain and their impact on enhancing the overall Sustainability of the \supply chain. Using concept mapping techniques, a hierarchy of practices are proposed across the end-to-end value chain and hypotheses are developed about achievability and impact on sustainability over time.

KEYWORDS: Sustainability, Green Supply Chain Management, Group Concept Mapping, Management Practices

INTRODUCTION

The problem of global sustainability is, in many ways a supply chain issue and requires supply chain-based solutions. This is for three reasons (Erkman 1997). Firstly, human industrial infrastructure and the broader biosphere are an integrated, system; Secondly, industrial systems are not just economic, consisting of currency flows, but are also physical, consisting of biophysical material flows; Thirdly, a Sustainable or Green supply chain recognizes the role of technology, among other factors, in playing a vital role in transitioning to a sustainable industrial system.

Furthermore, in a world where interconnected global trade has completely decoupled means of production and consumer demand, environmental impacts continue to increase at an ever-increasing rate (de Oliveira et al, 2018). As a result, more and more companies are asked and expected to come up with solutions to the ecological and human toll imparted by the system that provides the global community with increasingly sophisticated daily needs

When defining the scope of Green Supply Chain Management (GSCM), it is important to consider a variety of perspectives (de Oliveira et al, 2018). To do this we will rely on several definitions. An end-to-end view of supply chain activities is considered (Srivastava 2007), (Min & Kim, 2012). These definitions cover a functional perspective examining key organizational activities critical to product fulfilment including product design, procurement, manufacturing, packaging, logistics and end-of life management. These definitions provide solid basis for our research because they focus on the biophysical flows of a supply chain.

Definitions which focus beyond the functional activities of a single organization includes (Vachon & Klassen, 2006) and (Sarkis, 2012), emphasizing moreover the decentralized nature of multiple complex actors in the form of more than one company, are a necessary criterion when defining the modern supply chain. In this way we can think of Green Supply Chain Management as somehow dealing with an integrated system rather than a standalone entity.

It may also be helpful define green supply chain in a more entrepreneurial and holistic view in terms of how a Green supply chain can manage supply chains for non-traditional business models, and products and in non-traditional environments, such as emerging markets (Adel, 2021). This range of definition and perspectives may be of consequence when considering the diverse range of potential causes and solutions for mitigating environmental impacts by designing and deploying GSCM practices.

One challenge which a review of the literature indicates is how to combine both ways of deploying GSCM practices while also finding way to overcome many and varied barriers to implementation (de Oliveira et al, 2018). To address the problems the research will address the following questions:

- What are the specific activities within end-to-end supply chains which cause the most impact on the environment?
- What are the root causes of these activities which in many cases may be indirectly linked to environmental impact?
- What are the linkages between observable direct causes and the root, or indirect causes, which create causal loops or feedback loops?
- How can companies create action plans to influence these identified causal loops in order to reverse, reinforce or balance the behaviour of these loops and therefore increase or mitigate their environmental impacts?
- How do existing Supply Chain Management techniques such as Lean and Technology solutions like Digitalization play a part in the potential solutions?
- Are these approach and solutions capable of meeting the challenge?
- If they are not enough, are they a prerequisite?
- How can the deployment of solution be measured to ensure positive results and expected outcomes?
- What are the potential obstacles to the solutions coming from the divergent group of stakeholders which a typical complex supply chain inevitably encounters?

By conducting the reach which answer the above questions our aim is to fulfil several primary and secondary objectives:

Primary objectives

- Define and map the domain of critical activities in the end-to-end manufacturing supply chain which impact corporations’ ability to be environmentally sustainable and improve sustainability performance.
- Understand the root cause of unsustainable activities within corporations’ supply chains contributing to the myriad of specific environmental problems.
- Analyse the relationships and feedback loops of activities and flows which reinforce behaviours and their outcomes related to environmental sustainability.

Secondary objectives (possibly for future research):

- Identify potential solutions which can be deployed to allow organizations to change, transform, and transition their supply chain activities to become environmentally sustainable.
- Develop realistic ways of measuring progress and impact of implemented solutions.

- Identify barriers to deploying solutions including perverse incentives, the costs and benefits, and impacts upon different stakeholder groups and their level of influence.

LITERATURE REVIEW

The history of GSCM is rooted in the area of industrial ecology gaining traction in the 1960s and 1970s. (Lamming & Hampson, 1996) link environmental issues to key Supply Chain Management concepts including the purchasing function, quality management, Lean Manufacturing strategies, and collaborative approaches to managing business relationships. Conclusions from this study suggest Supply Chain Management will benefit from considering environmental factors as the world - including consumers, governments and business - demand more environmentally friendly products, increased accountability, and better management practices.

The concept of Lean as a potential supply chain tool with positive externalities or spillover effects for environmental performance appears in the literature consistently, if not extensively for over 10 years (Hart, 1995). Strong empirical evidence linking Lean Manufacturing as a specific Supply Chain Management tool to environmental performance has gained traction starting early this century (King et al, 2001). By using ISO 9000 as a proxy for Lean management, and ISO 14000 as a proxy for improved environmental performance, a clear link between Lean and Green has been empirically demonstrated (Rondinelli and Vastag 1998). Potential limitations of such studies, however, include the lack of contextual insight into the direct impact of specific supply chain management practices such Lean implementation, and explicit environmental goals.

Rao (2004) has suggested Lean management can be effective as a specific supply chain tool to reduce energy usage, material usage, pollution, and improve water conservation in the context of manufacturing in the South East Asia region of the world. Similarly, Sarkis and Zhu (2004) demonstrate a number of positive relationships between Lean management practices and environmental performance for Chinese companies. Empirical methods in both these studies build on the more qualitative nature of earlier studies. However, the regional focus of these studies leaves gaps with respect to both the general applicability of Lean, as well as for other geographic regions such as Central and Eastern Europe.

Klassen (Linton et al, 2007), in extending the view of green Supply Chain Management to include collaboration and integration with suppliers and customers, references Lean as an important supply chain strategy to address concerns of stakeholders with respect to internal operations. However, Lean is not considered as a key element in improving environmental performance, either in terms of strategic policies, which encompass decisions around technology, or tactical applications such as the management of logistics operations.

THEORETICAL DEVELOPMENT AND METHODOLOGY

Our research on identifying activities and root causes and overcoming barriers to be able successfully deploy GSCM solutions uses a “structured conceptualization” methodology. called concept mapping or group concept mapping (GCM). Group concept mapping is a structured methodology for organizing the ideas of a group on any topic of interest and representing those ideas visually in a series of interrelated maps (Kane and Trochim 2007). It is a type of integrative mixed method (Caracelli and Greene 1993) combining qualitative and quantitative approaches to data collection and analysis. Group concept mapping allows for a collaborative group process with groups of any size, including a broad and diverse array of participants.

Research Approach

The GCM process can be described as a sequence of concrete, operationally defined steps that yields a conceptual representation (Trochim and Linton, 1986). Conceptualization refers to the articulation of thoughts and ideas that are represented in some objective form. Based on Trochim and Linton’s (1986) early work, we use one specific type of structured conceptualization process, “concept mapping” (Trochim, 1989a; 1989b; 1989c; Trochim et al., 1994). In concept mapping, ideas are represented in the form of a picture or map. To construct the map, ideas first have to be described or generated, and the interrelationships among them articulated. Multidimensional scaling and cluster analysis are then applied to this information and the results are depicted in map form. The content of the map is entirely determined by the participants. Participants brainstorm the initial ideas, provide information about how these ideas are related, interpret the results of the analysis, and later decide how the map is to be utilized.

Concept mapping has been successfully deployed in previous papers with similar context, for example exploring systems related to environmental sustainability (Rondinelli and Vastag, 2000), quality performance within a complex supply chain (Ladinig and Vastag, 2021) and the implementation of green supply chains (McDaniel and Vastag, 2010).

Concept mapping brings several advantages. It provides a method to objectively articulate a large number and broad range of thoughts and ideas from a diverse group of experts (Trochim and Linton, 1986). It successfully enables a holistic visualization of a “complex, causally ambiguous” system (Ladinig and Vastag, 2021). This is important because it allows for rigorous cluster analysis through the grouping of independent ideas into similar clusters and the development of common themes from which insights and conclusions can be developed. Concept mapping is also well suited for analyzing practical, highly relevant case examples in real time and has demonstrated in previous research to be objective and empirically sound.

How the concept map was created

The GCM has been applied to identify management practices either used or observed with in an industrial supply chain which either and enhance or limit industrial value chain to become sustainable. It should be noted that this paper will present the preliminary results of the study as the complete data set is not complete. The study has enrolled eight participants. All eight participants have contributed to the initial phase of the experiment, a on hour brainstorming to develop the list of statements. The second phase of the experiment, the sorting of statements into groups or clusters, and the rating of the statements based on tow criteria; 1) ease of implementation, and 2) impact of the solution is has only been partially completed. As such this paper will present preliminary results. Full results and paper based on these are expected in July 2022.

Step 1 of the research was to develop the detailed design of the research program. This consisted of consultation between the co-authors to make key decisions regarding the structure and the number of participants within the group of individuals, the types of industries and organizations which the individuals represent, as well as the different functions within the end-to-end supply chain and the specific parts of the value chain the individual participants will contribute with their specific experience and expertise.

While initially the approach was to target one specific enterprise and select stakeholders across the different activities making up the end-to end supply chain, it was ultimately decided to select individuals across several enterprises representing different industries. This approach was for several reasons. Firstly, access to a group of individuals representing the end-to-end supply chain was far more accessible from different representative organizations than from one single enterprise. Secondly a broader selection of individuals from different enterprises and industries would represent a wider more general viewpoint and therefore a wider, more general applicability of conclusions with potential for greater relevance to a broader population of enterprises and industries. Finally, by selecting individuals from multiple organization it would help to ameliorate any bias towards practices, experience or observations that might be driven by a single enterprise in a single industry.

Selection of participants was organized in such a way to ensure critical criteria were met to develop meaningful input to the concept. In this regard the co-authors selected criteria based on functional expertise, industry, years of experience, geographical location and area or segment of the supply chain or value chain applicable to manufacturing companies. For Step 1 eight participants agreed to be interviewed and complete the necessary steps for data completion.

Step 2 of the research consisted of developing the specific statements from the appropriate set of individuals. To ensure a representative sample eight individuals were recruited based on their level of expertise (defined as more than 15 years of experience in a particular industry ore role), representation along key parts or segments of the value chain or supply chain (1. Raw material extraction and processing 2. Value added manufacturing 3. Sales & distribution 4. After sales service and delivery).

As part of the recruiting process individuals were sent a brief presentation outlining the research aims, the general instructions and the requirements of their involvement. Once participants were enlisted a common point of entry into the research was created to ensure a common starting point, eliminate any bias and ensure all participants had a common understanding of GSCM. For this purpose, a presentation about GSCM and Sustainability concepts was created, which also establish the objectives of the study to identify practices which help or limit a value chain to become sustainable. Participants scheduled two, one hour interview sessions. In the first session the participants were asked to brainstorm statements by competing a focus prompt: . . . *“A specific management practice either enhancing/limiting industrial value chains to become sustainable is . . .”*.

To aid in the brainstorm we used a mind mapping template and an online tool, Miro, to aid with the prompt and the brainstorming. Additionally, it was emphasized that the ideas should be generated in the widest possible context and that no ideas were considered off-limits. Participants were explained there would be a process of cleaning data in later stages of the research. After the initial brainstorming with participants and cleaning of the statements for basic grammar and meaning and clarification there were 123 statements generated. A second round of data cleansing was conducted focusing in eliminating duplication of ideas which resulted in a final list 86 statements. Statements were numbered such that it could identified at each stage of the research. For Step 2 eight participants were interviewed and contributed statements as part of the initial brainstorming. The 86 statements are listed in the Appendix.

Step 3 of the research focuses on creating and assessing the clusters. To conduct this step the combined list of 86 statements was sent back to all participants with a request to check for overlaps and correct wording and to add new statements if necessary. The final list of 86 statements was confirmed and agreed by all participants. These statements, describe the conceptual domain for specific management practice enhancing/limiting industrial value chains to become sustainable.

During the second interview participants examined how these statements, are related to each other using an unstructured card procedure (Rosenberg and Kim, 1975; Weller and Romney, 1988). All participants received both an excel spread sheet and a set of virtual post-it notes with the online tool, Miro, where a virtual whiteboard was made available for each participant with the same 86 statements written on them. Participants were then asked to sort the cards into piles "in a way that makes sense to you."

At the same time participants were asked to rank each of the statements twice using a 5-point Likert scale. The first ranking was based Ease of implementation: "relative to the other practices mentioned, how easy is it to implement this practice (where 1 is NOT very easy and 5 is VERY easy)". The second ranking was based on the impact of the solution/constraint: "relative to the other practices mentioned, what is the impact in terms of achieving Sustainability, if a company were it to implement/eliminate this practice (where 1 is NOT very impactful and 5 is VERY impactful)". The timing Step 3 is such that the fill results are not complete. At the time of this submission five of the eight second interviews are complete, four of eight rating are complete, and two of the eight pairwise clusters have been processed to empirically identify closeness between participants. We anticipate all eight participants will complete the full set of interviews and feedback and that a full analysis will be completed by July/August 2022.

Step 4 of the research is the analysis. Based on the sorting results, for each participant a binary symmetric matrix of similarities was formed; if statements i and j were placed in the same pile by participant k then the appropriate cell of the matrix is 1, otherwise it is zero. By adding up the individual matrices of similarities, the total similarity matrix was computed. At this stage this process has been completed for two of eight participants. The total similarity matrix was the input to a two-dimensional non-metric MDS (multi-dimensional scaling). Trochim (1989a) argued, referring to Kruskal and Wish (1978) that "Since it is generally easier to work with two-dimensional configurations, ease of use considerations is also important for decisions about dimensionality. For example, when an MDS configuration is desired primarily as a foundation on which to display clustering results, then a two-dimensional configuration is far more useful than one involving three or more dimensions." This analysis placed those statements that were piled together more often closer to each other in the two-dimensional space.

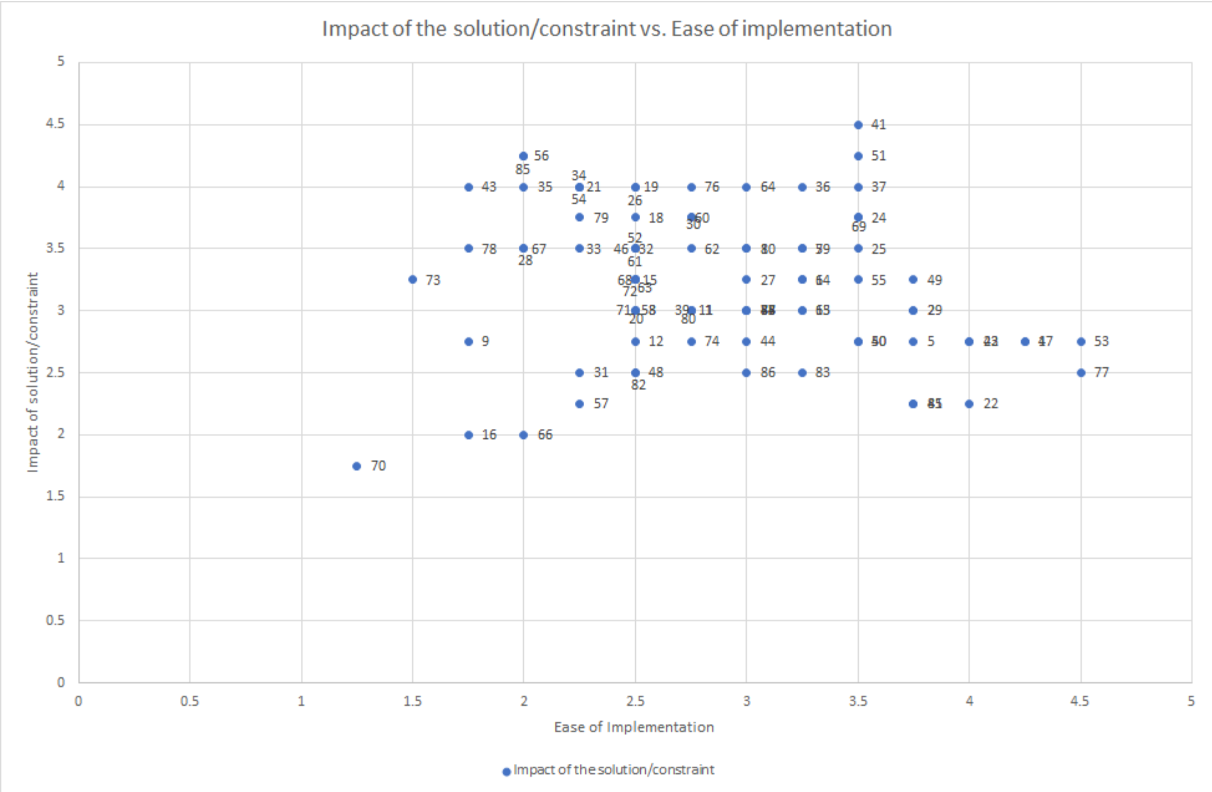
This will create a "point map," which can be shown to display the location of all brainstormed statements as dots on a page. Dots or ideas that are closer to each other generally are expected to be more similar in meaning.

Step 5 of the research is the evaluation of the results. At this stage of the research only 2 of the 8 participants have completed the sorting process so we are unable to show the visualization of the diagrams and interpret them. The result of the MDS process -- the two-dimensional configuration of statements – will provide the input for the hierarchical cluster analysis. The objective of this analysis will be to group individual statements on the map into clusters of statements, which presumably reflect similar concepts (Trochim, 1989a). We will generate several cluster solutions and the participants will reach a consensus on the “best” one. Their decision will be based on close examination of the statements that will be grouped together at that solution; the group will provide feedback whether it makes sense for them or not. The consensus “cluster map,” will then be created, it is expected to consist of between six to ten clusters and to show how the specific ideas can be grouped into more general clusters or concepts. We will show a visualization of how the original statement points enclosed by polygon shaped boundaries for the seven clusters.

RESULTS

The preliminary results were not enough to yield a full MDS or HCA map from which to interpret conclusions. However, based on the limited response we were able to visual, in a scatter plot, the rating of all the individual statements. This is presented below in Figure 1. While this does nor provide a rigorously empirical result it can be seen as a useful preliminary observation.

Figure 1: Impact of the solution/constraint vs. Ease of implementation



As a preliminary result what may be interesting is to examine two groups; 1) the high impact/ high ease of implementation group, defined as any points with a 3.5 and greater rating for both impact and ease of implementation, and 2) the low impact/low ease of implementation group, defined as any points with a 2.5 and lower rating for both impact and ease of implementation. This is depicted below in Figure 1.

Table 1: Comparing Quadrants based on high/low Impact vs. Ease of Implementation

Quadrant	Identifier	Statements	RIR*	REoIR**
High Impact/High Ease of Implementation	41	Recycling and reuse of materials	3.5	4.5
	51	Moving back to remanufacturing products due to cost & availability reasons	3.5	4.25
	37	Incentivizing employees to practice sustainable procurement	3.5	4
	24	Nurturing a collaborative mindset that promotes business people/functions and sustainability people/functions working together	3.5	3.75
	69	Regular assessments & audits of suppliers	4	4
Low Impact/Low Ease of Implementation	31	Promoting a Connected Farm/Connected supply chain which uses resources more efficiently	2.25	2.5
	48	Reducing weight of our products by redesigning parts with less weigh so less fuel is consumed	2.5	2.5
	82	Sustainability goals that impact or correspond very broadly to many individual jobs	2.5	2.5
	66	Packaging standards which incentivize producers NOT to use GMOs	2	2
	57	Investing in safety, both for employees, and in our products to provide safety to customers	2.25	2.25
	70	Eliminating GMO based food products despite the costs of doing so	1.25	1.75
	16	Using promising new technologies which are still immature or in initial phases of development	1.75	2

Note: Ratings based on a five-point scale, * Relative Impact rating, ** Relative Ease of Implementation rating

DISCUSSION AND CONCLUSIONS

Based on preliminary results and with out the benefit of the MSD based Hierarchal cluster analysis (HCA) it is difficult to make preliminary conclusions. Nevertheless, themes do emerge, based on the specific individual statements, however it is too early to draw conclusions without the quantitative and empirical analysis. With the MDS analysis the statements and their closeness can be clustered and empirically calculated clusters which can be named and validated by the group consensus will emerge in a final format.

APPENDIX

	Statement	Ease of implementation rating	Impact of the solution/constraint rating
1	Using 3D printing to print parts at the customer to reduce transport and fuel consumption	2.75	3
2	Supplying information in a timely manner to support sustainability practices	3.75	3
3	Eliminating consumables which are contaminated with non-recyclable elements, toxins, etc.	2.5	3
4	Employee benefits program which supports/encourages Sustainable commuting (e.g., EV charging points made available)	4.25	2.75
5	Using diversity programs to drive awareness of ESG practices through better reporting making companies more desirable to work with	3.75	2.75
6	Using ISO 14001 to ensure compliance to Sustainable Supply Chain standards	3.25	3.25
7	Using equipment (e.g., refrigerators in supermarkets) with sensors to save energy as well as money	3.25	3.5
8	Product distribution approaches which use Rail (more local) vs. Air (e.g., overseas, China, etc.)	3	3.5
9	Not putting undue economic pressure on our suppliers	1.75	2.75
10	Remanufacturing in all product lines	3	3.5
11	Implementing circularity in our supply chain processes resulting in more efficient material usage and remanufacturing	2.75	3
12	Promoting supply chain solutions to manufacture products based on renewable energy	2.5	2.75
13	Strictly following-up on company performance targets	3.25	3
14	Compliance to relevant regulations for electronic waste	3.25	3.25
15	Sustainable farming which uses sensors to analyze soil and weather enable more efficient production using less water	2.5	3.25
16	Using promising new technologies which are still immature or in initial phases of development	1.75	2
17	Creating awareness: e.g., the CEO has declared Sustainability aligns with company vision and "must win battles"	4.25	2.75

18	Using software (Eco Vadis) to screen suppliers based on sustainability criteria and ensure compliance to code of conduct and sustainability criteria, Health and Safety criteria, and circularity of supply chain	2.5	3.75
19	Investing in Green infrastructure e.g., green warehouses and facilities which use renewable energy, water recycling, automated lights, waste recycling	2.5	4
20	Product development practices & processes which supports sustainable Transport	2.5	3
21	Designing products that use renewable energy	2.25	4
22	Renewable initiatives driven by salespeople - via regulars monthly brainstormings	4	2.25
23	Valuing 'Fairness' to stakeholders including communities, suppliers, etc.	4	2.75
24	Nurturing a collaborative mindset that promotes business people/functions and sustainability people/functions working together	3.5	3.75
25	Establishing sustainability criteria for decision making in different functions and departments, for example procurement	3.5	3.5
26	Creating a sustainability culture	2.5	4
27	Eliminating the use of unsustainable packaging to meet consumers demand for convenience	3	3.25
28	Deploying Sustainable mining practices	2	3.5
29	Considering Sustainability targets in every target setting group or department	3.75	3
30	Increased us of sustainable packaging to meet consumers demand for reusability and recyclability	2.75	3.75
31	Promoting a Connected Farm/Connected supply chain which uses resources more efficiently	2.25	2.5
32	Management behaviors leading to responsible choices such as replacing road transport with rail transport	2.5	3.5
33	Innovation and design mindset that promotes the idea that innovation and Sustainability work together	2.25	3.5
34	Eliminating the inefficient processing of returned materials - e.g., burning motherboards for gold - leads to pollution	2.25	4
35	Making [sustainable products, e.g.] battery electric vehicles (BEV) a priority	2	4

36	Certifying not only your own suppliers but also that your suppliers' suppliers are compliant to Sustainability practices	3.25	4
37	Incentivizing employees to practice sustainable procurement	3.5	4
38	Implementing systems which allow our Parts & Services division to know; where the equipment is located / what phase of the life cycle it is in / customers' demand for parts and services	3	3
39	Using Sustainable labelling Initiatives like fair trade /eco rating / FSC labels, etc.	2.75	3
40	Incentivizing the use of EV (electric vehicles) for salespeople	3.5	2.75
41	Recycling and reuse of materials	3.5	4.5
42	Target setting for Sustainability in a top-down way, to all departments, individual ratings and compensation	4	2.75
43	Eliminating plastic materials due to plastic waste which is difficult and expensive to recycle	1.75	4
44	Certifying supply chains to become sustainable	3	2.75
45	Prioritizing battery electric vehicle (BEV) products to encourage less energy consumption during use	3.75	2.25
46	Digitalization, which can help replace parts with less down time, less materials consumption, less space, energy and fuel	2.5	3.5
47	Creating Sustainability policies that go "beyond compliance"	3	3
48	Reducing weight of our products by redesigning parts with less weigh so less fuel is consumed	2.5	2.5
49	Building Sustainability into the corporate mission	3.75	3.25
50	Creating awareness or understanding of cost/benefits or trade-offs from using Sustainable Procurement approaches	3.5	2.75
51	Moving back to remanufacturing products due to cost & availability reasons	3.5	4.25
52	Sustainable procurement practices which lead to better relationships with farmers which promotes more sustainable practices at the local level	2.5	3.5
53	Having a goal to reduce CO2 significantly in the next decade	4.5	2.75
54	Reducing JIT delivery practices which rely on air transport (less sustainable) vs rail transport (more sustainable)	2.25	4

55	Management behaviors leading to responsible choices such as increased use of renewable energy	3.5	3.25
56	Processing and reusing electronic waste	2	4.25
57	Investing in safety, both for employees, and in our products to provide safety to customers	2.25	2.25
58	Deploying additive manufacturing (3D printing) which can drive sustainable approach by reducing need of steels	2.5	3
59	Sustainable procurement practices ensuring recyclable steel or other recyclable components	3.25	3.5
60	Investing in fuel efficiency for our products and our customers	2.75	3.75
61	Supporting suppliers in their target setting and implementation	2.5	3.5
62	Actively seeking to reduce the carbon footprint of the supply chain - mainly for financial reasons	2.75	3.5
63	Sustainable procurement which uses less water in the product	2.5	3.25
64	Investing in technologies to measure and reduce carbon footprint	3	4
65	Using KPIs which are connecting business to sustainability	3.25	3
66	Packaging standards which incentivize producers NOT to use GMOs	2	2
67	Eliminate a centralized manufacturing strategy which creates more transportation for distribution of vehicles, parts and survives	2	3.5
68	Prioritizing battery electric vehicle (BEV) products to promote cleaner air in a mine, e.g., less pollution and greater health & safety, less energy during use	2.5	3.25
69	Regular assessments & audits of suppliers	3.5	3.75
70	Eliminating GMO based food products despite the costs of doing so	1.25	1.75
71	Creating a company culture based on Sustainability, by creating and documenting behaviors, training, etc.	2.5	3
72	Product design processes incentivizing refurbishment or Design for disassembly	2.5	3.25
73	Fostering a mentality and culture which incentivizes investment and innovation and moves away from being cost conscious	1.5	3.25

74	Using equipment (e.g., pipe cleaning in pubs necessary for brand attributes) with sensors to save, energy money	2.75	2.75
75	Participating in the Dow Jones Sustainability index in order to enforces accountability on companies to meet Sustainability KPIs from fund managers	3	3
76	Eliminating unsustainable raw materials for food products, like palm oil, which are cheap	2.75	4
77	Communicating and prioritizing Sustainability messages in standard and high-profile communications	4.5	2.5
78	Eliminating products, even if they are profitable, which rely on unsustainable mining practices	1.75	3.5
79	Designing products for a long life	2.25	3.75
80	Procurement practices using Sustainability certification and Traceability	2.75	3
81	Strictly following-up on performance targets of suppliers	3.75	2.25
82	Sustainability goals that impact or correspond very broadly to many individual jobs	2.5	2.5
83	PR and business values based on "being green"	3.25	2.5
84	Procurement practices actively seeking out local packaging solutions	3	3
85	Eliminating or reducing significantly procurement and outsourcing to LCCs (low-cost countries) which leads to long transport routes and less compliant policies for people and the planet	2	4.25
86	"Walking the walk" and not just "talking the talk"	3	2.5

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DECISION SCIENCES INSTITUTE

Are Business School Executive Education Programs Meeting the Training Needs of Today's Digital Supply Chain Employees?

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ABSTRACT

Digital technologies are being widely adopted to support supply chains, but employees often lack the skills needed to use them effectively. This study examines the extent to which business schools are meeting the supply chain training needs of corporate employees. Findings indicate that, although preferences for short, online, customized, flexible courses have been built into executive education programs, many critical digital supply chain topics are not being covered.

KEYWORDS: Supply chain, digital technology, eLearning, executive education

INTRODUCTION

Supply chain transparency, visibility, control, efficiency, and supplier and customer relationships, which were key make-or-break issues even before Covid-19, are even more important in the post-pandemic world (SupplyChainGameChanger.com, 2021; Khan, 2021; Dunakin, 2021). MIT's David Autor called the pandemic an "automation-forcing event", because companies rushed to adopt digital technologies that would enable them to remain engaged and connected remotely with their many stakeholders" (Leeson, 2020, p. 1; KPMG, 2020). At the same time, the need for supply chain employees with the skills to use them effectively has grown steadily over the past few years (Berry & Mok, 2018; Gonzalez, 2019; Volzer et al., 2019; Kenco, 2020; Committee for Economic Development, 2020), making upskilling and reskilling current supply chain employees an area of serious concern.

In a previous study, the adoption and use of digital technologies that are transforming supply chains was examined in a specific region in Southern Indiana and Northern Kentucky (Foroughi, 2021). Also of interest in the study was the level of employee technical skills and openness to training that a local college of business school, the Romain College of Business (RCOB) at the University of Southern Indiana, could offer, and the types of formats that would best serve employees (usi.edu/business/). The study identified a gap in the skills employees need to successfully implement digital technologies. At the local level, regional manufacturing industry is strong and increasingly automating processes (Whiteside, 2021). However, at the same time, current manufacturing employees lack the skills they need to transition to a digital workplace, the future workforce is not being adequately prepared for success in the digital workplace, and many employees risk losing their jobs to changing workplace skill needs (Whiteside, 2021). This same technology skill gap is being experienced by companies around the country, as is the urgent need to upskill and reskill employees (Binvel et al., 2018; Smith, 2020; ManpowerGroup, 2022). Also revealed in the previous study was a strong interest in technology training provided by the RCOB. The results also provided insights about the learning needs and expectations of today's employees and pointed to major adjustments colleges of business must make in order to remain competitive in the increasingly crowded eLearning market. The need for colleges of business to remain relevant to employers and employees seeking technology training is a

serious, widely experienced issue that is discussed in the media as well in academia (Binvel, et al., 2018; Krishnamurthy, 2020; Kaplan, 2021; Schlegelmilch 2020; ManpowerGroup, 2022).
The current study examines the extent to which colleges of business across the country are taking measures that will enable them to continue to be relevant as sources of technology training for employees around the country. The results will serve to guide efforts to further develop executive education programs offered at the RCOB.
In particular, the study seeks answers to the following questions:

1. What are the specific supply chain digital technology training needs and expectations of today's companies and employees?
2. To what extent have colleges of business made or begun to make the changes necessary to serve the digital supply technology training needs of today's companies and their employees?

The paper begins with a discussion of technologies recognized as transformative for supply chains, the need for digital technology training, the changing landscape of eLearning, and insights from survey studies; followed by the research methodology, results, discussion, limitations, conclusions, and future research directions.

LITERATURE REVIEW

Digital technologies that are transforming supply chains

For the past several years, the MHI & Deloitte Annual Industry Report has been following the adoption of the following technologies and their potential to disrupt or create competitive advantage for supply chains (MHI & Deloitte, 2022).
Robotics and automation are used for routine, manual tasks such as picking, packing, inspecting, classifying, and sorting orders; loading, unloading, and stacking; receiving and put-away; assembly operations; and processing such as welding, painting, and cutting.
Autonomous, self-driving vehicles equipped with sensors can provide data about the environment around them, work together to complete tasks, and provide visibility along the supply chain (Treblicock, 2018; McKinsey & Company, 2018; MHI & Deloitte, 2019, 2020, 2021, 2022; Banker, 2020).
Predictive analytics uses statistical models, data mining, and machine learning techniques to provide insights about data provided by digital supply chains and to identify the likelihood of future outcomes based on historical data. Predictive analytics analyzes datasets of large size, real-time or near real-time data which are often unstructured and derived from crowdsourcing, Internet applications, direct from customers at point of sale, and other sources (Ellis & Santagate, 2018; Benaddi, 2020; RiverLogistics; N-iX, 2021).
The Internet of Things refers to physical devices, vehicles, home appliances, and other items that are embedded with electronics, software, sensors, actuators, and network connectivity that enable them to connect and exchange data (Deloitte Development, 2018). IoT makes it possible to access or control remotely located objects across the supply chain, and facilitates real-time analytics, customer/market insights, customer and/or supplier collaboration, quality control, streamlined production, AI and machine learning, and temperature/humidity monitoring (MHI and Deloitte, 2021; Lund et al., 2019; Meola, 2021).
Automatic sensory and identification technologies enable robots to sense, identify, and react to, other devices (Deloitte Development, 2018; Lund et al., 2019; Odum, 2019; Ansari, 2021).
Global Positioning Systems (GSPs) receive signals from GPS satellites that enable calculations of an object's position and time, enabling the identification of the exact location of tagged items.
Real-Time Locating Systems (RTLS) can identify and track the location of objects within a building or other enclosure, track products and supplies through an assembly line, locate pallets

in a warehouse, track temperature and humidity, and send them to the supply chain cloud (Sainathan, 2018; Ansari, 2021; One Network Enterprises, 2021).
Inventory optimization tools provide efficient and effective management of inventory throughout the supply chain, resulting in minimal cost for holding and storage (MHI and Deloitte, 2020). Mathematical algorithms determine the most probable excess stock level and shortage level, helping a company achieve multi-echelon inventory optimization, cost-effective postponement strategies, stock keeping unit rationalization, optimization of inventory components, enhanced supplier intelligence, demand forecasting and planning, and Just-in- Time (JIT) strategies (MHI & Deloitte, 2019; DNSStuff.com Staff Contributor, 2021; Miller et al., 2021). Network optimization tools use mathematical modeling to reduce supply chain network complexities and optimize asset locations across the supply chain. Enterprise priorities and supply chain competencies in all areas of the supply chain network (sourcing, inventory, transportation, warehousing) are identified, prioritized, and mapped (Lund et al., 2021; Miller et al., 2021).
Artificial intelligence combines several types of other technologies in the simulation of human intelligence and the rapid solution of complex problems: machine and deep learning, reasoning, voice recognition, augmented reality, cognitive computing, natural language processing, and translation. AI systems adapt and learn as information, goals, and requirements evolve; and then, they interact easily with other processors, devices, and cloud services (Ellis & Santagate, 2018; Deloitte Perspectives, 2021; Mefford, 2020; Miller, 2021).
With enhanced vehicular sensor technology, driverless cars and trucks are more aware of their surroundings than is possible for human beings. Smart warehousing systems direct trucks to the correct inventory bay, where they are unloaded by robot forklifts, with flying drones inspecting and verifying the load. (World Economic Forum, 2021; Miller, 2022)
Wearable technologies are application-enabled computing devices, worn or attached to the body, that accept and process input from the Internet or other devices. Workers equipped with wearable technology do not need to input information and can capture, hands-free, leads and sales updates via voice messages. Smart glasses guide staff through the warehouse by virtual reality (Herhold, 2020). SmartWatches enable managers to receive 24/7 emails, voice mails, text message, and notifications. Mobile devices now eliminate wasted “travel” time within a warehouse by enabling employees to input/update data and create and print labels right on the spot (Advantech, 2019).
Cloud computing and storage use a network of remote servers to access shared resources like data servers, storage, applications, and other services. Users can store and process data in a privately-owned cloud or a third-party server, making data readily accessible from anywhere. Supply chain data stored on a cloud is available to anyone inside the company, as well as to distributors and suppliers, so that all of the stakeholders can access the same accurate, real-time information (MHI & Deloitte, 2017; Lowe, 2021).
Blockchain is a continuously growing list of digital records that are linked, secured through cryptography, and continuously updated. Blockchain can be used for transaction pr ocessing, records management, and other data-driven tasks. For supply chain clouds, blockchains can provide continuously updated and verified information from data inputs in shared ledgers that are available 24/7 to all enterprise stakeholders—internally and externally (Ellis & Santagate, 2018; MHI & Deloitte, 2021; Gstettner, 2019).
In additive manufacturing, special CAD software relays messages to a printer, which prints the desired shape in thin layers that are repeatedly printed on top of each other and fused together until the shape is complete (Knowles, 2019). Additive manufacturing reduces material inputs for manufacturing, as well as the cost of production processes, and enables faster reaction to demand changes (MHI & Deloitte, 2019, 2020; Knowles, 2019; Moreau, 2021).

The critical need for supply chain employee training

Supply chains have become global and “specialized, multi-tiered, and fragile” (Shih, 2021, p. 1). To meet consumer demands for customization, products have been outsourced to external suppliers that are often far flung across the globe. Fragmented and increasingly complex supply chains with multiple tiers of partners are difficult to monitor and control. As digital technologies like the ones described above address these issues by transforming supply chains, employee expertise in mastering and using them is more crucial than ever (Illanes et al., 2018). Upskilling and employee digital dexterity are being increasingly valued more than tenure and experience (McKinsey & Company, 2020; Eadicicco, 2019). As predicted by Toffler in 1971 “The Illiterate of the twenty-first century will not be those who cannot read and write, but those who cannot learn, unlearn and relearn” (Toffler, 1971, p. 414). With the half-life of technical skills now about 5 years and steadily decreasing (Kasriel, 2017), continuous, lifetime learning and corporate support for it, will be necessary for employees to succeed in the challenging and evolving work environment of the future (Manyuka et al., 2017; Richards & Dede, 2020). Predictions are that 85 million workers will be replaced by automation by 2025 (World Economic Forum, 2020); the good news is that by the same year, 149 million new technology jobs are expected to be available (Smith, 2020).
The MHI and Deloitte 2019 Annual Industry Report emphasized the importance of providing ongoing opportunities for employees to develop digital skills, tying career growth to employee participation in training, using younger digital-savvy employees to mentor older employees and assist in facilitating digital transformation, and the establishment of partnerships with STEM programs in colleges of business that encourage the development of future employees with the skills companies need. Eighty-seven percent of employers in a CarringtonCrisp & LinkedIn survey (2021) indicated that they plan to develop a formal lifelong learning strategy to upskill and reskill their employees that allows them to develop skills flexibly, informally, and online (CarringtonCrisp & LinkedIn, 2021). This sentiment was echoed in the World Economic Report 2020, which wrote that 95% of employers plan to retrain their employees (World Economic Forum, 2020). The need for lifelong learning is recognized by employees themselves, according to a Pew Research Report that found that 73% of surveyed employees consider themselves to be lifelong learners (Horrigan, 2016). Recognizing the lifelong learning message, Walmart has offered to pay 100% of tuition and textbook cost for any of its associates (Walmart, 2021); and other companies including Amazon, Google, and IBM offer learning/advancement opportunities to employees (Fain, 2019).

The changing eLearning landscape

Over the last several years, the landscape of corporate learning has expanded and diversified as a result of increasing digitalization of supply chains and the globalization of business. Concurrently, colleges of business are struggling to maintain currency in their curricula and to address the ever-evolving technology skills which industry demands (Schlegelmilch, 2020). Traditional four-year business programs are becoming less popular, as students weigh the cost of a four-year commitment that may not necessarily prepare them for the jobs of the future. Colleges of business are dealing with declining enrollments and the necessity of developing new pathways to serve the needs of today’s learners, which now include a new, expanded group of non-traditional students, many already in the workforce and eager to upskill to meet the technical demands of their jobs (Schlegelmilch, 2020). More and more colleges of business are now offering short-term executive education training for employees that is customized to specific organizational needs, addresses the requirement for lifelong learning, and recognizes training completion with digital recognitions that can sometimes count toward earning degrees and are shared on the learner's social media, resume, and employment applications (Crawford, 2021). The increased popularity of eLearning has created competition from a myriad of eLearning corporate training providers (Schlegelmilch, 2020). Online education providers like Coursera for Business, Udemy, Skillshare, MasterClass, EdX, Udacity, Khan Academy, KnowledgeCity and PluralInsight; social platforms like LinkedIn Learning, Twitter, YouTube, Instagram, Facebook; consultants like The McKinsey Academy, Accenture, the Supply Chain Academy; non-profit professional organizations like Association for Supply Chain Management, the Council of Supply Chain Management Professionals, and the Institute for Supply Management® (Foroughi, 2021); and publishers like Pearson and O'Reilly (Schlegelmilch, 2020). Additionally, prominent corporations are now developing and offering their own "corporate university" training programs, such as Unilever University, Amazon's Technical Academy and Associate2Tech; and IBM's Basic Blue for IBM Leaders (Fain, 2019). Colleges of business also face the challenge of competing with immersive, engaging learning modalities that are offered by an increasing number of alternative eLearning providers: from the more familiar virtual reality and augmented reality holograph technology; to AI programs like Microsoft's FLEXA, which can customize learning according to the specific needs of individual learners; to metaverse, which extends virtual reality by using avatars of learners and supporting interactive, real-life scenarios, and both face-to-face and hands-on learning (Schlegelmilch, 2022)..

In order to remain relevant and sought-after by employers and employees in the competitive eLearning marketplace, colleges of business must reach out to business and industry to determine what their employee training needs are and how to provide training in a way that is most effective and appealing to them. This relationship-building process can be enhanced and facilitated by surveying the specific needs of companies, such as in the earlier study (Foroughi, 2021), as well as consulting other previous studies. Foroughi's (2021) results were comparable to those in a MHI and Deloitte (2021) study in terms of supply chain challenges and challenges related to employees, with both studies underscoring ongoing issues with finding, hiring, and/or upskilling employees. Additionally, establishing partnerships with companies can develop information sharing between a school of business and the company that builds confidence and familiarity with the college's offerings, as well as the business' employee training needs (Lutchen, 2018).

Insights from survey studies

A previous study showed that companies are experiencing challenges related to the supply chain, the greatest challenges being cybersecurity risk, demand forecasting, hiring/retaining talent, and customer behavior/expectations (Foroughi. 2021). Employee skills are strongest in communication/interpersonal skills, general business, and project management, but much weaker in data manipulation skills, systems implementation, change management, analytics/modeling/visualization, Six Sigma, statistics and quantitative skills, and supply chain degree/certification. Employees appear to have skills that can maintain the status quo of operations, but lack the more technical and analytical skills that are necessary for implementing digital technologies. Results indicated positive attitudes about the idea of training offered by the local college of business. Preferred training course formats were similar to those in the MHI and Deloitte (2021), as well as the CarringtonCrisp & LinkedIn (2021) studies (described below), and the Coursera for Business (2018) study. Employees want short, online, flexible start-finish courses with customized content that is relevant to their specific skill needs, prepare them for the future, and offer certifications or microcredentials.

CarringtonCrisp & LinkedIn (2021) surveyed attitudes of both employers and employees about corporate training. Only 35% of employers reported using college of business corporate training programs for employee learning, because they find that other learning providers better meet their needs (24%), and that colleges of business are too expensive (24%), too theoretical, and sometimes outdated (20%). However, employers indicated that they would like to develop a closer relationship with colleges of business to co-create relevant content (79%) and short-term flexible employee training that facilitates and supports lifelong learning (76%). Eighty-one percent agreed that their organization plans to create long-term relationships with learning providers to build understanding of their business and to maximize the impact from learning; 83% indicated that measuring the impact of learning and development will become key when selecting a learning provider.

Employees surveyed wanted to update skills on an ongoing basis—with flexibility as to when, where, and how they learn. They preferred online, short-term/module format, low-cost training that earns them valued recognitions, accelerates their career prospects, supports lifelong learning (69%) and has flexibility that suits their lifestyle, career, and commitments (71%). Employees wanted to update skills on an ongoing basis (67%), take training during work hours (41%), expected employers to fund the training, wanted more guidance from employers about skills they need to develop (70%), and thought that employers should value informal learning when making hiring decisions (69%). They also indicated that college of business programs are often too expensive (52%) and do not always impact career growth (44%). More than half (58%) of employees agreed that the availability of so many eLearning options beyond higher education has made them less sure of the value of formal university programs. Regarding degrees they plan to seek, employees indicated interest in industry-recognized qualifications (e.g.CPA, CFA, ACCA, CIM, CMI,ETC) (21%), a traditional or microcredential MBA that prepares them for the workplace of the future (77%), stackable certificates that can lead toward a degree (13%), and a degree they can earn in a series of modules over an extended time period (34%).

Insights about employee training format/content preferences were also provided by a Coursera for Business survey study (2018). Employees preferred content that is relevant and applicable (49%), offered in a format that fits their schedule (32%), is valued by colleagues (28%), includes opportunity to earn a valuable credential (23%), and is provided by the employer (20%). Preferred training time commitments for training sessions included, in descending order: 1) 45 minutes of less in length, 2) 45-minutes to 2 hours, or 3) a half-day or longer. Preferred learning formats were online courses (50%), in-class training (49%), training materials to study on their own (45%), attending conferences (39%) and webinars (39%), and consulting friends, co-workers, and mentors (34%).

METHODOLOGY

This study aimed to examine the extent to which college of business executive education programs are offering courses in digital supply chain management and coverage of the eleven skills identified as crucial training areas for supply chain employees. The first step was to locate a list of business schools in the United States 2022 (executive courses.com) through an Internet search. The executive education websites of these business schools were examined for coverage of supply chain, technology innovation, digital transformation, and the 11 technical crucial skills. Thirty-five of the 90 schools covered were determined to be lacking in these areas, and they were eliminated from the list, leaving a total of 55 schools. Second, there was interest in knowing the extent of coverage of the skills of interest in business schools considered peer, aspirant, and competitive to the Romain College of Business at the University of Southern Indiana (usi.edu/business), the university referred to in the Introduction (AACSB Knowledge Service). Three out of six peer institutions (Arkansas State University, University of Central Missouri, and Southeast Missouri State University), one out of five aspirant institutions (University of Houston-Clear Lake), and one out of eight competitor instructions (Western Kentucky University) were added to the list of institutions for further investigation (AACSB

Knowledge Service).
The final list, shown in Appendix I, included executive education programs at 60 universities in the United States, with a mixture of private, public, and technical-focused institutions represented.
The 60 business school executive education programs identified were examined on the following criteria, which were based on the skills identified in this paper and on the needs and preferences identified in surveys of employers and employees:

- Short-term time length—Does the duration of executive education courses reflect the need to build specific skills in a short period of time?
- Flexible delivery modes—Are executive education courses offered in a variety of delivery modes, such as live online, asynchronous online, face-to-face on campus, face-to-face on company's site, and on-demand?
- Customized content—Are executive education programs and courses customized to fit the training needs of companies and their employees?
- Relevant content—Does executive education reflect coverage of supply chain, digital transformation, technology innovation, cybersecurity, and the eleven crucial skills of interest in this study?
- Completion recognition—Are participants given recognitions to honor their completion of training, such as certificates, digital badges, or mini-MBAs?
- Cost—Is a range of costs available to suit the budgets of individuals and organization seeking training?
- Do any universities partner with other online education partners to offer courses?

RESULTS

Course length

All programs examined offer short term options (1-2 days to several months) and staggered start/finish for courses through the year to fit the busy schedules of working individuals.

Flexibility of delivery mode

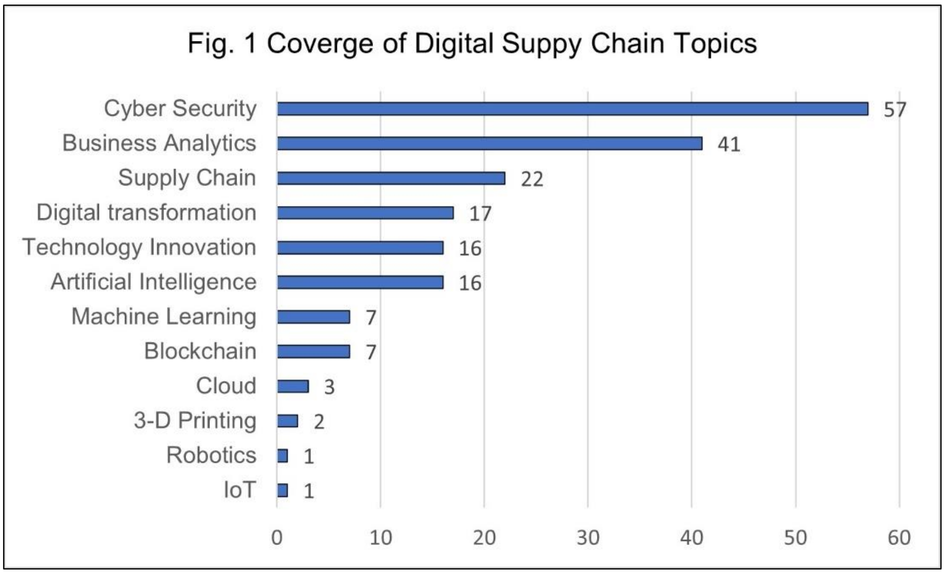
All programs offer a mixture of face-to-face, live online, asynchronous online, on-demand, on campus or on site at the workplace.

Customized content

Readiness to address the particular training needs of companies and their employees with customized training is offered by all of the executive education programs examined. Additionally, some programs break their executive education programs/courses down into those for individuals and those for organizational groups (California Institute of Technology, Georgia Institute of Technology, University of California-Berkeley, Pepperdine University, and Harvard University). For many others, open enrollment in existing programs is offered to both individuals and to organizational groups (University of California-Berkeley, Georgetown University, Pepperdine University). Columbia University and Georgetown University offer organizations the opportunity to enroll their employees in any of their MBA courses. Although this was not the main focus of this study, another trend is for some technical and business courses to be housed outside of business schools in their universities' continuing education, workforce education, or professional education departments. Harvard University Extension School, Berkeley Extension School, and Yale University Extension School, for instance, are well known for offering non-credit professional education courses.

Content reflective of supply chain and digital technologies

Appendix II shows the breakdown in the number of executive education sites that include coverage of each digital supply chain topic, and Fig. 1 compares the coverage represented in the executive education programs examined in this study.



Eight of the 11 essential digital skills were found to be covered in the 60 executive education programs examined: Business analytics in 41/60 (69%), AI in16/60 (27%), blockchain and machine learning in 7/60 (12%), cloud computing in 3/60 (5%), 3-D printing in 2/60 (3%), and robotics and IoT each in 1/60 (2%). Cyber security was covered in 57/60 (95%) programs, supply chain in 22/60 (37%), digital transformation in 17/60 (28%), and technology innovation in 16 (27%). Blockchain, machine learning, cloud, 3-D printing, robotics, and IoT were covered in 12% or fewer programs; and autonomous vehicles, automatic sensory/IS technologies, inventory and network optimization tools, and wearable technologies and mobile devices were lacking in all of the executive education programs examined.

Partnerships with other online education providers

Results indicate that a number of universities are partnering with online education platforms to 1) develop and offer online courses, 2) offer and market already packaged courses (from educational platforms) on university websites, and 3) market and feature existing university courses on the partner's platform. These partnerships have been included in this discussion in order to present a fuller picture of what universities are doing to make their programs, including those relevant for adult learners, available.
Trilogy Education (Trilogy Education Services) partners with universities to develop and offer programs such as web development, data analytics, cybersecurity, digital marketing, and technology project management. Partners include the following universities that are included in

this study: Northwestern University Bootcamps, Rutgers University Bootcamps, University of California-Berkeley Extension, University of North Caroline-Chapel Hill, University of Pennsylvania, University of Texas Center for Professional Education, Case Western Reserve University, Washington University's Engineering, and Columbia University's Engineering. BISK (bisk.com), which also assists universities in developing and implementing online courses, is used by Michigan State University and Villanova University. Get Smarter (getsmarter.com) partners with universities to select, design and deliver online short courses. Users include University of California-Berkeley, Harvard University, Massachusetts Institute of Technology, Northwestern University, Stanford University, and Yale University

The second category of online education providers offers its own programs, which are made available through university websites. Ed2Go (ed2go.com) online courses are used by Southeast Missouri State University, the University of Central Missouri, and the University of Southern Indiana. The University of Central Missouri also uses Career Step (careerstep.com), which provides industry-recognized credentialing courses; JER Online (jeronline.com), which offers non-credit continuing education workforce courses and certificates; and both University of Central Missouri and Western Kentucky University use ed2Go (ed2go,com) and MindEdge (mindedge.com), which provides professional education courses for corporate and industry employees.

The third category includes platforms like Coursera (coursera.org) and edX (edX.org), which market existing university programs on their platforms, making them accessible to learners worldwide, increasing the global footprint of universities, and boosting enrollment in their courses. Table 1 includes universities in this study that offer courses on Coursera and/or on edX:

Table 1 Universities that Offer Courses through Coursera and edX

UNIVERSITY	COURSERA PLATFORM	EDX PLATFORM
Arizona State University	X	X
California Institute of Technology		X
Carnegie Mellon University	X	X
Case Western Reserve University	X	
Columbia University	X	X
Cornell University		X
Georgetown University		X
Georgia Institute of Technology	X	X
Harvard University		X
Massachusetts Institute of Technology		X
Michigan State University	X	
New York University	X	X
Northwestern University	X	
Purdue University		X
Rutgers University	X	
Stanford University	X	X
University of Arizona	X	
University of California-Berkeley		X
University of California-San Diego	X	X
University of Chicago	X	X

University of Houston	X	
University of Kentucky	X	
University of Maryland System		X
University of Michigan	X	X
University of Minnesota	X	
University of Pennsylvania	X	X
University of North Carolina-Chapel Hill	X	
University of Texas System		X
University of Virginia	X	
University of Washington	X	X
Yale University	X	
Totals (31 universities in total)	21	20

It should be noted that most Coursera ad edX courses can be taken free of charge and without affiliation with/acceptance into a program at the schools listed. There are fees for some aspects of the course such as feedback, certificate of completion and/or some course materials, but even with fees ranging from $50-$150, these courses remain very affordable. Also relevant to the discussion in this study is the fact that Coursera for Business and edX for Business offer customized training programs for organizational employees. Cost-wise, edX for business courses start at $349 per learner per year, and Coursera for Business start at $399 per learner per year.

Completion recognitions

Table 2 includes universities that offer professional certificates, mini-MBAs, and digital badges. Four of the executive education programs reviewed offer national professional certifications. Digital badges offered by three of the examined programs can be included in resumes and on social media. Mini-MBAS, offered by 8 institutions, encapsulate the main subject areas covered in MBA programs into short-term, modules completable in a few days or weeks. Two Mini-MBA programs have a data analytics focus--University of Houston offers a Mini-MBA in Data Analytics, and Rutgers University offers Mini-MBAs in several areas, including Digital Supply Chain, Business Essentials, Digital Marketing, Data-Driven Management, Driving Innovative Business Solutions, and Artificial Intelligence. Additionally, Clemson University offers mini-MBAs in Data Analytics and Visualization and in Marketing Trends and Digital Transformation.

Table 2 Executive Education Program Mini-MBAs and Digital Badges	
INSTITUTION	PROFESSIONAL CERTIFICATES, MINI-MBAS, DIGITAL BADGES
Clemson U. Powers College of Business	Mini MBA, including in Data Analytics and Visualization, and Marketing Trends and Digital Transformation (each one 6 4-hour sessions, $1,200.00
Eastern Kentucky U. College of Business	Supply Chain Certificate in Production & Inventory Management, Digital Badges
Miami U. Farmer School of Business	Mini-MBA, online, self-paced, offered to alumni only, free of charge

Pepperdine U. Graziadio School of Management	Mini-MBA:5-days Digital badge
SE Missouri State U. Harrison College of Business and Computing	Pro Certificates in Computer Science, Computer Applications, through ed2go
State U. of New Jersey Rutgers Business School	Mini-MBAs, including in Digital Supply Chain, Business Essentials, Digital Marketing, Data-Driven Management, Driving Innovative Business Solutions, AI. Online self-paced, 12 wks, $3,495 In-Person Accelerated, 5 days, $4995.Digital badge upon completion
U. of Buffalo School of Management	Mini-MBA online, self-paced (Doable in 4-6 months) $995
U. of California San Diego, Rady School of Management	Mini-MBA, online via Zoom, 7 weeks, $300
U. of Central Missouri Harmon College of Business and Professional Studies	Professional IT Industry Certifications
U. of Houston- Bauer College of Business	Mini-MBA in Data Analytics, in-person, 5 days, $4,995
U. of Houston-Clear College of Business Lake Center for Executive Education	Management Information Systems Certificate for working professionals and Professional Industry Certification in Purchasing/Supply Chain Management
U. of Southern Indiana Romain College of Business	Workplace skill enhancing certificates, Digital Marketing Certificate, Microsoft certificates
U. of St. Thomas Opus College of Business	Mini-MBA, in-person, 5 days, $3995
Western Kentucky U. Gordon School of Business	Center for Applied Data Analytics, MindEdge certificate in Cybersecurity, Excel certificates

Cost

Fees for executive education programs/courses vary greatly, depending on the university at which they are offered and the delivery mode and length of the program/course. Table 3 presents a few examples of fees for various executive education programs/courses.

Table 3 Examples of Executive Education Program/Course Fees

UNIVERSITY	COURSE/PROGRAM AND FEES
American U. Kogod School of Business	Graduate Certificate in Analytics, $1,800 per credit hour x 12 = $21,000
Arkansas State U. Neil Griffin College of Business	3-D Printing Workshop, 1 day, $25
Carnegie Mellon U. Tepper School of Management	Analytics and Decision-Making: Unlock the Power of Data, online, 3 days, $4,100
Case Western Reserve U. Weatherhead School of Management	Digital Transformation: Strategic Tools & Frameworks for Success, 4 wks, $695
Columbia U. School of Business	Digital Marketing Strategy-in-person, 3 days, $6,650
Cornell U. Johnson School of Management	Leadership Certificate in Technology, 7 two-week courses, 3 month program, $2,520

Harvard Business School	Competing in the Age of Digital Transformation, 4 days, on- campus, $10,250
MIT Sloan School of Management	Technology and Operations- Ex: a self-paced online, 6 weeks,6-8 hrs/wk, $2,800
Michigan State U. Broad College of Business	Business Analytics: $4,613 for 2 courses, each 8 wks.
New York U. Stern School of Business	Digital Marketing and Social Media Strategy: Leveraging Analytics and Artificial Intelligence, live online, 5 days, 9:30 a.m.-2 p.m., $5,400.00.
Ohio State U. Fisher College of Business	Graduate Certificate in IT Business Strategy online, 10 months, in-state-$19,570
Temple U. Fox School of Business	Executive Approach to AI and Machine Learning, 3 hours of Zoom meetings, on one day, $2,000 per company login (up to four participants)
Thunderbird School of Global Management	Supply Chain Management Fundamentals Business Analytics, online, on-demand, $2,673
U. of Chicago Booth School of Business	Digital Innovation Strategy and Management—live-online, 4 days, $2,500
U. of Michigan Ross School of Business	Digital Transformation and Innovation, online synchronous and unsynchronous, 5-wks, $2,000
U. of St. Thomas Opus College of Business	Supply Chain Management, 2 days, live online, $1795
U. of. Virginia Darden School of Business	Introduction to Digital Transformation, online, self-paced, 6 wks, $1,800

DISCUSSION AND LIMITATIONS

This study of executive education programs at schools of business in the United States focused specifically on skill development opportunities for corporate employees in supply chain management and the digital skills which are crucial for employees who are to use digitally transformed supply chains. The purpose was to gauge the extent to which these topics are being covered in executive education programs, as well as the extent to which the expressed preferences of employers and employees regarding customized content, length, delivery flexibility, completion recognition, and cost are being met by these programs. The insights into coverage of supply chain and digital technologies in the study, are, admittedly, not generalizable to the many other institutions of higher education in the country. This study represented a one-time sample of training that is being offered to employers and their employees at a particular point in time in topics that are crucial for the survival and competitiveness of today's business and industry.

Executive Education Format Issues

All of the executive education programs examined in this study feature customized programs that can fill skill gaps quickly. Their websites feature short-term courses, with flexible start and finish times. Executive education programs are addressing employee needs and preferences regarding learning mode and are providing multiple modes of content delivery—live online, asynchronous/on-demand online, or face-to-face on campus or at the employer's location, often with more than one delivery mode offered for the same course. Executive education programs offer the option of customizable programs developed with the employer to fit skill needs, as well as open enrollment courses that are available to individual employees or groups of employees. A modest number of executive education programs offer industry-recognized certificates and digital badges to mark completion of a program, and three universities offer mini-MBAs that focus on specific digital technology areas. The cost of executive education programs/courses varies greatly across universities. As a recognition of the factor of cost, many universities offer discounts to organizations for their custom programs if the organizations become university partners. Also offered are discounts to individual learners, veterans, alumni, and groups of learners for open enrollment courses.

Digital Supply Chain Content Coverage

However, beyond course format issues, the results for the coverage of digital supply chain management and the digital skills of interest in this study are concerning. While this study found that cybersecurity, at 57/60 (95%) and business analytics at 41/60 (68%) were the topics most covered in executive education programs, coverage of the remaining topics was alarmingly deficient. Only eight of the eleven topics identified as crucial for digital supply chains were included in executive education programs/courses. At the same time, a significant trend was revealed. When business schools, including some at the most prominent universities, for whatever reason, choose not to offer some courses in digital technology areas on their own, they collaborate with online course developers and providers to make these topic areas available. Still others offer their courses through platforms like Coursera and edX. Business schools appear to realize that they can raise their profile and enrollment numbers by working with other eLearning providers to develop and/or post their courses. This trend is also consistent with suggestions made by educational experts that business schools provide multiple pathways to learners (Krishnamurthy, 2020; Schlegelmilch, 2020) in order to remain viable, relevant, and easily accessible to them.

University of Southern Indiana and its peer, aspirant, and competitive programs

One of the goals of this study was to provide information that is valuable to the university to which reference was made in the Introduction—the Romain College of Business (RCOB) at the University of Southern Indiana, as it plans to extend and maximize its ability to serve the stated supply chain and digital training needs of local companies. Currently, the RCOB offers several online accelerated certificates to both undergraduate students and adult learners such as company employees—Data Analytics for Business, Cybersecurity, and Supply Chain Management--each requiring the completion of 12 hours (four courses) of coursework. These certificates represent a step toward increasing offerings in topics that address issues of great importance to today's employees. Close examination of the USI website reveals that, although there are a number of additional skill-building learning opportunities for employees and other adult learners, under Credit/Non-Credit Courses, Online Learning, Professional Development, and the Center for Adult Learner Success, this information is not presented and/or interconnected in a concise, manner that clearly communicates the various learning pathways to potential employers and employees. USI's MBA Program has been highly successful since it joined forces with Instructional Connections (Instructional Connections), which markets the courses and provides academic coaches for large online courses. The MBA Program might consider offering mini-MBAs such as those identified in this research, particularly mini-MBAs that focus on a particular area, such as the University of Houston's Mini-MBA in Data Analytics, Rutgers University's Mini-MBA in Digital Supply Chain Management, and Clemson University's Mini-MBAs in Data Analytics and Visualization and Marketing Trends and Digital Transformation. The RCOB's CIS and CS programs work closely with an IT Alliance of regional IT executives, who advise the programs about curricular and other issues in order to keep these programs current and reflective of the needs of area business and industry. Establishing an advisory group like this, a Supply Chain Council, could bring ideas from supply chain executives to bear on coursework in this area.

Regarding a comparison of USI's executive education offerings with those of peer, aspirant, and competitive universities, USI's Romain College of Business, with three online accelerated certificates (Data Analytics, Cyber Security, Supply Chain Management), compares to SE Missouri State University's Harrison College of Business and Computing, which offers online certificates in Cloud Computing, Web Development, and Cybersecurity within the business school; and to University of Houston-Clear Lake Center's Management Information Systems Certificate for working professionals and Professional Industry Certification in Purchasing/Supply Chain Management. SE Missouri State University also offers a new Supply Chain Management major and certificate for undergraduate students. All of the peer, aspirant, and competitive universities, as well as USI itself, offer customized training for organizations and industry-specific certificates through their workforce development/community engagement, continuing education departments. As described earlier, Southeast Missouri State University, the University of Central Missouri, the University of Southern Indiana, and Western Kentucky University supplement their technology offerings with Ed2Go (ed2go.com) online courses. The University of Central Missouri also uses Career Step (careerstep.com) and JER Online (jeronline.com), and along with Western Kentucky University, uses MindEdge (mindedge.com).

CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

In conclusion, although it is encouraging that cybersecurity and data analytics are the topics with the most coverage in the executive education programs reviewed in this paper, gaps were also identified in coverage of other digital technologies that are crucial in today's supply chains. Blockchain, machine learning, cloud, 3-D printing, robotics, and IoT were covered in 12% or fewer programs, while autonomous vehicles, automatic sensory/IS technologies, inventory and network optimization tools, and wearable technologies and mobile devices were lacking in all of the executive education programs examined. With information readily available about today's employees' learning needs and preferences, more and more colleges of business will, hopefully, address needed changes in curricula and course content to prepare employees for success in the ever-evolving demands of the digital workplace. In the end, this is the only way for business schools to compete and survive in the crowded eLearning marketplace. "With the world still dealing with the COVID-19 pandemic, a school that continues with the same offer it had before the crisis will have misjudged the potential uncertainty and change facing employers. Instead, listening to employers and learning with them about the 'new normal' is a must-do activity to develop relevant programs for the future" (CarringtonCrisp & LinkedIn, 2021, p. 22).

Future research will continue to gauge the ability of business schools to remain valid and sought-after for employee executive education. It would be interesting to measure the impact of wider adoption of content that addresses minority and gender inclusion as well as environmental stewardship and sustainability, on the popularity of business school executive education programs; as well as to undertake another review of business school executive education programs that directly compares their programs to what is offered by alternative sources of digital eLearning for employees.

APPENDIX I

Appendix 1: Universities Whose Executive Education Programs are included in this study		
PRIVATE UNIVERSITIES (24)	TECHNICAL-FOCUSED UNIVERSITIES (7)	PUBLIC UNIVERSITIES (29)
American U. Kogod School of Business	California Institute of Technology	Arkansas State U. Neil Griffin College of Business
Baruch College Zicklin School of Business	Carnegie Mellon U. Tepper School of Management	Eastern Kentucky U. College of Business
Case Western Reserve U. Weatherhead School of Management	Georgia Institute of Technology	Florida International U. FIU School of Business
Clemson U. Powers College of Business	MIT Sloan School of Management	Indiana U. Kelley School of Business
Columbia U. School of Business	Purdue U. Krannert School of Business	Michigan State U. Broad College of Business
Cornell U. Johnson School of Management	Rensselaer Polytechnic Institute	Ohio State U. Fisher College of Business
Drexel U. LeBow College of Business	State U. of New Jersey Rutgers Business School	Penn State U. Smeal College of Business
Georgetown U. McDonough School of Business		SE Missouri State U. Harrison College of Business and Computing
Harvard Business School		U. of Arizona Eller College of MNGT
Loyola Marymount College of Business Administration		U. of Buffalo School of Management
Miami U. Farmer School of Business		U. of California Berkeley Haas School of Business
New York U. Stern School of Business		U. of California San Diego, Rady School of Management
Northwestern U. Kellogg School of Business		U. of Central Missouri Harmon College of Business and Professional Studies

Pepperdine U. Graziadio School of Management		U. of Georgia Terry College of Business
Stanford U. Graduate School of Business		U. of Houston- Bauer College of Business
Temple U. Fox School of Business		U. of Houston-Clear College of Business Lake Center for Executive Education
Texas Christian U. Neeley School of Business		U. of Maryland Smith School of Business
Thunderbird School of Global Management		U. of Michigan Ross School of Business
U. of Chicago Booth School of Business		U. of Minnesota Carlson School of MNGT
U. of Pennsylvania Wharton School of Business		U. of North Carolina Belk College of Business
U. of St. Thomas Opus College of Business		U. of North Carolina-Kenan-Flagler Business School
Villa Nova U. College of Professional Studies		U. of San Francisco Masagung Graduate School of Management
Washington U. Olin Business School		U. of Southern California Marshall School of Business
Yale U. School of Management		U. of Southern Carolina Darla Moore School of Business
		U. of Southern Indiana Romain College of Business
		U. of Tennessee Knoxville-Haslam College of Business
		U. of Texas McCombs School of Business
		U. of. Virginia Darden School of Business
		Western Kentucky U. Gordon School of Business

APPENDIX II

Note: The following abbreviations were used in the table, due to space restraints.
DA = Data Analytics
SC = Supply Chain
DT = Digital Transformation
AI = Artificial Intelligence
TI=Technology Innovation
ML = Machine Learning
IoT = Internet of Things
BC = Blockchain,
CS = Cybersecurity
3D = 3-D Printing
Cloud = Cloud Computing

Coverage of Digital Supply Chain Topics in Executive Education Programs											
University	DA	SC	DT	AI	TI	ML	IOT	BC	CS	3D	Cloud
American University	X								X		
Arkansas State								X	X	X	
Baruch College	X			X	X			X	X		
Cal Tech	X	X				X			X		
Carnegie Mellon U.	X						X	X	X		
Case Western Reserve U.			X	X					X		
Clemson U.	X								X		
Columbia U.			X						X		
Cornell U.	X				X				X		
Drexel U.	X				X				X		
Eastern Kentucky U.		X							X		
Florida International U.		X	X		X				X		
Georgetown U.									X		
Georgia Tech	X	X				X			X	X	
Harvard U.	X		X	X	X				X		
Indiana University	X								X		

Loyola Marymount College								X	X		
MIT	X			X	X		X		X		
Miami U.	X	X	X						X		
Michigan State U.		X							X		
New York U.	X			X	X				X		
Northwestern U.		X	X	X					X		
Ohio State U.			X						X		
Penn State U.	X	X							X		
Pepperdine U.	X							X	X		
Purdue U.		X							X		
Rensselaer Polytechnic Institute	X	X		X		X					
SE Missouri State U.					X				X		
Stanford U.	X	X		X	X				X		
Rutgers U.	X	X		X					X		
Temple U.	X			X		X			X		
Texas Christian	X								X		
Thunderbird School of Glob. MNGT	X	X							X		
U. of Arizona									X		
U. of Buffalo	X	X							X		
U. of California-Berkeley	X		X	X	X	X			X		
U. of California-San Diego		X			X				X		
U. of Central Missouri									X		
U. of Chicago	X				X				X		
U. of Georgia	X		X						X		X
U. of Houston-Bauer	X								X		
U. of Houston-Clear Lake		X			X				X		
U. of Maryland				X					X		

U. of Michigan	X	X	X						X		
U. of Minnesota	X		X		X				X		
U. of North Carolina -Belk	X				X						
U. of North Carolina-Kenan-Flagler	X		X					X	X		
U. of Pennsylvania	X		X	X					X		
U. of San Francisco	X					X			X		
U. of Southern California	X		X					X	X		
U. of South Carolina	X								X		
University of Southern Indiana	X				X				X		X
U. of St. Thomas		X							X		
U. of Tennessee Knoxville-	X	X	X						X		
U. of Texas	X	X		X		X					X
U. of. Virginia D	X		X	X					X		
Villanova U.	X	X							X		
Washington U.	X	X							X		
Western Kentucky U.	X								X		
Yale U. School of Management			X						X		
Total	41	22	17	12	16	7	1	7	57	2	3

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Artificial Intelligence Adoption: A Conceptual Framework

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ABSTRACT

The increasing interest in Artificial Intelligence (AI) has major societal implications that will influence the responsibilities of decision-makers and policy analysts. While there is already an extensive literature regarding AI methods, there is a lack of studies in the case for the implementation of AI in organizations. There are two popular theories about how innovation happens: The Technology Organizations-Environment (TOE) framework, and Diffusion of Innovation theory (DOI). This paper provides an interpretation of these theories about the adoption of AI technologies and proposes a framework for the adoption of AI at company level.

KEYWORDS: Artificial Intelligence, Trust, Adoption, TOE, DOI

INTRODUCTION

Artificial intelligence (AI) is a broad discipline that uses a range of terms such as "machine intelligence", "intelligent agent", "intelligent behavior" and "intelligent system" in its definition. Previously, AI was considered as machines that can think like humans, reason and make decisions, and this perspective has advanced to also consider general human-level AI such as: acts like a human or acts and interprets the world like a human (Russell et al., 2003).
Recent developments in machine learning, expert systems, natural language processing, speech recognition, deep learning and robotics have the most significant impact on AI and business (Purdy & Daugherty, 2016). In this regard, AI has emerged to improve decision making, ecosystems, and re-creation of the customer experience (Gartner, 2017a). The field of AI has become an active area of research in numerous fields and industries including engineering (Pham & Pham,1999), science (Cartwright, 1997), education (Lajoie & Vivet, 2002), medicine (Ramesh et al., 2004), business, accounting, finance, marketing, economics, and law (Rauch-Hindin, 1986). It is already being applied to such endeavors as the self-driving car, healthcare, and new media (Bollier, 2017). However, while there have been significant reports of AI in the literature (eg Aghion et al. 2017; Fernald & Jones, 2014; Purdy & Daugherty, 2016) this has not been the case for AI adoption factors for organizations. In particular, AI will play a significant role in the economic growth of countries such as the US (Makridakis, 2017) and India (Vempati, 2016). A recent report by PwC, estimated that the potential contribution of AI to the global economy will increase by 14% (15.7 trillion USD) by 2030. Multiple recent survey results indicated that managers felt compelled to adopt AI to catch the trend: Deloitte’s report (Hupfer, 2020) shows 37% of the adoption rate, and 50% of respondents in the McKinsey Global Survey (McKinsey, 2020) believed they would adopt AI in at least one business functions.
A considerable amount of empirical IS research has focused on IT adoption at the organizational level (Aboelmaged, 2014; Gopalakrishnan & Damanpour, 2006; Yang et al.2015). Over the last three decades or so, we have seen IT being studied firstly for creating competitive

advantage then for maintaining and sustaining that advantage. Various theories such as DOI (Rogers, 1995) were applied to understand this phenomenon (Oliveira & Martins, 2011). Knight (2015) claimed that bringing AI into an organization or workplace can increase productivity and help people make better, faster decisions. However, getting everyone to buy into the idea is a challenge. According to a report by Gartner (2017a), 59% of organizations are still gathering information about whether to adopt AI, and only 6% have deployed AI technology. Despite AI's benefits, doubts and distrusts about AI is still a common inhibitor for AI Adoption. Therefore, trust has been given importance to AI adoption. But as far as we can search, limited AI adoption literature at the corporate level has considered trust a key construct. Therefore, in this study, a conceptual model is proposed for AI adoption following the Technology-Organization-Environment (TOE) framework and Diffusion of Innovation (DOI) theory, with the trust construct.

LITERATURE REVIEW

Artificial Intelligence adoption

Adoption of innovation have been studied at either an individual level (Oliveira & Martins, 2011) or at firm level (Aboelmaged, 2014). Several adoption models have been proposed and applied to improve competitiveness and maintain resources efficiently (Alshawi,2007; Ruikar et al. 2006). Numerous domains have been studied and adoption models have been developed at firm level to allow firms to benefit from e-innovation. For example, emaintenance (Aboelmaged, 2014), cloud computing (Yang et al. 2015), e-marketing (Duan, 2010; Yan et al.2009; Zhai, 2010), and e-business (Ifinedo, 2005; Molloa et al. 2010). Findings from the literature on adoption have shown different factors that need to be considered when carrying out new innovation adoption. Technology factors, including relative advantage, and compatibility have the ability to positively influence new technology adoption (Aboelmaged, 2014; Idris, 2015; Ifinedo, 2005; Yang et al. 2015). For the organization factors top management support (Ifinedo, 2005;Yan et al. 2009) is the characteristic that can significantly influence the adoption of IS. Government regulatory issues is the main environmental factor that can affect new innovation adoption (Aboelmaged, 2014; Idris, 2015; Ifinedo, 2005; Yang et al. 2015).
AI is about the skills, data, processes, structures, and strategies of an organization (Salleh et al. 2011). AI adotopn therefore involves more than just AI technology. However, due to many factors such as unclear relative advantage for AI and lack of AI skills (Curran & Purcell, 2017), many organizations still challenge the adopters of AI. To analyze the perspective of a firm's adoption of AI, we consider two theoretical frameworks: TOE and DOI. The Technology-Organization-Environment (TOE) framework (Tornatzky and Fleischer, 1990) is a multi-perception theory developed to provide a framework for investigating the adoption of IS at the firm level. On the other hand, the Diffusion of Innovation theory (DOI) seeks to explain 'how, why and at what rate new ideas and technology spread' (Rogers, 1995). Both theories are similarly applied to adopting new innovation at firm level (Oliveira & Martins, 2011).

Technology-Organization-Environment (TOE) framework

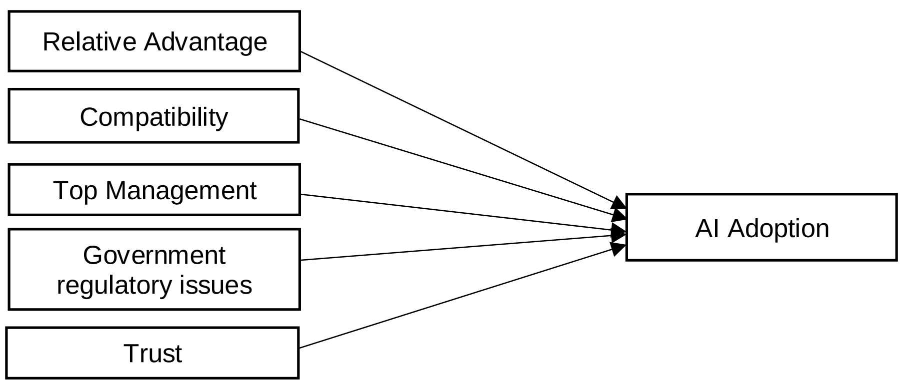
The TOE framework is used at the organizational level to explain factors that influence adoption decisions. Tornatzky and Fleischer (1990) found that the decision to adopt an innovation at the firm level is not only built on technological factors but is also influenced by organizational and environmental contexts. The technological dimension includes all the relevant technologies available within and outside the firm. The organizational dimension describes business characteristics and resources that might influence the adoption process such as firm size, managerial structure, decision-making and communication. The environmental dimension refers to the structure of the industry including the firm's competitors, suppliers, customers and regulatory environment (Tornatzky & Fleischer 1990). To date, the TOE theory has been widely examined in ICT and other disciplines such as e-commerce (Oliveira & Martins, 2011) and enterprise resource planning (Bradford and Florin 2003). Other fields where it has been tested include e-maintenance (Aboelmaged, 2014), cloud computing (Yang et al. 2015), e-marketing (Duan, 2010; Yan et al. 2009; Zhai, 2010), e-business (Ifinedo, 2005; Molloa et al.2010) and e-commerce (Idris, 2015). The TOE framework has also been tested in various fields including e-maintenance (Aboelmaged, 2014), cloud computing (Yang et al. 2015), e-marketing (Yan et al.2009), e-business (Ifinedo, 2005) and e-commerce (Idris, 2015).

Diffusion of Innovation theory (DOI)
Rogers (1995) studied how new ideas are communicated through a culture and found a basic pattern that was almost universally present as innovation ideas diffuse through a culture. DOI adoption of innovation at firm level depends on individual characteristics (such as the leader), internal characteristics and external characteristics of the organization (Rogers, 1995). DOI theory determines five characteristics of a new innovation that may be essential for adoption of new innovation: relative advantage, compatibility, complexity, trialability, and observability. Relative advantage refers to the degree of additional benefits in comparison with current innovation. Compatibility is about how well an innovation fits with the organization's values and needs. Complexity refers to the difficulty of understanding and adopting the innovation. Trialability refers to the ease of use and testing of the innovation. Observability is the extent to which the potential innovation is perceptible (Rogers, 1995). Several IS studies have investigated DOI at firm level in different areas, such as adoption of e-business, enterprise resource planning (Bradford and Florin 2003) and cloud computing (Yang et al. 2015).

THEORETICAL MODEL

The fundamental concept of the proposed framework is that aspects of technological, organizational and environmental factors are essential for AI adoption. It presents the research hypotheses from the perspectives of AI adoption. According to Webster & Watson, (2002) research framework and hypotheses need to be justified based on a theoretical explanation, practice from past empirical findings and empirical findings from related research areas. Unlike other adoption theories, the TOE framework does not specify a set of factors that affect innovation adoption (Aboelmaged, 2014). Therefore, the factors we have chosen are assumptions based on past experience and practice from related research area as discussed in the section above.

Figure 1: Conceptual Model



Relative advantage
Relative advantage refers to the perceived benefit of adopting AI at the firm level. In the context of this research, perceived AI benefits refers to the degree to which AI is better than other competing technologies (Zahi, 2010). Rogers (2003) outlined that the perceived benefit of an innovation has a significant effect on an organization's intention to adopt an innovative technology. Prior research (Aboelmaged, 2014; Kumar et al. 2016; Ifinedo, 2005; Zhai, 2015; Yang, 2015) also found a positive relationship between the relative advantage of new technology and the acceptance of an innovation. AI allows an organization to obtain a competitive advantage, reduce costs (Press, 2016) and opportunities to transfer into new businesses (Ransbotham et al. 2017), raise top-line profits, increase efficiency and amplify human intelligence (Curran & Purcel, 2017). Technology such as deep learning (DL), natural language generation (NLG) and machine learning (ML) allow firms to have a competitive advantage (Curran & Purcel, 2017) when adopting AI, which leads to the following hypothesis:

H1: Relative advantage has a positive influence on AI adoption.

Compatibility
A significant number of studies have shown a positive relationship between compatibility and intention to adopt an innovation (Ifinedo, 2005; Yang, 2015; Yan, 2009; Zahi, 2010). Compatibility refers to the extent of the innovation and its ability to provide value and experience while addressing the needs of the expected adopters (Rogers, 1995). Chui (2017) stated that successful AI transformations require a solid AI business case and should align with existing strategies. Ifinedo (2005) found that a greater match between the adoption process and the diffusion of technology innovation leads to an easier adoption. Thus, this research posits the following hypothesis:

H2: Compatibility has a positive influence on AI adoption.

Top management support
Top management support refers to the engagement of a top-level leader for IS/ implementations (Ifinedo, 2005). Resource-based theory identifies top management support as a moderating factor and claims that a lack of support not only fails to improve a firm's competitive position but also increases its failure to adopt an innovation (Wade & Hulland, 2004). Top management commitment can also have a significant positive influence on new technology adoption (Zahi, 2010; Yang et al. 2015) in terms of articulating a vision (Yang et al. 2015), providing capital funds and allocating resources. For example, for research into IS adoption, top management support was shown to promote the acceptance of cloud computing (Yang et al. 2015) and e-business (Ifinedo, 2005). In general, applying AI to drive the business transformation is a strategic decision (Gartner, 2017b). The following hypothesis is therefore proposed:

H3: Top management support has a positive influence on AI adoption.

Government regulatory issues
Government policy has been recognized as one of the factors that firms need to consider (Aboelmaged, 2014; Idris, 2015). In this study, regulatory issues refer to the assistance provided by the government authority to encourage the adoption of AI innovations at organization level. In the context of AI, different governments have different policies. For example, in the United States, preparations are being made to adapt regulatory challenges to those 'AI-enabled' products such as self-driving cars to encourage AI innovation (Makridakis, 2017). Hence, this study proposes the hypothesis:

H4: Government regulations can have a positive influence on AI adoption.

Trust

Though trust has been hardly examined empirically in corporate-level AI adoption studies, it has been considered a significant factor in the many discussions about AI. Ryan (2020) explained to the reader from the trust theory that, because AI cannot be held accountable for their actions, only calculative side type of trust can be established, while the emotional aspects of trust, such as normative trust and affective trust, are not relevant to AI. Glikson (2020) summarized from the literature review four types of AI characteristics that can contribute to trust: tangibility, transparency, reliability, and immediacy behaviors. They listed the manifestations of these characteristics in three formats of AI: robot AI, virtual AI, and embedded AI. For AI in decision support systems, which is embedded AI, transparency about how the AI algorithms work will help build trust; trust is higher in tasks requiring low human intelligence; behavior-tracing, which may be used for AI analysis, decreases human trust in AI. Ferrario et al. (2020) stated that the trust between AI and humans is built incrementally, starting from the simple pragmatic belief that AI can improve the business, to epistemic reasons for reflective trust: rational understanding of how AI works, what benefit can be achieved from using certain AI functions. Hence, this study proposes the hypothesis:

H5: Trust has a positive influence on AI adoption.

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Barriers That Prevent Small And Medium-sized Enterprises (SMEs) From Implementing Circular Economy Practices

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ABSTRACT

A circular economy returning produced goods, is integral to the drive towards sustainable practices. The common goal of the circular economy is difficult to implement for small and medium-sized enterprises (SMEs) being hindered by factors varying from one country to another. SMEs in aggregation are the largest employers in emerging economies, but this is where they face the greatest challenges. Government and industry practices and policies are not developed in emerging economies. This study observes and analyzes the structure of circular systems in emerging economies and presents recommendations and potential solutions for practical implementation.

KEYWORDS**:** Circular Economy, Sustainability, SME, Emerging Economies, Social Responsibility

INTRODUCTION & PROBLEM MOTIVATION

A circular economy (CE) is an "economic system that represents a change in paradigm in how human society is interrelated with nature and aims to prevent the depletion of resources, close energy, and material loops and facilitate sustainable development through its implementation at the micro (enterprises and customer), mesa (Economic agent integrated in symbiosis) and Marco (city, regions, and governments) levels" Mura et al., 2020). In other words, public institutions, communities, and business organizations must work together to create business models that rebuild capital and resources by ensuring that human, natural, social, financial, and manufactured resources reused as many times as possible.

Small and medium-sized enterprises are independent firms that employ fewer than a given number of employees. This number is determined based on each country's standards. In the European Union, an SME is an organization that does not employ more than 250 employees (OECD., 2005) However, in the USA, medium-sized enterprises are organizations that use less than 500 employees. In some other countries, a firm that employs 200 workers is considered an SME (OECD., 2005). Firms with fewer than 50 employees are considered small businesses, and firms with less than ten employees are considered micro-enterprises (OECD., 2005).

Small and medium-sized businesses play a vital role in the world's economic development. According to Dey et al., small, and medium-sized enterprises make up about 90% of the world's businesses, and these firms hire 50 -60% of the world's population (2020). Although small and medium-sized firms contribute significantly to the economic well-being of society worldwide, these organizations are responsible for 70% of the world's industrial pollution (Dey et al., 2020).

Despite Small and medium-sized businesses hurting the environment, many refuse to implement CE practices (Dey et al., 2020).

Lamata et al. projected that the demand for raw materials would double as the population increases in the next forty years (2022). In addition, this increase in the consumption of our natural resources has increased our ecological footprint year after year; however, research connecting CE practices to green practices among SMEs is rare (Lamata et al., 2022).

For humanity to transition from a linear to a circular economy, small and medium enterprises must achieve sustainability to meet social and environmental challenges in the 21 first century (Lamata et al., 2022). .

The motivation of this project is to identify barriers that SMEs face in emerging and developed markets when implementing a circular business model using academic articles. The project aims identify the similarities and differences regarding barriers small and medium-sized enterprises face when implementing a circular business model in both economies.

BACKGROUND AND AND LITERATURE REVIEW

Academic literature used to identify the barrier categories that prevented small and medium enterprises from implementing circular economy business models. According to a study by Rizzio's et al., barriers are the following: company environmental culture, lack of capital, lack of government support/effective legislation, lack of information, administrative burden, lack of technical and technological know-how, and lack of support from a supply-demand network (2016).

The company environmental culture category refers to the thinking, customs, and approach of the company's managers and workers towards adopting circular business practices. A manager of an SME is often the owner and is responsible for the company's strategic decisions. Mangers or risk-averse owners are more than likely to hinder the implementation of a circular business model. However, some organization's leaders see the benefits of adopting CE business practices in their business models.

The belief and conduct of employees also play a significant role in SMEs adopting a circular business model. According to Rizzio et al., working in an environmentally friendly organization may motivate some employees to embrace CE practices, but others may view green practices as an additional workload (2016). The views of investing in a circular economy business model can differentiate among stakeholders within the organization. The barrier aims to identify how stakeholders in small and medium-sized businesses hinder the implementation of a circular economy business model. The barrier aims to identify how stakeholders in small and medium-sized businesses hinder the implementation of a circular economy business model.

The second category, lack of capital, refers to small and medium enterprises' lack of funding that prevents them from transitioning to a circular economy business model. For example, the European Union's grants are hard for SMEs to obtain, and it is challenging for small and medium enterprises to get the collateral or guarantee required by banks. This barrier category aims to identify financial factors that hinder small and medium-sized businesses from adopting a circular economy business model.

The next category of lack of government support/ effective legislation refers to the lack of a severe legislative framework encouraging SMEs to integrate green solutions in their operations. For example, the European Union waste legislative framework does not have a classification of waste material to separate waste from byproducts materials used for recycling (Rizios et al., 2016). The goal of this barrier category is to identify government support/practical legislation factors that hinder small and medium-sized businesses from adopting a circular economy business model.

The fourth category lacks information and refers to small-medium enterprises lacking knowledge about circular economy practices to implement a circular business model. According to Rizios et al., a survey involving 300 European firms indicated that most organizations had never heard of the term circular economy (2016). This barrier category aims to identify information factors that hinder small and medium-sized businesses from adopting a circular economy business model.

The fifth category of administrative burden refers to eco-friendly business practices in a circular business model. The process of monitoring environmental performance data is complex and is costly for SMEs to do. For example, small and medium-sized businesses must report the ecological data to different officials in diverse formats, which is expensive for small and medium-sized enterprises. Ratios et al. 2016).

The following category of lack of technical and technological know-how refers to SMEs not having the technology to make it possible to transition to a circular business model and the staff with the expertise to help the company transition to a circular business model. According to Rizios et al., SMEs to change business as usual operations require developing new sustainable production and consumption technologies in eco-design and life cycle assessment integrated into the traditional business model (2016). For SMEs to utilize this technology, their staff must have the expertise to manage the technology. This category aims to identify technical and technological know-how barriers that hinder small and medium-sized businesses from adopting a circular economy business model.

The last category, lack of support from the supply and demand network, refers to SMEs not being able to gain support from all parties in the supply chain to implement a circular economy. For a circular economy to work, suppliers and customers must engage in sustainable activities. However, suppliers and service partners refuse to participate in the innovative circular economy process because they fear losing their comparative advantage in business. Customers are not aware of green products, and they do not put great demand on small and medium businesses to meet sustainability criteria or develop a circular economy business model. This barrier category aims to identify supply and demand network barriers that hinder small and medium-sized companies from adopting a circular economy business model.

OBSERVATIONS AND DATA

Countries were identify using academic articles. Countries used to identify barriers in developed economies were Spain, Italy, and 25 countries from the European Union. The region used to determine obstacles in emerging economies is India. Figure 1 shows the barriers are not the same for developed and emerging economies. SMEs think that CE does not increase business profitability and sustainability in the market falls under the company environmental culture category. Small and medium enterprises that do not see CE as a priority also fall under the company environmental culture category. These barriers mentioned by countries in Developed economies were not a concern for countries in emerging economies based on the academic literature. The barrier unorganized waste collection and picking sector in India falls underneath the lack of support from the supply and demand network category. This barrier mentioned by emerging economies is not a concern for countries of developed economies.

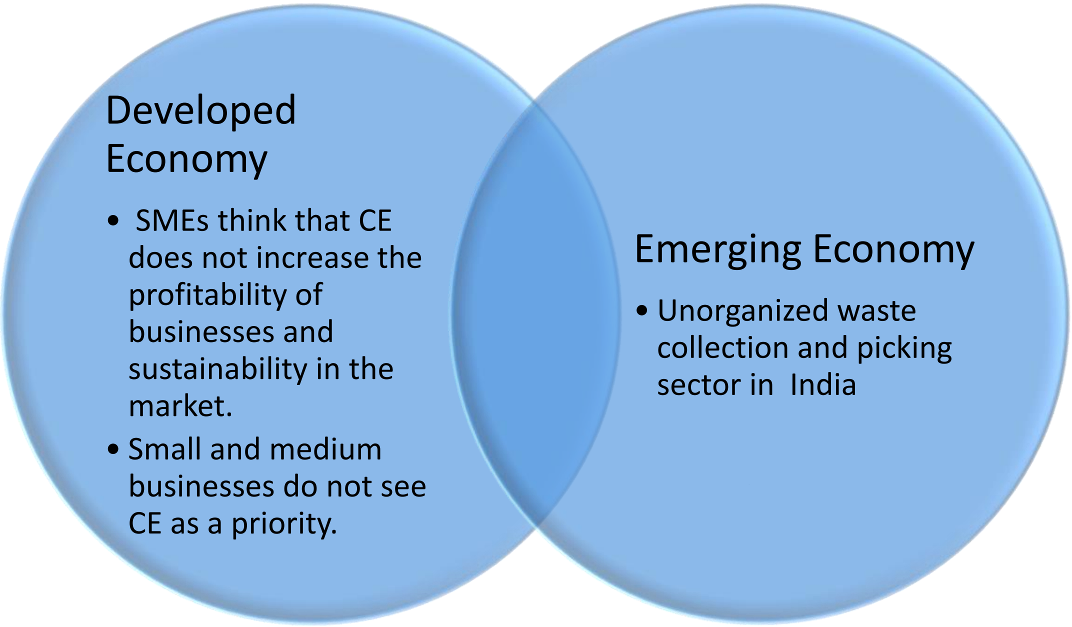

Figure 1: Developed Economy & Emerging Economy barrier differences diagram

Figure 2 diagram are similar barriers that SMEs in emerging and developed economies face when implementing a circular economy business model worldwide. SMEs in both economies agree that the lack of demand from the demand side hinders SME wellness in adopting the Circular Economic (CE) Business model. This barrier falls under the lack of support from the supply and demand network category. They also agree that the current legal framework prevents small and medium enterprises from implementing a circular CE business model, significantly hindering CE's ability to become green organizations. This barrier falls under the lack of government support/ effective legislation and administrative burden categories. SMEs in both economies agree that lack of leadership is a stumbling block in the organization becoming eco-friendly, and this barrier falls under the company environmental culture category. The last barrier is the lack of resources and capabilities that fall under the lack of capital and technical and technological know-how.

RESULTS AND RECOMMENDATIONS

Small and medium enterprises (SMEs) in emerging and developed economies see the lack of demand from the demand side as a factor that hinders the implementation of the Circular business model. This barrier refers to customers' demand for green products or green services. According to a study done in India, customers are not that interested in buying products created from recycled and reused material (Malik et al.,2022). So, the demand for green products or green services is low globally

The lack of leadership barrier refers to the leadership staff of SMEs in both economies not taking an aggressive approach to help small and medium businesses transition to a circular business model. According to Ormazabal et al., done in Spain, companies' leadership hinders circular economy adoption in SME organizations (2018). Also, research done by Malik et al. is calling on business leaders to develop a work culture in SMEs that allow employees to experiment and discover innovative ways to apply circular economy practices to the organization's culture (2018).

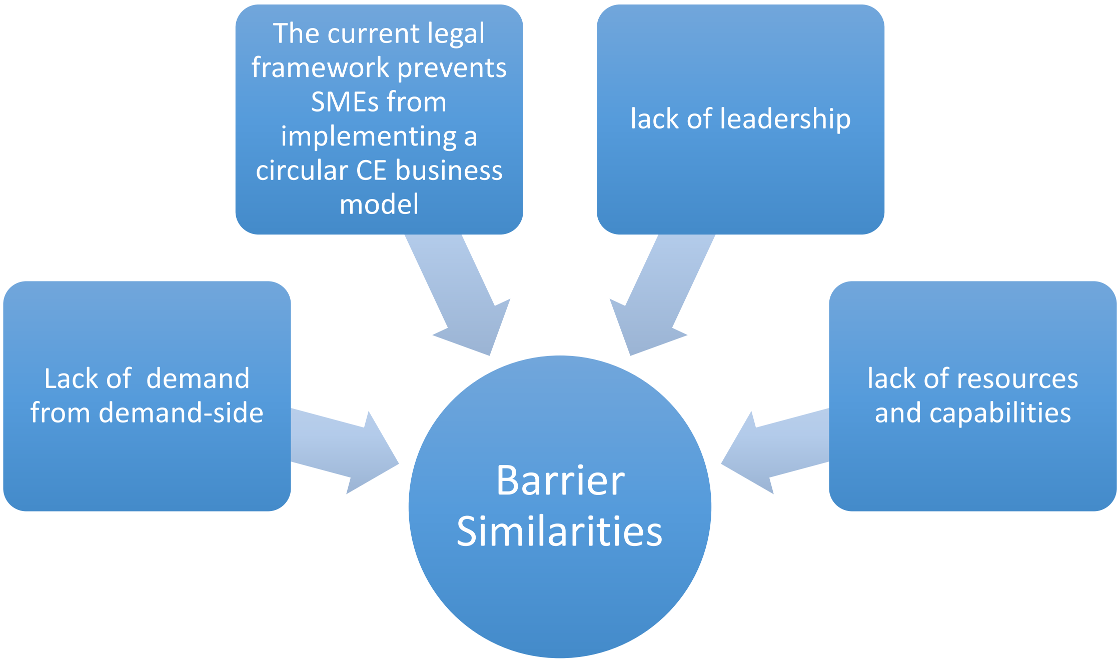

Figure 2: Developed Economy & Emerging Economy barrier similarities diagram

The barrier lack of resources and capabilities touches on the financial obstacles that SMEs face in emerging and developed economies a. small and medium enterprises from emerging and developed economies are most likely not to engage in CE because of the lack of funds. According to a study by García-Quevedo et al., the lack of funding hinders innovation activities that will help SMEs develop a circular business model (2019). This barrier also touches on the lack of capabilities, such as SMEs having inadequate information systems and a small percent of their staff being qualified environment manager professionals (García-Quevedo et al., 2019). Therefore, SMEs in both economies lack human expertise and the technical skills needed for their organizations to transition to the CE business model.

The barrier current legal framework prevents SMEs from implementing a circular economy business model is a big issue for both small and medium-sized enterprises in both economies. Governments worldwide do not have circular economy standards for different industries or rules for enforcing CE practices (Malik et al.,2022). Not having a legal blueprint regarding CE implementation makes it hard for SMEs to develop a strategy to meet environmental regulations requirements to create a circular business model. As a result of this legal framework bottleneck regarding CE regulation, many SMEs are more likely to avoid participating in the circular economy.

The current circular legal framework requires Small and medium-sized enterprises to collect a lot of environmental performance data to meet environmental regulations. Collecting this data is a costly and complex affair for SMEs. According to a study transitioning to a CE business model requires monitoring and reporting data, which is expensive for small and medium enterprises. They can't afford specialized departments to deal with the complexity of CE regulations or hire administrative staff to manage the process. SMEs that encounter administrative burdens are unlikely to partake in the circular economy movement.

SMEs in Emerging and developing economies also face different barriers that prevent them from implementing a circular economy business model. In developed economies, SMEs think that CE does not increase the profitability of their business and sustainability in the market. As a result, they are less likely to invest in green materials or technology that help transition to a circular business model (Ormazabal et al.,2018). However, in emerging economies, small and medium-sized enterprises did not identify this as a barrier

Another barrier that SMEs in developed economies do not have in common with small and medium-sized enterprises in the emerging economy is that small and medium businesses do not see CE as a priority. Unlike SMEs in emerging economics, small and medium-sized enterprises believe that a circular economy is a priority. In India, researchers are requesting that more business cases be developed to articulate the benefits of a circular economy (CE) to SME owners to speed up the adoption of CE practices in the country (Malik et al.,2022).

It is recommended that governments and leaders of the world reduce regulatory fragmentation to make it easy for SMEs to adopt a circular business model. The statute should indicate what waste is and what is not (Mura et al., 2020).

It is also recommended that a sound incentive system is in place to encourage SMEs to adopt a circular business model. For example, organizations that invest in renewable energy should receive a reduction in tax payments or labor costs (Mura et al., 2020).

It is also recommended that more business cases be done to build awareness of circular economy benefits to the general public in order to speed up the adoption of circular economy practices among SMEs on a global scale.

CONCLUSIONS

Circular economics focuses on creating an economy capable of restoring itself by developing eco-friendly innovations that protect our natural resources. Small and medium enterprises are the largest employers of the world's population, but unfortunately, they are also responsible for most industrial waste. The existing research defined barrier categories to identify the barriers that prevented small and medium enterprises from implementing circular economy business models. SMEs in emerging and developing economies face different and similar obstacles that prevent them from implementing a circular economy business model.

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Beauty Contest and Social Fintech: An Economic Analysis

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ABSTRACT

With the advance of financial technology (Fintech), traders in financial markets are using the information available on social media to gauge investor sentiment and form higher-order beliefs. Following the insight of Keynes (1936) on financial markets being akin to a beauty contest, we develop an analytical model to analyze how higher-order beliefs, driven by the Fintech revolution, affect market efficiency and social welfare of investors. Since accounting disclosure is a main source of public information, our results highlight that the use of Fintech in financial trading can dramatically affect the optimal level of accounting disclosure (i.e., transparency) in the market.

KEYWORDS: first-order beliefs, higher-order beliefs, Fintech, public information, private information

DECISION SCIENCES INSTITUTE
Business analytics in supply chain management performance

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ABSTRACT

Business analytics plays a pivotal role in the supply chain management. Over the past decade, many empirical studies have been conducted to examine the role of business analytics in the supply chain management performance. These empirical studies have investigated how business analytics capabilities improve supply chain management performance in various business settings (e.g., technical, organizational, environmental) and what business factors (e.g., culture, innovation, agility) regulate the benefits of business analytics. The previous empirical studies provide broad, diverse, and even inconsistent pictures of the effect of business analytics in the supply chain management. In this study, we proposed a consolidated research model based on the previous empirical studies and will use the meta-analytic structural equation modeling (MASEM) technique to test this research model.

KEYWORDS: Business analytics, Data analytics, Business intelligence, Supply chain management performance, Meta-analysis, Structural equation modeling

INTRODUCTION

The fast development and application of business analytics have greatly reshaped the business landscape. Business analytics has become one of the most valuable strategic capacities in business operation and decision-making. Supply chain management significantly benefits from business analytics. In the past decade, there have been many empirical studies of the roles of business analytics in supply chain management. These empirical studies examine various effects or different factors related to business analytics on supply chain management performance. Although they provide a broad view of the benefits of business analytics, there is lack of a systematic examination of how business analytics improves supply chain management and how different business contexts (e.g., technical, organizational, environmental) regulate the benefits of business analytics. There are even inconsistent findings.

With over 10 years of empirical studies, we can conduct a meta-analysis of business analytics in supply chain management. This study aims to provide a consolidated view of how business analytics benefits supply chain management performance in different business contexts and in different research models. With the latest developed meta-analytic structural equation modeling (MASEM) technique, we will test our research model using the previous empirical findings.

LITERATURE REVIEW

Business analytics (BA) is a set of data-driven computer technologies for business problems solving and decision-making. BA is "the application of a broad range of analytical techniques and methods and data-driven analytic methodologies to different business domains." (Chae et al., 2014). That is, BA applies a variety of data analysis, statistical models, computer algorithms, and quantitative techniques to solve problems. BA is often categorized into four models or techniques: descriptive, diagnostic, predictive and prescriptive. Descriptive models answer the question "what happened". Diagnostic models answer the question "why did it happened". Predictive models answer the question "what to do". Today, BA has been greatly enhanced by rapidly developed computer's data processing capability, mathematic models (e.g., statistical models, artificial intelligence), and availability of huge amount of data such as big data. BA has become a fundamental decision-making tool and corporate's strategic capability. BA has been widely used in various decision-makings and business process managements.

Supply chain management (SCM) is the business processes, more specifically, the chains of activities (Burgess et al., 2006). The foundation for SCM is the supply chain integration which aligns, links, and coordinate people, processes, information, knowledge, and strategies across the chains of activities to implement the efficient and effective flows of material, money, information, and knowledge in response to customer demands (Stevens & Johnson, 2016).

BA helps managers monitor the chains of activities such as information flow, material flow, and money flow to achieve the success of SCM (Arunachalam et al., 2018). BA improves the SCM performance by increasing the visibility (Barratt & Oke, 2007), resilience, robustness (Brandon-Jones et al., 2014). BA also improves the performance of demand predictions, inventory management, production and service scheduling, and product development in SCM (Lin, 2016).

In the past decade, there are numbers of empirical studies of the effects of BA on SCM performance (Wamba et al., 2017; Gunasekaran et al., 2017; Srinivasan & Swink, 2018; Wamba et al. 2022). These empirical studies examine the effect of BA capabilities on SCM performance in various business contexts. For example, Srinivasan & Swink (2018) found that the analytics capabilities positively influence SCM performance, and this effect is moderated by organizational flexibility; Wamba's et al. (2020) findings indicate that the effect of BA not only directly applies on the SCM performance, but also is mediated by the supply chain agility and adaptability. Our literature review show that BA plays different roles on SCM performance in different business contexts (e.g., organizational cultural and leadership styles, industry sectors, business processes), and some studies provide inconsistent findings. This study collected the previous empirical studies and will conduct a meta-analytic structural equation modeling (MASEM) on the proposed research model.

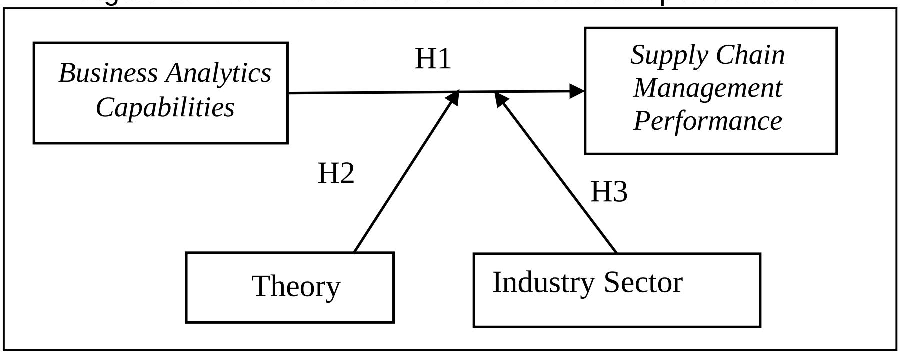
RESEARCH MODEL

Our literature review shows that most empirical studies applied Resource Based View (RBV) (Barney, 1991) and Dynamic Capabilities (Teece et al., 1997), followed by Organizational Information Processing Theory (OIPT) (Galbraith, 1974, 1977; Tushman & Nadler, 1978) as the theoretical foundations for their research models. The previous empirical studies have examined the effects of BA capabilities on SCM performance in different business settings with different research models. BA capabilities included how well BA provides descriptive, diagnostic, predictive, and prescriptive decision-making, and problems-solving.

SCM performance is defined as the procedures to measure the effectiveness and efficiency of the supply chain, and it includes the measures of cost, quality, time and customer responsiveness, and flexibility (Neely et al., 1995; Beamon, 1999). SCM performance plays a significant role in the successful functioning of an organization, and there are various measurements of the SCM performance including plan, source, make, deliver and return (Kamble & Gunasekaran, 2020). For example, the performance measurements should include supply chain activities such as process modelling, data integration, software support, forecasting (Shepherd & Günter, 2006), collaboration, agility, flexibility, and IT support (Arzu Akyuz & Erman Erkan, 2010).

According to the previous research findings, we proposed the following research model. BA capabilities directly influences SCM performance, and this causal relationship is regulated under two importance control variables: theories used in the research models and industry sectors under study. Using different theories and studying different industry sectors may provide different pictures of BA's effects and even inconsistent findings.

Figure 1: The research model of BA on SCM performance



Based on the research model above, we proposed the following hypotheses for statistic testing.

Hypothesis 1: Business analytics capabilities positively influence supply chain management performance.

Hypothesis 2: The effect of business analytics capabilities varies among the theories.

Hypothesis 3: The effect of business analytics capabilities varies among the industry sector of the firms.

METHODS

We will conduct a meta-analytic structural equation modeling (MASEM) in the following steps.

Data Collection and Coding

We have collected 38 empirical studies published in 28 business research journals between 2010 and 2021. These studies will be coded by two independent coders and the coding reliability will be reported.

Meta-Analytic Structural Equation Modelling (MASEM)

MASEM uses the correlation matrices to create a pooled correlation matrix, which is then analyzed with structural equation modeling (SEM) (Viswesvaran & Ones, 1998). MASEM allows the researchers to conduct a more precise and theory-driven quantitative review of the previous empirical studies (Dwivedi et al., 2019). The advantage of MASEM is that not all relationships specified by the theory need to be investigated in each primary study, as the required population correlations can be meta-analytically evaluated (Joseph et al., 2007; Viswesvaran & Ones, 1998).

In this study, we plan to use the two-stage MASEM or TSSEM (Cheung & Chan, 2005; Cheung 2015). TSSEM has two stages involved. In the first stage, a correlation matrix is pooled, which is then used to fit SEM in the second stage. Like a conventional meta-analysis, TSSEM can use fixed- and random-effects models (Tang & Cheung, 2016). The fixed-effect model assumes the population effect sizes are homogeneous and it provides the conditional inferences to the studies included in the analysis; the random-effect model doesn’t have this assumption and it provides unconditional inferences which generalizes beyond the studies included in the analysis (Hedges & Vevea, 1998; Hunter and Schmidt, 2000). In this study, we plan to generalize from the previous findings beyond the extant literature, and thus we will use the random-effect model in TSSEM.

DISCUSSION AND CONCLUSIONS

In this study, we intend to examine the benefits of BA in SCM performance based on the previous empirical findings. Our research model is built upon the previous empirical evidence and examine the findings from a consolidated perspective. This research model will statistically test the causal relationship between the effects of BA capabilities and SCM performance and how selected theories and industry sectors regulate this relationship. We expect the findings from this study will provide a in-depth insight into the effects of BA in SCM and help understand the inconsistent findings from the previous studies.

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Cinderella Wears Hijab: Profiling and Clustering the Global Market for Hijabistas via Twitter Text Analytics

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ABSTRACT

This paper aims to investigate the dynamics behind Twitter user-generated-content in relation to hijab/modest fashion based on a random sample of 144,800 tweets. Sentiment analysis was conducted, while a detection algorithm was implemented to identify the main influencers in relation to the hijab/modest fashion market. Results identify and profile the influencers and opinion leaders in the hijab/modest fashion global market. Results also show high diversity of emojis usage in hijab related tweets which highlighted the advantage of using them within hijab fashion brands' communications. Finally, a partitioning around medoids (PAM) clustering method was applied to define consumer clusters.

KEYWORDS: Hijabistas, Hijab fashion, Twitter analytics, Text mining, Sentiment analysis

INTRODUCTION

Fashion is considered a social act into the threshold of modernity (Saeed *et al.*, 2021; Shafee, 2020; Slater and Demangeot, 2021). Modest fashion reflects the appearance of a generously covering attire driven from religious beliefs or cultural conventions, while traditionally being connected to the Abrahamic faiths (Aune *et al.*, 2021; Zaki *et al.*, 2021).). Modest fashionista represents a practicing fashion-conscious woman dressed stylishly while adhering to the commitment of modesty. Modest fashionistas are usually connected to social-media networks (SMN), where they follow new trends and communicate their individuality, believes, experiences, and style of fashion (Hassan and Ara, 2021; Kavakci and Kraeplin, 2017; Krisjanous *et al.*, 2021). Recent studies have confirmed the role played by modest fashionistas as fashion leaders, social-media and blogging influencers, innovative decision-makers, information seekers and communicators (Sumarliah et al., 2021a). The modest fashion market currently represents 11% of the worldwide clothing market and is expectated to reach $406 billion by 2024 (Alanadoly & Salem, 2021; Zaki *et al.*, 2021; Aune *et al.*, 2021; Dinar Standard, 2020).

On the other hand, user-generated-content (UGC) had widened its reach due to the availability of smart devices. UGC can lead opinions, influence preferences and attitudes and encourage engagement through the exchange of experiences and emotions (Mazzoli *et al.*, 2019). Previous studies found that the fashion sector is heavily influenced by SMN, where influencers have wider impact on the market, affecting consumers' purchasing decisions, brands' marketing intelligences, strategies and decision making (Mainolfi and Vergura, 2021). UGC offers huge amount of data that could provide a deeper interpretation for consumer trends and interests. UGC can also provide accurate marketing predictions (Pantano *et al.*, 2019; Shen, 2021). Twitter is a leading social microblogging platform with daily active users of 192 million tweeting 575K tweets per minute (Ahmed *et al.*, 2017; Giles, 2018; Li *et al.*, 2018; Statista, 2021). Thus, Twitter is considered a very effective source for opinion and text-related mining for analytical and predictive research purposes (Bolici *et al.*, 2020; Singh *et al.*, 2020; Trivedi and Singh, 2021; Valcarce de Veer and Valdivia-Vizarreta, 2021; Viñán-Ludeña and de Campos, 2021).

However, despite the popularity of fashion bloggers, modest fashion represents a gap in understanding market trends. Based on the report 'state of the global Islamic economy 2020/ 21', modest-fashion sector has difficulty understanding the needs of the wide demanding market, while modest-brands suffer from a large gap in public relations, which affects the ability to profile consumers and predict market directions (Dinar Standard, 2020). Previous studies had highlighted the role of SMN in fashion marketing strategies, profiling consumers, and predicting trends (Detterbeck and Sciangula, 2019; Esteban-Santos *et al.*, 2018; Mainolfi and Vergura, 2021). Studies have also highlighted the role of microblogging in identifying consumers and markets trends (Blasi *et al.*, 2020; Wanqi, 2020; Zervoudakis *et al.*, 2021), while recent literature spotted the gap related to fashion consumers' UGC as a means of predicting market trends (Guercini *et al.*, 2018; Kim *et al.*, 2020). However, to the best of authors knowledge, no prior studies have attempted to profile and cluster the global market for hijabistas. In this study, we fill this research gap as we attempt to answer the following two research questions:

RQ1. Can opinion-mining technique present effective predictions to consumer trends and behavior patterns in relation to the modest-fashion market?

RQ2. Can opinion-mining technique effectively profile modest fashion consumers in meaningful clusters that can help marketing intelligence and strategies?

By answering the research questions, we contribute to the current fashion literature by presenting a deeper understanding of the modest fashion consumer. Besides, profiling modest-fashion consumers through tweets, will add breadth into defining the needs of this promising market segment in a way that might help developing successful marketing strategies to fit each fashion market segment. The article is organized as follows. Literature review is dealt with first. This section is followed by the methodology section where the process of conducting the study will be explained. In this section research design, sampling, and data analysis will be defined. The fourth section presents the results of the analysis. This is followed by the discussion of the research results. Finally, implication, limitations and a future direction will be presented.

LITERATURE REVIEW

Nelson et al. (2019), in their study for fashion consumers' use of social-media networks, they confirmed that fashion consumers target Facebook and Instagram for entertainment, while seeking twitter to express their opinions and staying updated through following influencers, brands, and fashion events. Brands on the other hand, seek Twitter to increase fashion awareness. Their findings were aligned with Dindar and Dulkadir Yaman (2018), as they confirmed that 34.5% of Twitter fashion consumers express their opinions through the platform. The term 'opinion-mining / sentiment analysis' refers to the use of public textual information by users to extract meaningful subjective and objective data that drive marketing decisions and prediction of analytics (Gul *et al.*, 2021; Gulati, 2021; Zervoudakis *et al.*, 2021). Commercial businesses are aware of the importance and diversity of extracted user public data analytics to visualise their markets, decide future developments, predict emerging trends, and make appropriate reflective decisions responding to consumer expectations (Li *et al.*, 2019; Valcarce de Veer and Valdivia-Vizarreta, 2021).

In relation to the fashion markets, previous studies conducted similar methods of analysing social-media, blogging and microblogging data in order to provide a deeper understanding for the demanding fashion consumer. A study by Blasi et al. (2020) questioned if there is a relationship between sustainable/eco-friendly practices of fashion brands and those brands been perceived by consumers as fashionable, stylish, and up to trends which led to consumption. They compared the relationship for three levels of the fashion market: luxury fashion, middle market and fast-fashion through brands' Twitter data. They found a very strong correlation between tweeting the words: 'fashion', 'glamour', and 'environment' for luxury brands than for middle-market and fast-fashion brands. Another study done by Greco and Polli (2020) performed emotional text mining and network analysis to categorise the communication about sportswear brands, and profiling those communications from consumers' perspective. They collected a sample of 107,500 users' tweets that include sportswear brands' names to be bottom-up processed and categorised. Semiotic themes related to consumer communication of brand identity and symbolic representations were clustered through emotional text mining with connection to consumer profiling. Based on this analysis, they were able to cluster consumers and their purchasing preferences. Shen (2021) investigated the influence of micro-bloggers in shaping consumer behaviours towards fashion brands. The study collected 20,000 tweets from ten of the highest-ranked Irish micro-bloggers from 2015-2018, analysed and categorised them into main keywords, while using the keywords to create a segmentation. Based on the clearly defined segments, the study was able to define areas and methods of twitter influencing the fashion market.

Looking at the followers/consumers data, Mazzoli et al. (2019) analysed consumer tweets associate to fashion brands to investigate its correlation with brand communications and the correctness of brand messages delivered to consumers. The study mined twitter data from well-known fashion bloggers and fashion luxury brand's consumers and compared them to the tweets of the brands themselves. In other words, they compared the words associated with the accounts of the brands communicating its identity, with the words used by bloggers and consumers to identify or communicate those brands. Their sample consists of 30 well-known international ranked fashion bloggers, where they analysed 329 of the tweets of bloggers compared to 1,334 tweets of official brands. Those tweets where highlighting brands' personalities, products, and official events. Their results confirmed that the words associated with brands in relation to their image or identity are in alignment with consumer-based brand equity, which relates to satisfaction, loyalty and purchase intentions. In relation to the same topic, Pantano et al. (2019) sentimentally analysed consumer tweets using machine learning for big data analytics to develop a value from UGC in a way that helps marketing intelligence. They analysed 9,652 tweets between retweeting and comments relates to different marketing strategies of three fast fashion brands in UK. In their method, they presented a way that allows brands assessing positive, neutral, and negative consumer opinions in way that give brands access to quick insights from consumers in relation to their own strategies as well as competitors' strategies.

Although the works mentioned above presented new directions of understanding the fashion market and its constantly changing consumers through analysing consumers' generated data, yet they none highlighted the emerging market of modest-fashion. Due to this gap, this study will compute consumer sentiments focusing on modest-fashion segment. Based on the collected data valuable information will be executed to help profiling and segmenting this market in a way that help further and deeper understanding for consumer's needs, expectations and behaviour patterns.

METHODS

Following Findlay and Rensburg (2018), a four-step methodology was adopted to conduct the analysis:

. A web scraping package within the R software statistical environment was used to collect the tweets via Twitter's representational state transfer application programming interface (REST-API).
. Sentiment analysis was conducted on the collected tweets using three major lexicons, namely the NRC lexicon (Mohammad and Turney, 2012), the AFINN lexicon (Nielsen, 2011) and the Bing lexicon (Liu, 2012).
. Community, homophily and influencers' detection algorithms were applied to identify the major communities and influencers within the hijabistas' Twitter network.
. Finally, the partitioning around medoids (PAM) clustering method was used to cluster the market for hijabistas into distinct homogeneous clusters/segments.

The four-step methodology outlined above is explained in some detail in the following sub-sections.

Twitter sampling

A random sample of 144,800 tweets dealing with the keywords "hijabistas" or "hijab fashion" was collected using the publicly available Twitter REST-API. The tweets were posted over five years' period (2016-2020). Although hashtags, keywords or target users can be used to collect tweets (Boecking *et al.*, 2015), it has been demonstrated that hashtag search can lead to the selection of a biased sample (González-Bailón *et al.*, 2014). To avoid linguistic bias, the search was also limited to tweets posted in English language. Takhteyev et al. (2012) noted that English is the most widely used on Twitter with estimates ranging between fifty to seventy-three percent. Figure 1 depicts the geographic location of a sample of geo-located tweets. However, it should be noted that geo-tagged tweets represent only one percent of the tweets (Mostafa, 2018). The graph shows that most of the geo-located hijab fashion tweets are posted from nations such as Malaysia, Indonesia, the UK, the USA, Pakistan, India, Canada, Saudi Arabia, and Nigeria. This reflects the fact that the Muslim diaspora represents around one quarter of total Muslim population (Neio Demirci *et al.*, 2016). Figure 2 focuses on hijab fashion tweets emanating from Europe. The graph shows that there are heavy tweets from France, Belgium, the UK, Germany, Switzerland, the Netherlands, Italy, and Poland. This is not surprising given the fact that around thirteen million Muslims live in Western Europe (Bonne and Verbeke, 2008).

Figure 1: Geo-tagged hijab fashion tweets

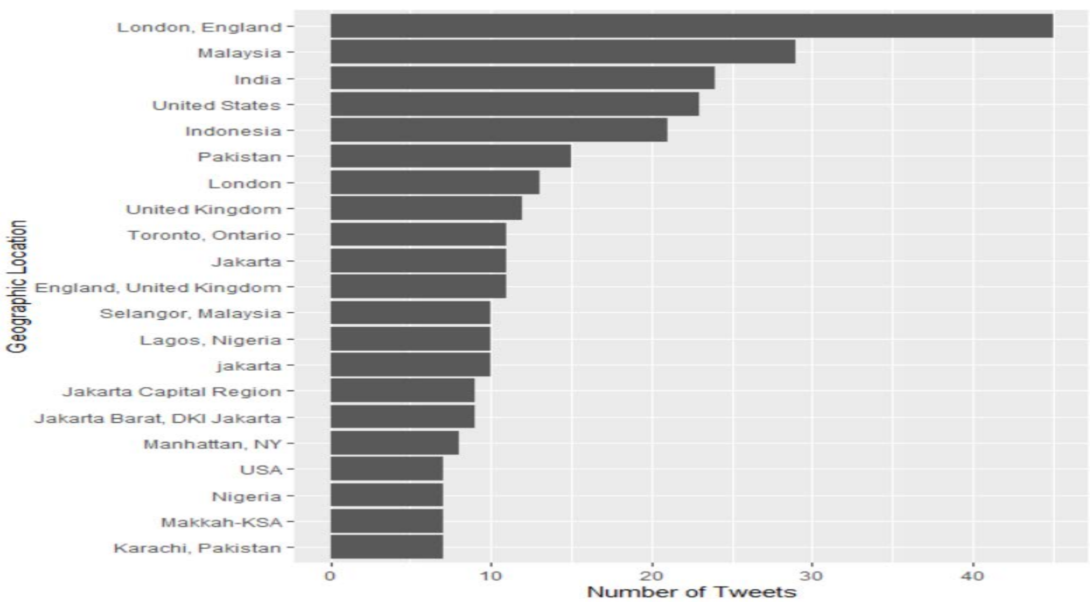
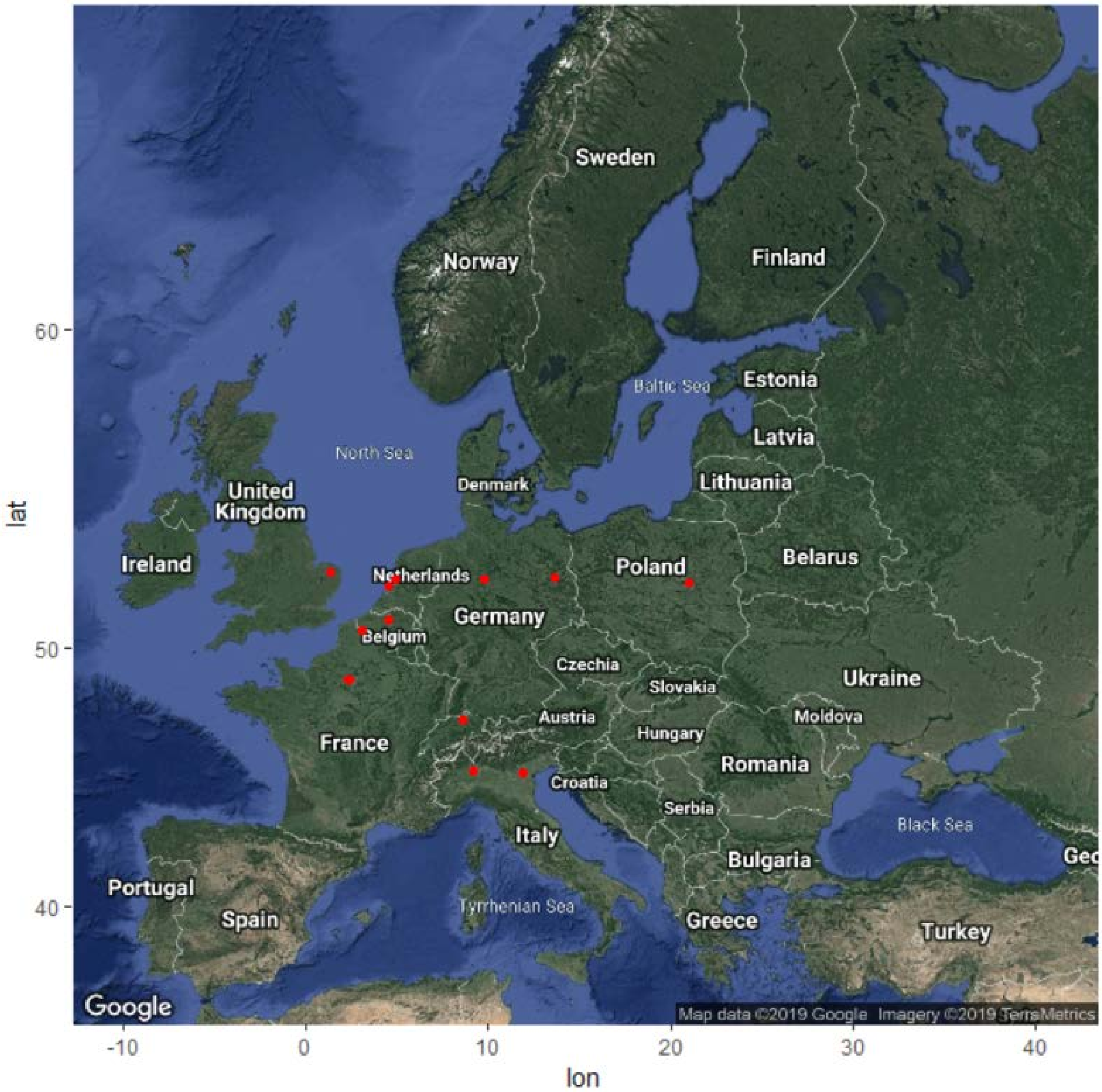


Figure 2. Geo-tagged hijab fashion tweets map of Europe
Note: Map produced using the 'ggmap" package in the R environment via an authentication code obtained from the Google Maps service



Sentiment analysis and lexicons

Sentiment analysis, also known as opinion mining, examines emotions expressed towards a specific subject (Mostafa, 2018). (Oliveira *et al.*, 2017)noted that the major aim of sentiment analysis is to extract "subjective information from large volumes of unstructured data by combining data mining techniques, machine learning, natural language processing, information retrieval, and knowledge management." Sentiment analysis is usually conducted by comparing the phrase/tweet presented against a pre-defined expert lexicon entry. Several lexicons have been developed to obtain sentiment expressed in a written text, including the LIWC lexicon (Pennebaker *et al.*, 2003), the Q-WordNet lexicon (Agerri and García-Serrano, 2010) and the subjectivity clues lexicon (Wiebe *et al.*, 2004). In this study we use three well-established lexicons that have been successfully used to conduct sentiment analysis on social media data, namely the NRC lexicon(Mohammad and Turney, 2012), the AFINN lexicon (Nielsen, 2011) and the Bing lexicon (Liu, 2012). The NRC lexicon classifies sentiments into eight major categories: trust, joy, sadness, surprise, disgust, anger, fear, and anticipation. The lexicon also is capable of classifying sentiments into dichotomous positive and negative words. the AFINN lexicon uses the valence of words to assign them into a positive or negative scale categories. In a similar vein, the Bing lexicon classifies sentiments into negative or positive scores.

Community, homophily and influencers' detection

Social media community detection is based on the idea that such communities form "insular and unmistakable" clusters of like-minded sub-groups (Lynch *et al.*, 2014). Carrington et al. (2004) argued that although community detection is conducted on network data, it is akin to the traditional cluster analysis. This technique aims at identifying the areas of the social network "where there are relatively dense interconnections between nodes compared to other regions of the network" (Mostafa, 2020). In this study we select the (Clauset *et al.*, 2004) community detection algorithm because it has been demonstrated to be more efficient compared to other algorithms (Vermeer and Araujo, 2019). This algorithm also allows solutions with overlapping communities which is quite common in social media networks (Blondel *et al.*, 2008). Overlapping communities might indicate a "homophily effect" (McPherson *et al.*, 2001), which occurs when actors in a "virtual-room-like" environment tend to focus on similar topics or express common interests (Findlay and Janse van Rensburg, 2018). Although there are several techniques to detect homophily effect, we use the ternary plot, also known as the simplex plot in game theory, as it has been found to be an efficient tool in visualizing three variables in two dimensions (Bakk and le Roux, 2017).

A key objective of social network analysis is to identify influencers (Hsu *et al.*, 2013). Influencers can be defined as individuals who build a network of followers and are regarded as trusted in one or several social media platforms (de Veirman *et al.*, 2017). Within Twitter, influencers are "the accounts that had the largest impacts on the conversation within each community as they were retweeted and mentioned the most." (Findlay and Janse van Rensburg, 2018). Therefore, whereas the total number of tweets posted represents a "tweet count", an "impression" is a measure that gauge the "interaction generated by the tweet through retweets, mentions or replies" (Mostafa, 2020).

PAM Clustering

In this study we use the PAM algorithm to cluster the hijabistas global market into distinct clusters. This algorithm was first proposed by Kaufmann & Rousseeuw (1987) and was found to be robust in dealing with noisy datasets characterized by the existence of outliers (Nitsche *et al.*, 2017). PAM starts by assigning every object in the dataset to its closest medoid in a dissimilarity matrix. Determining the optimal number of clusters represents a major challenge in applying the PAM algorithm (Ketchen & Shook, 1996). In this study we use the silhouette index method to obtain the optimal number of clusters (Barbieri *et al.*, 2001). In this method a silhouette index near one indicates good classification, whereas a silhouette near – 1 indicates misclassification (Kaufmann and Rousseeuw, 1987).

RESULTS
Preliminary analysis

Significant data cleaning is needed to deal with user-generated content on social media (Boiy and Moens, 2008). Following Geetha et al. (2017), we started by removing numbers, punctuations, white spaces, URLs, and special characters. The cleaning process also involved transforming letters from upper case to lower case. However, emojis/emoticons were kept for further analysis as they are considered an integral part of "modern-day digital communication" (Kejriwal *et al.*, 2021).

Since analyzing a corpus usually starts with generating word lists, we started by generating word lists as this step represents "the most radical transformation of a text used in linguistic analysis" (Barlow, 2004). Figure 3 depicts the result. The graph was constructed by ordering and ranking all the hijab fashion tweet words. Not surprisingly, the most widely used words include terms such as "hijab", "fashion", "wear", etc. We also used the word lists to test Zipf's law, which states that there is an inverse relationship between word frequency and its rank. It has been argued that validating Zipf's law is "the first step towards statistical analysis of languages" (Mehta and Majumder, 2016). Figure 4 confirms the existence of Zipf's law within the hijab fashion tweets as the relationship between word frequency and its rank shows an exponential decay typical of Zipf's law.

Figure 3. Word frequencies in hijab fashion tweets (> 150 words)

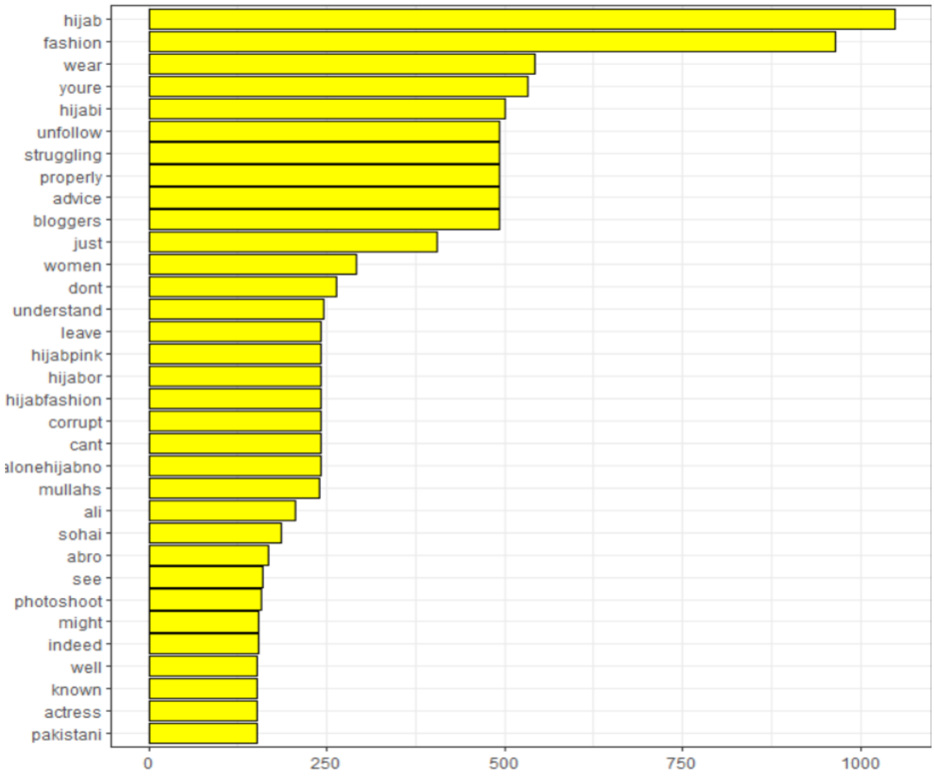
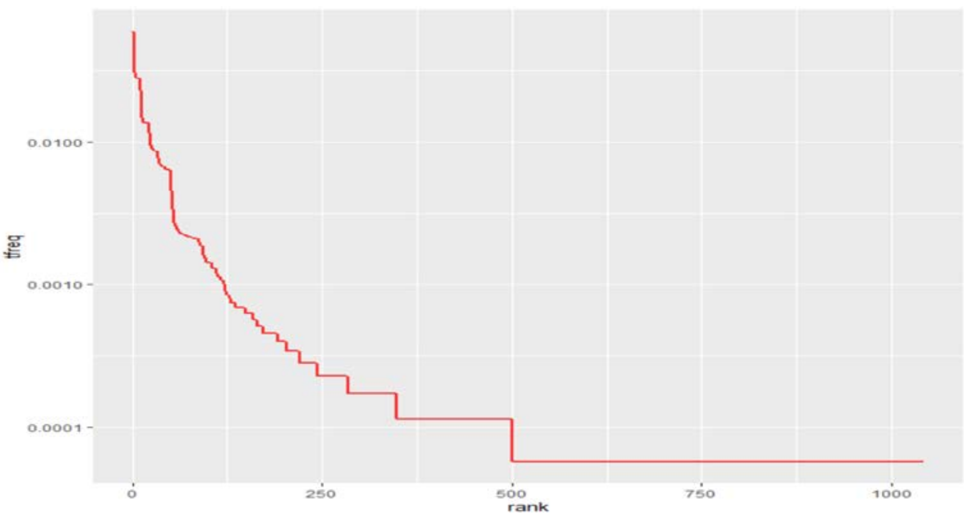
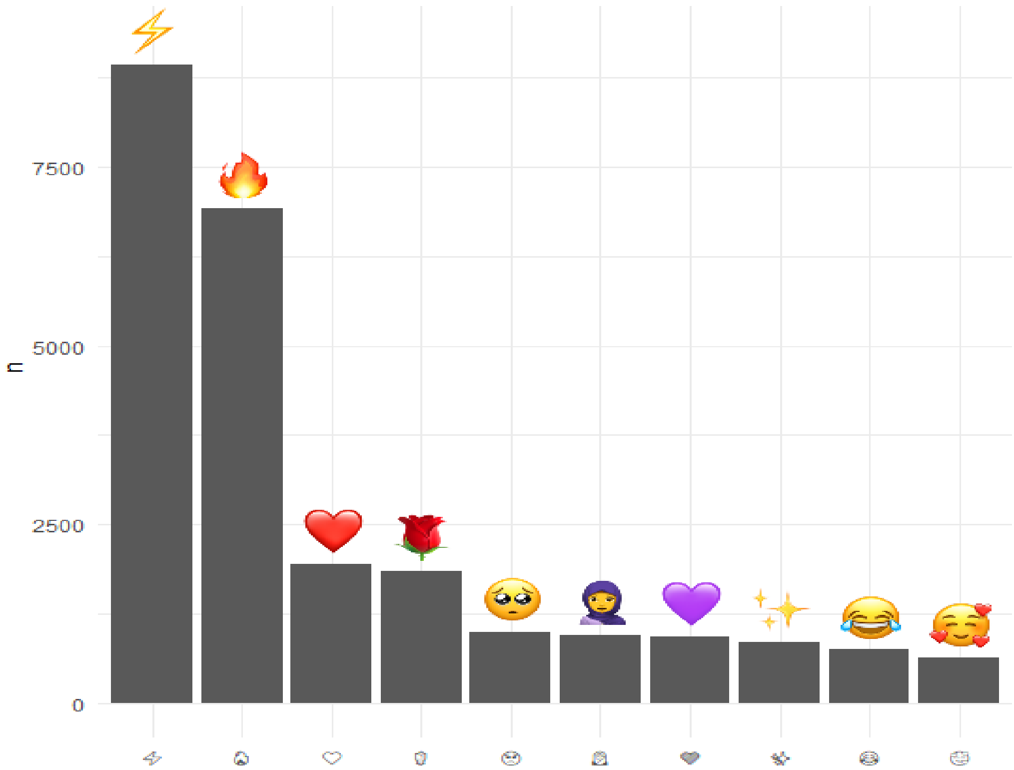


Figure 4. Zipf's law in hijab fashion tweets



Our preliminary analysis also involved extracting all the emojis used in the hijab fashion tweets. Because they can provide extra-linguistic cues not provided by the written text (Skiba, 2016), the analysis of emojis' frequencies can reveal how digital communications are conducted on social media platforms. Figure 5 shows the most widely emojis in hijab fashion tweets. From the graph we see that the top ten most widely used emojis include the high voltage, the fire/flame/hot, the red and purple hearts, the red rose, the woman wearing a headscarf, the sparkles, and the face with tears of joy. The high voltage emoji represents a lightning bolt, but it can be used to signify power, magic, energy, or strong emotions presumably attached to hijab as a fashion statement. The fire emojis is the second most widely used emoji and it can be used to symbolize love and energy. It is also a recognized symbol of "sexual attractiveness" as it signifies hotness, passion, and desire. The red heart is probably the most widely used symbol that represents love and romance. On the other hand, the purple heart, which is usually used by fashionistas, signifies glamour and vibrant rhythm. A woman wearing a headscarf/hijab is among the top ten most widely used emojis and this symbol usually conveys modesty and submission to the rules of Islamic religion. The face with tears of joy, once selected by the Oxford English Dictionary as the "2015 word of the year" comes in ninth place. This symbol signifies joy. However, it can be used sarcastically to symbolize things far from being adorable or funny. Taken together, the emojis used within the context of hijab fashion seem to be generally positive as they convey a sense of love, joy, desire, and affection.

Figure 5. Most widely used emojis in hijab fashion tweets



Sentiment analysis

Figure 6 depicts the classification of the hijab fashion sentiments into eight major categories using the NRC dictionary. This dictionary also provides a binary classification (positive/negative) of the sentiments. From the graph we see that the total number of positive sentiments (around 50,000) is higher than the total number of negative sentiments (around

30,000). We see also that positive sentiments like trust, anticipation and joy are much higher than the negative sentiments such as fear, anger, sadness, and disgust). To check the robustness of this finding, we compared the results obtained using the NRC dictionary against the results obtained using the AFINN and the Bing dictionaries. Figure 7 shows the result of the comparison. From the graph we see that while results differ in absolute terms, they follow generally the same sentiment trajectory, with distinguishable peaks and dips roughly around the same positions in the tweets. Figure 8 shows a temporal perspective of the sentiments' trajectory over the study period (2016-2020). The graph shows, in general, an upward trend in positive sentiments such as trust, joy and anticipation and a downward trend in negative sentiments such as anger, disgust, and sadness. Taken together, the sentiment analysis results show a positive sentiment towards hijab fashion/hijabistas.

Figure 6. NRC sentiment classification of hijab fashion tweets

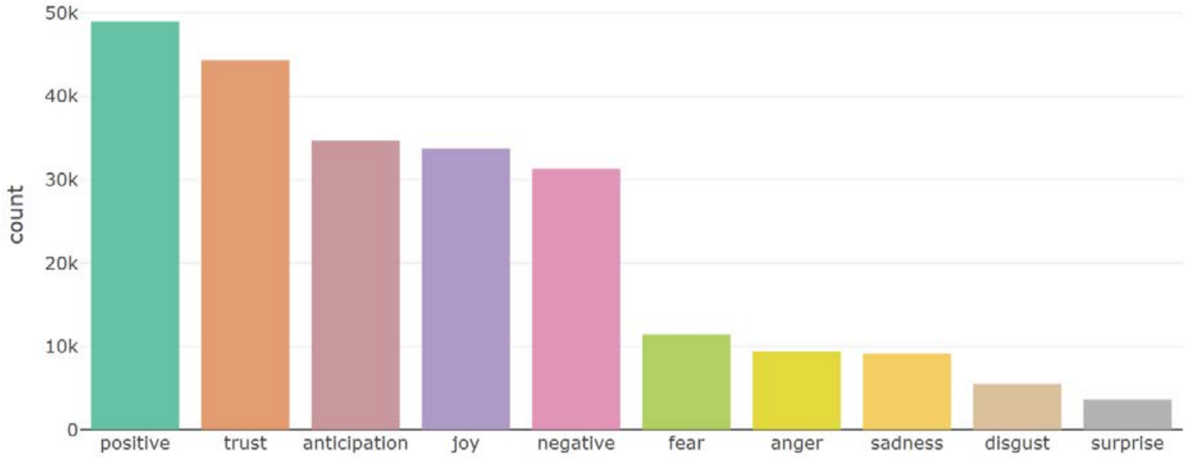


Figure 7. NRC, AFINN and Bing sentiment classification of hijab fashion tweets

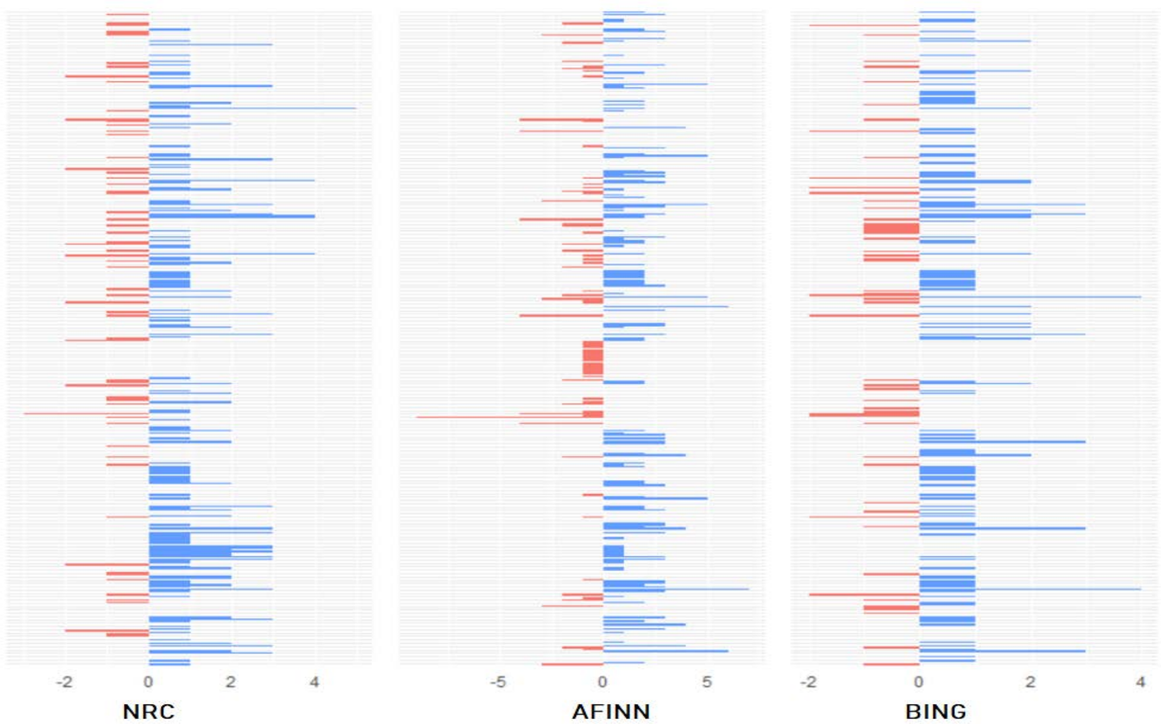
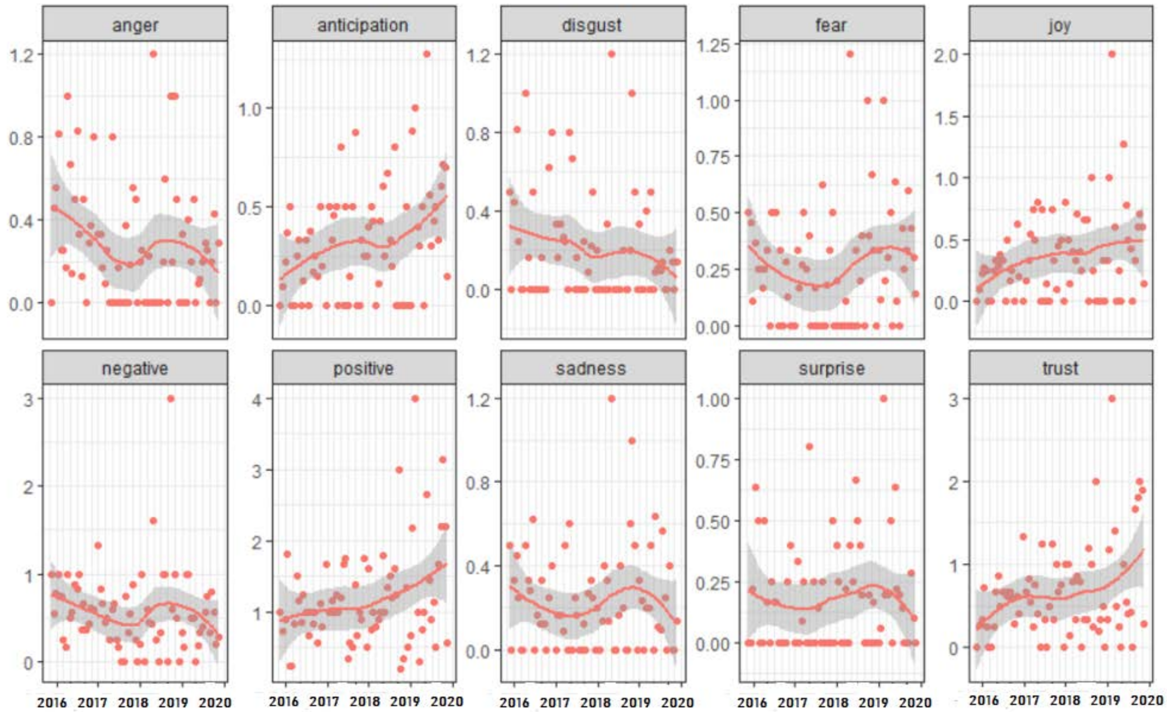


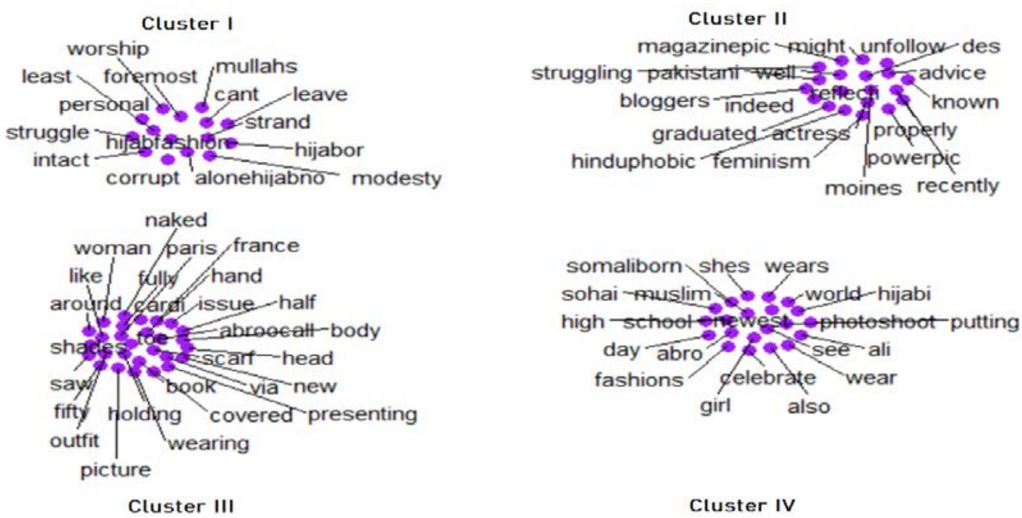
Figure 8. NRC sentiment classification of hijab fashion tweets over time (2016-2020)



Community detection

We run the Clauset et al. (2004) community detection algorithm on the hijab fashion tweets. Figure 9 shows the major four clusters obtained represented in a semantic network graph. In this graph vertices represent words, whereas arcs represent ties among words. Because the hijab fashion tweets were created by different tweeters nested within different communities, the resulting network can be taken to reflect “the collective cognitive structure among the creators of the text” Yuan et al. (2013). For example, cluster I focuses mainly on worship and modesty, whereas cluster II deals mainly with hijab fashion from a feminist perspective. Cluster III appears to deal with body image, while cluster IV seems to focus on the use of fashionable hijab style in celebrations.

Figure 9. Semantic network of hijab fashion tweets based on within-clusters’ correlations



We use the ternary plot to detect the homophily effect in the hijab fashion tweets. To reduce the computational burden, we construct the graph based on original tweets receiving at least two likes. The graph shows that, once tweeted, a tweet can be retweeted, liked, or replied to. However, while a post on Facebook is usually deemed successful as judged by the sheer number of comments/replies, provoking a sheer number of replies on Twitter signifies quite the opposite (Kušen and Strembeck, 2018). Figure 10 plots the ternary plot for the hijab fashion tweets. From the graph we see that most of the tweets fall on the bottom right, indicating that most of the tweets were liked or favored, whereas only few tweets were replied to. The graph implies that the hijab fashion communities tend to discuss different topic in a friendly and amicable manner, which is a sign of homophily (McPherson *et al.*, 2001).

Figure 10. Hijab fashion ternary plot of retweets, replies and likes

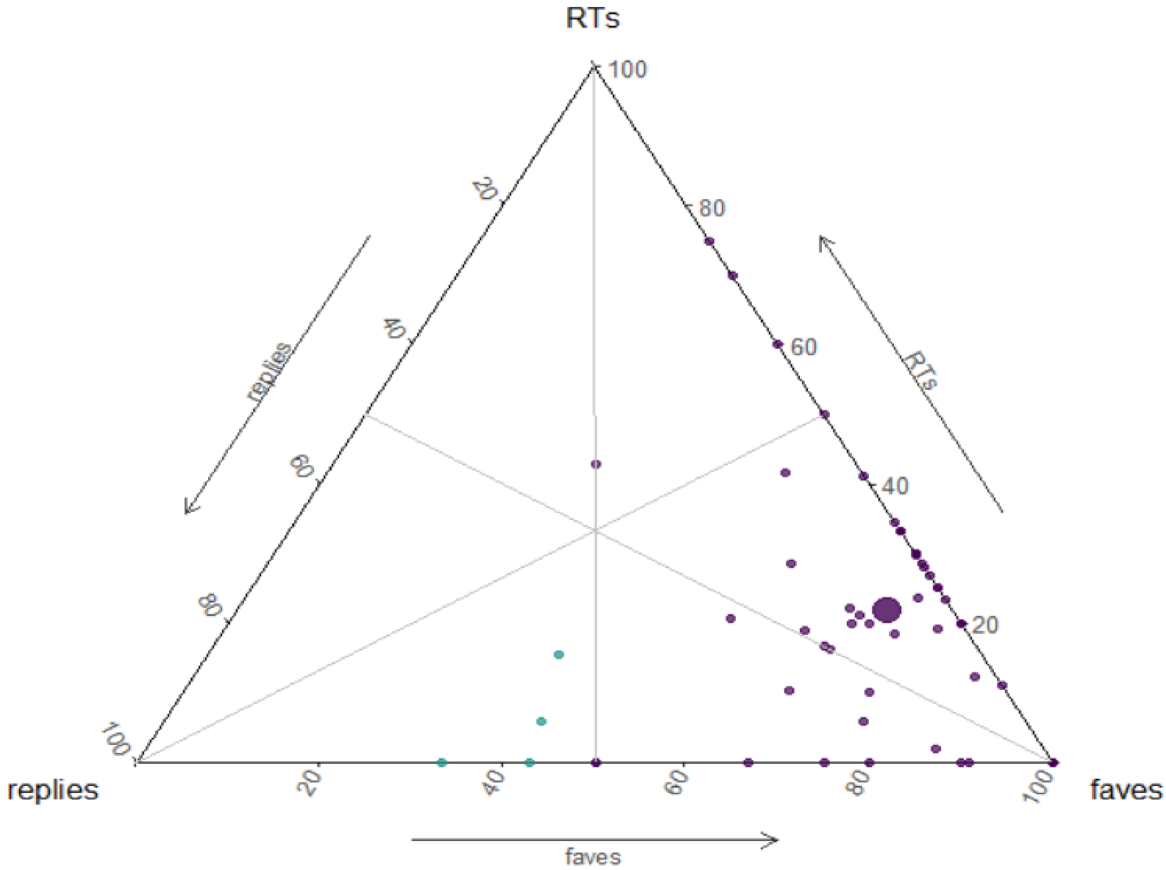
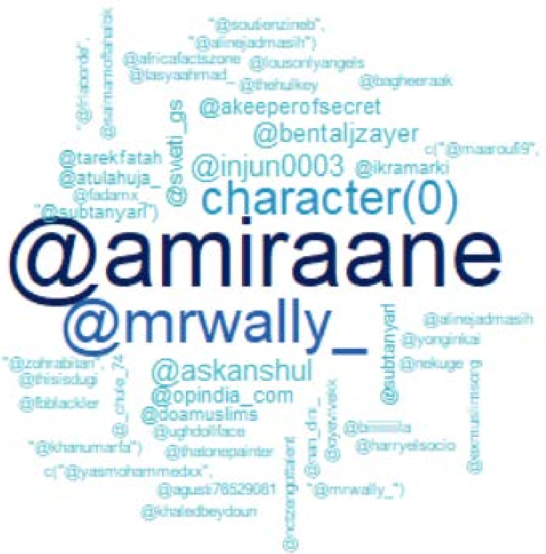


Figure 11 depicts the major hijab fashion influencers in a simple wordcloud. A wordcloud plot is an appealing visual tool that can be used to summarize textual data. The size of each word and its closeness to the cloud center determine its significance (Liao *et al.*, 2019). Identifying the key influencers in the network reveals the most important opinion leaders who "can set agendas by causing or facilitating dialog focused on a particular topic" (Huffaker, 2010). From the graph we see that the most important influencers are "@amiraane", "@mrwally" and "@askanshul." Such key influencers usually tend to communicate with opinion seekers to disseminate their experience and attitudes related to hijab fashion products and brands as they "generate interest, desire, learning and, crucially, new beliefs and intentions." (Ilich and Hardey, 2018).

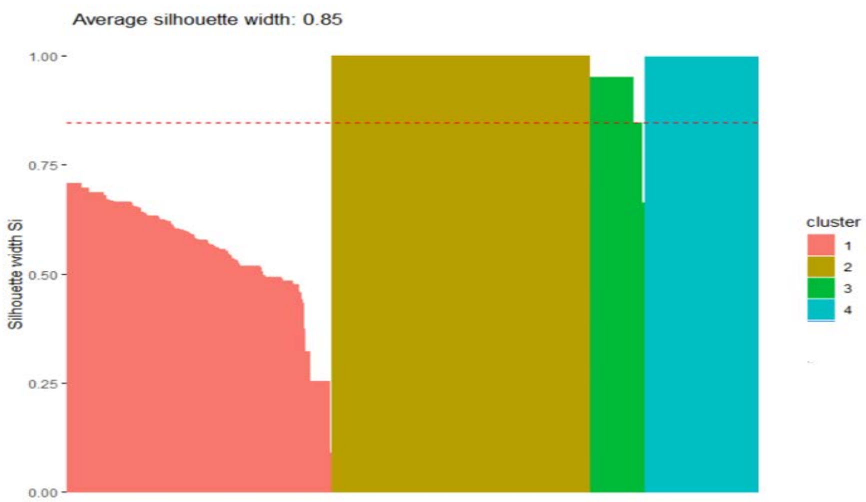
Figure 11. Hijab fashion major screen handles/influencers



PAM clustering

We run the PAM clustering algorithm to cluster hijabistas based on the whole sample of 144,800 hijab fashion tweets. Based on the community detection results, we set the optimal number of clusters to four. Figure 12 shows the resulting four cluster solution. The graph shows that first cluster (in red) is the largest cluster, and it includes 55,100 consumers (average silhouette width = 0.55), whereas the brow cluster is the second largest with 53,900 consumers (average silhouette width = 0.99). The third cluster in green is the smallest with 11,600 consumers (average silhouette width = 0.89). Finally, the blue cluster comprises 24,200 consumers (average silhouette width = 0.98). Since the average silhouette width was 0.85, this might be taken to indicate that a robust clustering solution was achieved.

Figure 12. PAM clustering of hijab fashion tweets



Since tweets in cluster I focuses mainly on topics such as "modesty" and "worship", this cluster was termed "Spiritualists." Consumers in this cluster appear to wear fashionable hijab styles in strict adherence to Sharia laws. Cluster II appears to deal with hijab fashion through feminist lens. This cluster was termed "Feminists." In fact, the feminist standpoint theory has been extensively applied to scrutinize Muslim women's standpoints on hijab. Results revealed that "hijab functions to define Muslim identity, perform a behavior check, resist sexual objectification, afford more respect, preserve intimate relationships, and provide freedom" (Droogsma, 2007). In a similar vein, al Wazni (2015) found that compared to Western feminists, "Muslim women are no less in congruence with the values of choice, freedom, and gender equality." Cluster III seems to deal with body image, and it includes topics such as "body" and "naked." This cluster was termed "Idealists." It appears that although the hijab has been seen through the feminist lens as a sign of "subjugation to male dominance," there is a stream of research that started to appear a decade ago, which argues that hijab indeed protects women against "negative body image ideals" al Wazni (2015). For example, in a survey dealing with body image attitudes among a sample of Australian women, Mussap (2009) found that hijab may protect "by buffering against appearance-based scrutiny (through adoption of traditional clothing) and by insulating from exposure to Western ideals (by discouraging consumption of body-centric media)." The last cluster seems to focus on the use of fashionable hijab style in celebrations. This cluster includes topics such as "photoshoot" and "celebrate." This cluster was termed "Celebratists." Consumers in this cluster appear to use hijab mainly as "brand statement." (Mohamad and Hassim, 2021) argued that this new trend has emerged "through the intersectionality of culture, religion and consumption."

DISCUSSION AND CONCLUSIONS

Based on a sample of 144,800 hijab fashion tweets, the present research takes a Twitter analytics text mining approach to profile and cluster the global market for hijabistas. Although a single tweet cannot currently exceed 280 characters, active Twitter users exceed half a billion and the sheer number of tweets posted daily can be used to obtain an unbiased estimate of consumers' real sentiments (Bliss *et al.*, 2012). Since tweets posted on Twitter can reduce information transaction costs by diminishing geographical constraints (Coiera, 2000), marketing researchers can use the tweets posted globally to capture the real sentiment and preferences of the consumer. Unlike the traditional face-to-face interviews and focus groups, microblogs are freely available, and they do not usually suffer from social desirability because web platforms offer "relative anonymity to users" (Fang *et al.*, 2014). Furthermore, sentiments expressed on social network platforms can be used as a benchmark against objective criteria such as sales and revenue data. Since prior research found that around one-fifth of all microblogs mention a brand name (Jansen *et al.*, 2009), it follows that managing hijab fashion brands on social media through marketing and advertising campaigns should form an integral part of any proactive marketing strategy. Through such marketing strategies, the "blogosphere" can be utilized by brand managers to monitor microbloggers' opinions and to intervene, if necessary, to quickly communicate with disgruntled customers. Tweets showing positive sentiment towards hijab fashion can also be used as a viral marketing tool to promote such brands.

Our results show high diversity and density of emoji usage in tweets dealing with hijab fashion tweets, including the high voltage, the fire/flame/hot, the red and purple hearts, the red rose, the woman wearing a headscarf, the sparkles, and the face with tears of joy. This finding is in line with (Kejriwal *et al.*, 2021) who found that the "heart emoji was found to be much more common in some of the Arabic-speaking Middle-Eastern nations than in Western nations that tended to favor smiley-based emojis more." This result implies that emojis should not be treated as universal across cultures. Thus, widely used hijab fashion emojis might be used by marketers to communicate effectively with consumers based on their culture since prior research has shown that there is a possible cultural gap in emojis' perceptions among consumers (Kimura-Thollander and Kumar, 2019).

Detecting hijab fashion influencers, or opinion leaders who "can set agendas by causing or facilitating dialog focused on a particular topic" (Huffaker, 2010), is important research finding since such actors tend to create creative intimate content that other consumers are most likely to appreciate and imitate (Mostafa, 2020). The major influencers identified include "@amiraane", "@mrwally" and "@askanshul." Such prolific hijab fashion actors represent opinion leaders "who connect with opinion seekers in order to communicate brand attitudes and experiences" (Mostafa, 2020). This result suggests that only a small close-knit group of influencers/micro-celebrities dominate the flow of information in the hijab fashion network. Brand managers should target such micro-celebrities as such influencers can "navigate the contradictory demands of the social worlds they inhabit" (Boy *et al.*, 2018). Prior research has argued that it is imperative for brand managers to use social mediators to engage with the public (Himelboim *et al.*, 2014). We argue that micro-celebrities occupy a central position in the hijab fashion network and as such they can bridge the "structural holes" in the network because they have an immense "structural advantage" as information brokers (BURT, 1999).

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References available upon request.

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Clinical Decision Support Systems Implementation: Pros and Cons

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ABSTRACT

According to the CMS, healthcare spending in the United States has increased steadily since the 1960s. CDSS was implemented to improve efficiency by reducing spending through prevention and early detection of diseases and reducing unnecessary tests. Despite the benefits of CDSS, there are risks which, although minimal, must be addressed. The current study examines how CDSS is implemented and used in the healthcare industry in the US; by evaluating its benefits and drawbacks on two government mandates, namely, HiTECH Act and PAMA. The paper offers suggestions for improving effectiveness in US healthcare using EHRs.

KEYWORDS: clinical decision support systems, electronic health records, clinical decision support, appropriate use criteria, Centers for Medicare & Medicaid Services, clinical decision support mechanism, Healthcare Management

INTRODUCTION

Clinical Decision Support has been defined as a technique for enhancing health-related decisions and actions with pertinent, organized clinical knowledge and patient information therefore, improving healthcare and healthcare delivery (Osheroff, 2012). According to Charles & DelVecchio (2018), CDSS is an application that analyzes data to help healthcare providers make decisions and improve patient care. The goal of CDSS is to lower the cost of medical treatment, increase efficiency, and decrease the risk of improper diagnosis. With CDSS, healthcare administrators aim to benefit from clinical advice and assistance at the time of care and recommend the best treatment plan based on multiple factors of patient-related data (DelVecchio, 2018). There are two main types of CDSS: knowledge-based representing the majority at about 85% of all CDSS and non-knowledge-based which is just a fraction. Knowledge-based CDSS uses patient information in the data repository and analysis tools to provide results as well as signaling alerts to healthcare providers; while, non-knowledge-based CDSS utilizes machine learning such as artificial neural networks to analyze clinical data. The goal of this research is to analyze the implementation and use of CDSS in healthcare; as well as to evaluate its benefits and drawbacks on two government mandates, HiTECH Act and PAMA.

The paper also offers suggestions for improving effectiveness in the US healthcare using EHRs. To do so, we will first review the landscape of CDSS and present both HiTECH Act and PAMA.

BACKGROUND OF CLINICAL DECISION SUPPORT SYSTEMS

The CDC review by the Community Prevention Services Task Force found that CDSS has led to significant improvement in the quality-of-care practices for Cardiovascular disease prevention: 1) recommendations for screening and preventative care, 2) evidence-based clinical test, and 3) cardiovascular disease related treatments prescribed (CDC, 2021). The global CDSS market focuses on product type, model, user interactivity, application, and regional adoption. In 2018, the leading product segment in the market accounted for 42% of the overall CDSS market combined CDSS tools integrated with either electronic health records (EHR) or computerized provider order entry (CPOE) systems (Cision, 2019). The primary focus for the global growth of CDSS is to address the need to reduce the rate of medication errors, which significantly increase healthcare costs (Cision, 2019). Despite the benefits, CDSS is experiencing a low adoption rate because of the challenges pertaining to its implementation. CDSS tools are perceived by some physicians as a threat to their professional autonomy.

One roadblock slowing the implementation of CDSS was the lack of assurance of healthcare professional that decision support models were not to replace physician training. Physicians' reticence against adopting CDSS rests in the low confidence in the evidence provided by such models. In addition, to physicians do not appreciate the idea of overreliance on a device rather than their years of medical expertise. Furthermore, the need for regular updates of databases, from which the information is extracted to create a knowledge base is necessary to reduce medication errors and misdiagnosis. Although the main drivers are the rising healthcare costs and rapidly increasing rate of hospital readmissions might be attributed to CDSS. The increase use of clinical decision support systems in recent years was driven by the passage of the HiTECH Act which stipulated that, by 2015, healthcare providers should demonstrate a meaningful use of Health IT, or face a reduction in Medicare Reimbursement (DelVecchio, 2018). Below is an overview of the HiTECH Act followed by an analysis of the PAMA.

HiTECH Act of 2009

The Health Information Technology for Economic and Clinical Health Act (HiTECH Act) was part of a stimulus package under the Obama administration and was signed into law in February of 2009. The HiTECH Act is broken into four subtitles: First, promotion of Health IT, Second, testing of Health IT, Third, grants and loan funding, and fourth, privacy and security of Health IT. The primary goal of the HiTECH Act was to increase the usage of health information technology and specifically the use of electronic health records (EHRs). A secondary goal was to strengthen the language of the Health Information Portability and Accountability Act (HIPAA) and impose stricter penalties when a patient's privacy is breached (HIPAA, 2021). The HiTECH Act mandated and provided incentives to help medical providers implement EHR systems; as prior to it, only 10% of hospitals utilized EHRs due to the high implementation cost. As a result, Department of Health & Human Services was given more than $25 billion to incentivize medical providers to implement and use EHR systems in a meaningful way such as issuing electronic prescriptions and the exchange of health information to improve quality of care (HIPAA, 2021). The Financial incentives were significant and increased yearly as new requirements were added under the "meaningful use" program; and medical providers that did not meet the requirements faced a financial penalty including a reduction of reimbursement for Medicare & Medicaid.

The “meaningful use” program also known as the Medicare EHR Incentive Program became a components of the Merit-Based Incentive Payment System (MIPS), mainly with the introduction of the Medicare Access and Chip Reauthorization Act-MACRA (ONC, 2019). MIPS is a collaboration between different CMS quality programs that are: meaningful use, physician quality reporting program, and value-based payment modifier. MIPS was set to achieve the following four goals: 1) improve quality safety, efficiency, and reduce health disparities; 2) engage patients and family; 3) improve care coordination, population and public health; and 4) maintain privacy and security of patient health information. These four goals were set to create: better clinical outcomes, improve population health outcomes, increase transparency and efficiency, empower individuals, and robust research data on health systems (ONC, 2019). Therefore, by 2017, 86% of office-based physicians and 96% of non-federal acute care hospitals had implemented EHR (ONC, 2021). As HiTECH Act is the government mandate increasing the use of EHRs, PAMA is the government mandate requiring physicians to consult AUC.

Protecting Access to Medicare Act

The Protecting Access to Medicare Act (PAMA) established a new program requiring physicians to consult appropriate use criteria (AUC) when ordering advanced imaging exams such as: computed tomography (CT), positron emission tomography (PET), nuclear medicine, and magnetic resonance imaging (MRI) under the Medicare’s Prospective Payment System (PPS) beneficiaries. The AUC requires that when an advanced diagnostic imaging service for a Medicare beneficiary is ordered the provider must consult a qualified clinical decision support mechanism (qCDSM) for appropriate use criteria. This allows practitioners whose advanced imaging ordering patterns are abnormal to be subject to a prior authorization (CMS, 2021). Consultation is required in medical settings includes: physician offices, hospital outpatient departments, ambulatory surgical centers, and independent diagnostic testing facilities (PAMA, 2020). The plan was that the AUC program be fully implemented and running by January 2022. The CMS has the following exemptions to the PAMA criteria of utilizing a qCDSM for AUC evaluation: emergency services, services furnished under Medicare Part A, and Hardship, including insufficient internet access, EHR or CDSM vendor issues, and extreme or uncontrollable circumstances.

As the passage of PAMA tied advanced diagnostic imaging services to AUC, the Society of Nuclear Medicine & Molecular Imaging revised their AUC development methodology and classified their AUC development to include a systematic review of evidence followed by developed AUC for various scenarios using a Delphi process (SNMMI, 2021). AUC is used to determine the appropriate time to perform a specific medical procedure or provide a service. A service is “appropriate” when its health benefits exceed the risk by a predetermined margin. For example, if a patient needed a cardiovascular scan but also suffers from kidney failure and is at risk of having his kidney damaged by the “dye” used in the procedures, the healthcare team would need to evaluate the risk of the procedure to the cardiovascular system; they may either opt for a different scan that doesn’t utilize the damaging “dye” or in case the alternative is not the best option, they may determine if there is enough of risk to the kidneys to modify the scan. Appropriate use criteria are usually evidence-based, but in certain cases there is insufficient “concrete” evidence and a decision may be reached by the consensus of expert opinions.

BENEFITS AND RISKS OF CDSS TECHNOLOGY

Most people trust in the power of medicine to regain their health, but some have their mind fixated on how taking the wrong medicine can be detrimental to one's health. Prevention of wrong procedures or adverse drug reaction can be a game changer in the field of medicine. The awareness of medicines that can possibly give patients more hardship can be a benefit of healthcare facilities using CDSS. A more detail analysis of the advantages of CDSS is needed for understand why the government thinks it is necessary to mandate technology tools to healthcare facilities.

The Benefits of CDSS Technology

The world today is driven by social culture in which the leading factor is innovation in all the sectors of society. Medical devices have been introduced in healthcare to access patients' conditions, improve the process of early detection, and increase longevity. Patients are concerned with the process of life and overall outcomes of their actions and are aware of government spending on healthcare. For instance, if the government passed an act giving senior citizens allowances for healthcare, some facilities will device a skim to sell those senior citizens services geared toward requesting services they don't need, therefore, tapping into government funds. There is a strong correlation between drug allergies and the mixing of medicines that do not mesh chemically; however, adverse drug reactions may come from other sources. The Royal College of Physicians, classified drug reactions into either Type A or Type B reactions. Type A reactions, referred to as augmented reactions, are dose-dependent and predictable based on the pharmacology of the drug; while Type B are bizarre idiosyncratic reactions, that are not predictable based on the pharmacology (Coleman & Pontefract, 2016). Regardless, when the drug is administered, the adverse reactions take its toll on the patient's health. While type A reactions can be avoided if research is conducted on the patient and the dosage adjusted based on background information; Type B is unpredictable and may require a more systematic course of action deriving from previous occurrences and a cost-benefit analysis.

Technology tools, such as CDSS, may help organize past data and provide much accurate information. Men are, for instance, expected to be checked for prostate cancer at the age of 40; however, if there is a family history of the disease, the men in the family must be screened earlier. Early detection is usually vital, because, although all disease detected could not have been prevented or be cured, the purpose of early detection may just be to slowdown the progression and alleviate the patient condition over time; therefore, increasing the patient longevity. Longevity often derives from of one taking good care of oneself by knowing the dos and don'ts of the pathology and respecting healthcare professional advices about the illness. Another benefit of early detection is that when someone knows that he has a medical condition, he develops a plan of action to take care of himself; and those individuals, which are given clean bill of health are at peace and joy, and therefore, relieve from the stress of not knowing and increase longevity. This stress from knowing that if misused, CDSS may have unintended risks that are discussed next.

The Risks of CDSS

Mistakes can happen when using a CDSS and create problems for doctors or patients if not properly handled. Problems range from the rigidity of the systems, alert fatigue, or human errors. Rigidity, since CDSS cannot be changed in a short period of time, doctors cannot always access patients' information quickly and efficiently; which can interrupt workflow for physicians and healthcare facilities and cause a loss in productivity and lose of money. Alert fatigue may be dangerous to patients' health and safety as physicians do not take every alert seriously. The main concern about alerts are their inconsistency, which can cause doctors to put priority on patients who may not need urgent assistance. Another issue with alert fatigue is the over alerts that doctors and physicians get throughout their workflow. Some doctors ignore alerts completely while others attend to every alert they get, which is dangerous because after answering many unimportant alerts a physician may be slow to respond to or ignore to a very critical one. Alerts such as drug interactions are sometime ignored but can be a real problem. There are potential sources of errors from CDSS, for instance, the auto complete features which can be problematic for doctors when filling out patient's information as it adds misstate to the data. In addition, alerts such as drug interactions are sometime ignored but can be a real problem.

Hospitals or medical facilities will be liable for the mistake; therefore, updating the system can also lead to typing errors. Another source of error can be the timing of the system; as workflow is essential to keeping the hospital running at an efficient rate. If an alert comes at a bad time, it can cause a chain of events that can lead to disaster. Some alerts can come late or are delayed which be hard to take any action. If hospitals do not want to lose productivity or slow down workflow, they must maintain a consistent and reliable system that can alert physicians promptly in case of emergency. The health and safety of the patients is top priority for hospitals and medical facilities and CDSS has the potential to save lives; but there needs to be adjustments to prevent systems failure resulting into accident or lose of live. Most pitfalls and errors could be avoided with CDSS, which benefits can revolutionize the medical field.

Digging deeper the drawbacks and threats of CDSS, may create a system that might revolutionize medicine and save many lives. A study on the effectiveness of a CDSS, commissioned by the Agency for Healthcare Research and Quality (AHRQ), revealed that an improper use of CDSS can be more harmful than not deploying the CDSS at all. CDSS must be integrated with the organization's existing workflow, which is often complex. Some CDSS are stand-alone and do not allow communication with EHR systems; therefore, those CDSS may be detrimental to a provider and can potentially lead to major issues. It can be difficult to quickly and frequently update the CDSS with information from clinical research and medical trials. Problems such as alert fatigue, loss of autonomy, workflow changes, anxiety due to potential legal repercussions of CDSS often occur. Even though some alerts are vital for patients' survival, low value alerts can fatigue doctors and make them not take every alert seriously. This is very dangerous, because uncertainty in the medical field can lead to hazardous actions from the doctors and present a health risks for patients.

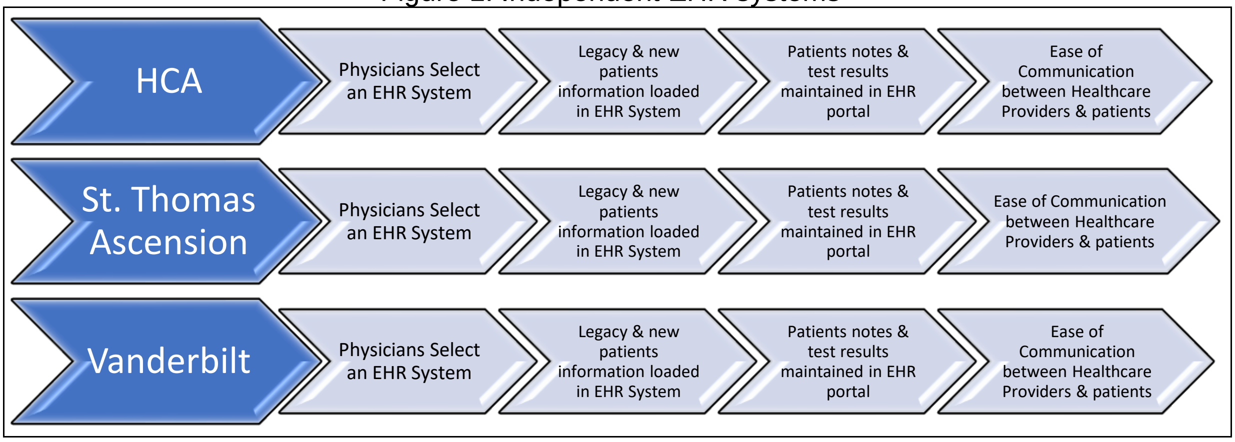
Though many doctors and the medical literature say that EHRs are the best way going forward, some believe that there are still some problems that remain a disadvantage for the electronic system. Some of the financial issues include but are not limited to, temporary loss of productivity, privacy and security concerns, and other unintentional consequences; as a result, the system can cost companies thousands of dollars to implement into the workflow. Menachemi & Collum (2011) argued that "Financial issues, including adoption and implementation costs, ongoing maintenance costs, loss of revenue associated with temporary loss of productivity, and declines in revenue, present a disincentive for hospitals and physicians to adopt and implement an EHR." Similarly, in a 2002 study of a 280-bed acute care hospital, the projected cost for a 7-year long EHR installation was approximately $19 million (Schmitt & Wofford, 2002). These thousands of dollars anticipated to put these systems in place and do not include the cost of hiring and training physicians and medical staff on the new system, of maintenance and of upgrading the system on a regular basis. Another disadvantage is the disruption of workflow for medical staff, which can cause a loss in productivity and potential loss of revenue if adjustments are not made in a reasonable amount of time. The average loss of revenue for a provider would be at least $9,000 per provider or physician. Wang et al. (2003) analyzed several internal medicine clinics and estimated a productivity loss of 20% in the first month, 10% in the second month, and 5% in the third month, with productivity subsequently returning to its original levels; they reported a loss of about $11,200 per provider in the first year.

Privacy and security are also major issue that many people foresee into the future. Today, policymakers have taken measures to make sure that all information and patient data is safe and secure. Recent legislation has imposed regulations specifically relating to the electronic exchange of health information that strengthen the existing Health Insurance Portability and Accountability Act privacy and security policies. Parver (2009) reported that “Although few electronic data are 100% secure, the rigorous requirements set forth by the new legislation make it much more difficult for electronic data to be accessed inappropriately.” People fear that information going through electronic system may not be properly protected; but since medical facilities are for most transitioning to a more electronic workplace, policies and rules are being put in place to help protect patients’ data.

PROPOSED MODEL OF CDSS TECHNOLOGY

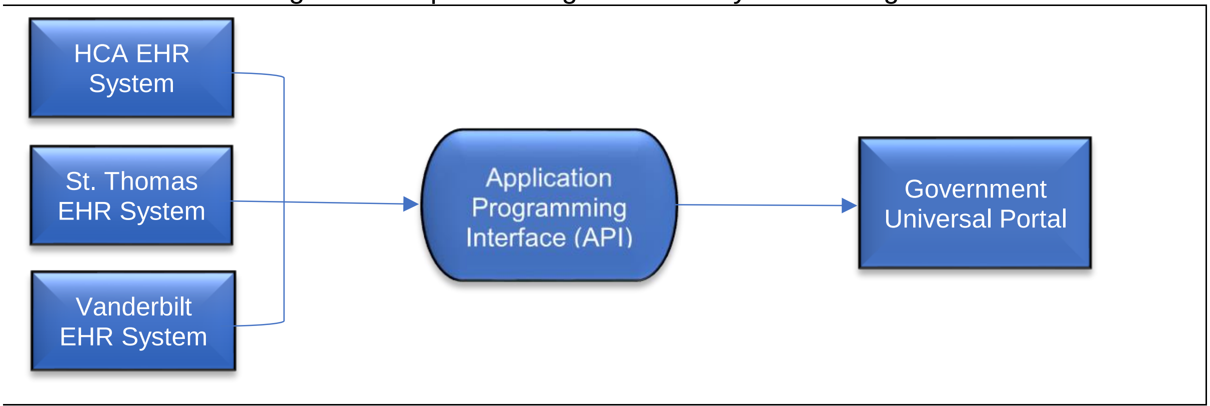
Vanderbilt Clinical Informatics Center (VCLIC) and Vanderbilt University Medical Center (VUMC) launched the Clickbusters program to reduce the number of EHR alerts at VUMC (Jason, 2021). The goal was to reduce the number of alerts received and to improve the quality of alerts. VUMC examined the signals that were used and those that were not. Which optimized the signals used and enhanced there impacts on the user. The CDSS has led to the improvement of the medical field and an increase in the quality of healthcare, but there is room for further improvement and changes are needed on how the CDSS works, looking into the future to protect the patients and make the work of the doctors easier and more efficient. Khairat et al. (2018) analyzed previous studies on user acceptance related to clinical decision support systems (CDSSs) and reported that, CDSSs reduced medical errors and improved patient outcomes, but they felt short of their full potential due to user acceptance.

Figure 1: Independent EHR systems



While EHR are used widely across the US many of these systems cannot talk to each other and still require printing and snail-mailing of records from different hospitals. If you look at the main healthcare systems in Nashville (HCA, Vanderbilt, and Ascension) they all have EHR systems that allow doctors to electronically track a patient's health history and communicate a patient's test results back to the individual through a secure portal. While this system is beneficial it does not allow records to be shared with a provider under another Healthcare system. If you see a primary care physician and a dermatologist at Vanderbilt then all your records are available for both physicians to review and there is not an issue; however, if you see a primary care provider at HCA and dermatologist at Vanderbilt then your primary care provider cannot see or review your medical records from the dermatologist. Figure 1 shows how the current EHR system works and all the healthcare systems are independent and do not intermingle.

Figure 2: Proposed integrated EHR systems using API



To improve the implementation of CDSS; one solution is to involve physicians in the design process by utilizing their expertise on user expectations and the usability of the system; another solution is an input-process-output-engage(IPOE) model which would add an "engage" stage that displays the CDSS process to the physician as a component of their decision-making while allowing their professional autonomy (Khairat et al., 2018). Given the opportunity presented by COVID-19 at an attempt to a universal system, the US could develop or purchase a "universal EHR system" which individual medical practices will have to update with an application programming interface (API) to utilize this universal EHR system so records can seamlessly be shared between different medical facilities. Once you have EHR utilization at more than 95% range you can then focus on deploying other CDSS systems and implementation will increase as more trust in built in EHR and their benefits are more visible to the patient and care providers. Figure 2 shows how an API system can be utilized to connect all the existing EHR systems to a new, universal EHR patient portal so providers can achieve a complete view of their patients' health.

CONCLUSION

Khairat et al. (2018) summarized favorable and unfavorable responses: on the one hand, favorable responses included: ease of use of the system, perceived time savings, and perceived usefulness regarding improving care and patient health; On the other hand, unfavorable responses involved workflow interference-excessive alerts, increased time troubleshooting computer issues, and decreased face-to-face time with patients-, validity of the system, and lack of efficiency; results showed that the least favorable system was reminders and alerts for evidence-based guidelines tested most likely due to "alert fatigue". This can affect doctors' response and in turn pause a risk to patient health. EHR systems and CDSS technology need to come at no risk to patients but rather to be an asset for healthcare facilities reducing medical errors. The healthcare system could benefit from a uniform system that could allow healthcare facilities to connect a universal EHR portal using application; therefore, allowing physicians to access patient's information in a timely manner and reducing errors. However, this universal system should be received physicians' inputs to ensure that it is set to their specifications and meet their needs for their patients. In any case technology should come to improve any existing system, alleviate physicians' workload, and guarantee better healthcare for patients.

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CONNECTING AUTOMATED SERVICES TO PRODUCT DEVELOPMENT IN THE LIGHT OF CUSTOMER EXPERIENCE

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ABSTRACT

We present the results of a survey which was carried out on Strategic Orientation (SO) and Customer eXperience (CX) issues in product-service development regarding automated-services. The paper focuses on CX issues comparing the use of automated services to human-based services. The results showcase that many human-services features are more important than automated-services features when it comes to the development of services. Aligning the Industry 4.0 paradigm, which uses intelligent manufacturing through cheap and ubiquitous sensors with high computational speeds, with a social CX approach is an imperative for companies that want to stay ahead in today's volatile and competitive market.

KEYWORDS: Product development, human-based services, automated services, and customer experience (CX)

INTRODUCTION

Gaiardelli et al. (2021) claim that today manufacturing companies are pushed by saturated and commoditized global competitive environments to change the nature of their businesses, from being 'owners of competencies and resources to becoming integrators of skills, resources, and technologies able to realize complex value creation processes'. This new reality necessitates the provision of the so-called Product-Service System (PSS): 'A system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfies customer needs and has a lower environmental impact than traditional business models' (Goedkoop et al. 1999). PSS can be considered as a market proposition that extends the traditional functionality of a product by incorporating additional services, often embracing sustainability aspects (Bianchi et al. 2009). PSS is a combination of services, products, networks and infrastructures delivered as a system to the customer. The PSS business model development requires a combination of the technical intensified digitalization and the social Customer eXperience (CX) enabling a transformation from hard-wired value chains to adaptive product-service value creation networks.

The principles of the Total Quality Management (TQM) were the core of a disciplined approach which aimed at the continuous improvement and at customer satisfaction (Deming 1986). As the global market has rapidly changed and customers have become more demanding, the development process had to adopt a user-oriented approach which put emphasis on users and their requirements throughout each developmental stage (Siakas and Siakas 2016). This can be notices even in more recent approaches as is the case of Agile development (Lampropoulos and Siakas 2018) and DevOps (Lampropoulos et al. 2019), users and customers actively participate and affect the development process as their role and opinion offer significant value and competitive advantages and it is vital when it comes to successful product and service innovation (Siakas and Siakas 2016). Additional services have shown to be a potential enabler for customer loyalty and business growth (Ardolino et al. 2016). As the competition for innovation rises in the increasingly demanding global market and CX is mainly materialized through strategies including social networking, crowdsourcing, open innovation, artificial intelligence (AI), Internet of Things (IoT) and Big Data, there is a need for a holistic approach to be adopted (Sivula & Kantola 2016). By focusing on improving CX and having users at their core, enterprises can enhance their customers' satisfaction and loyalty, improve their word-of-mouth marketing, become more flexible and stay ahead of the competition (Colomo-Placios et al. 2014). The value of any service and product is created, comprehended and defined by the customer/user and their usage which for the case of services is also named value-in-use (Siakas & Siakas 2016). Trends in manufacturing including connectivity, digitalization and automation are changing the way organizations and customers' perceived value (Chávez et al. 2021).

The advances in Information and Communication Technologies (ICTs) and the intensified digitalization have urged manufacturers to redefine their value propositions through increasing traditional product offerings with supplementary services (Gaiardelli et al. 2021). Machchhar and Bertoni (2021) assert that the required solutions include both product and service-related dimensions incorporated in a PSS. Regarding complex systems, the interpretation of customer needs into functional requirements do not only include the physical entity that only is one part of the complete solution. The development of a solution requires the development of a complete PSS, including both the main product and supplementary services. The challenge in such a PSS can be to find the accurate analogy of products and services that create value for the customer process (Machchhar & Bertoni 2021). Chávez et al. (2021) also emphasize that there is a need to further investigate the customer's perception of value associated with a PSS to further address the strategies manufacturers should implement.

Established systems engineering processes relying heavily on modeling and simulations are used in complex development projects to guide design decisions. This has led to more accurate mechanical simulations including Multidisciplinary Design Optimization (MDO) to support design decisions that rely on the use of Design Automation (DA) (Amadori 2012). To enable DA, Knowledge-Based Engineering (KBE) is a method for utilizing existing knowledge in the engineering design process (Machchhar & Bertoni 2021).

Poot et al. (2020) presented how all the phases in product development from a customer need to production preparation can be automated via KBE systems. They demonstrated an integrated viewpoint on integrated sales and design via DA frameworks.

As services and products are the end results of the developmental strategy that a company followed, the crucial role of having customer-oriented development is apparent. In order to satisfy customers' requirements, it is essential to implement a business model that focuses on developing user-centred products. The business model is often regarded as the third dimension of innovation within an enterprise as it contributes to continuous and discontinuous types of innovations (Morris 2013). By utilizing an appropriate business model, product innovation that has users at its core can be seamlessly connected to services throughout the product development life cycle.

The fourth industrial revolution, named Industry 4.0 was the result of the rapid and continuous technological advancements which led to the development of intelligent, autonomous and automated services (Lampropoulos et al. 2018). This fact has resulted in the development of non-human-based services which in return have drastically affected the overall CX (Ameen et al. 2021). Nonetheless, as enforcing technology-based solutions cannot replace all services is vital to examine which services can remain human-based and to what degree and which can be completely automated.

Hollebeek et al. (2021) argue that Artificial Intelligence (AI) is likely to spawn revolutionary transformational effects on automated services by impacting the ways in which firms engage with their customers. The ability to deliver automated, human-like, digital interactions is a fact that will change Customer Engagement (CE) regarding customer interactions with companies, offerings, brands in automated service interactions. The more seamless the automated services are, the lower the likelihood of customers being aware that their interaction is with a machine instead of a human frontline staff (Hollebeek et al. 2021).

Strategic orientation (SO) and CX strategies are the two perspectives based on which the enterprises, product and service development can be assessed and evaluated as they constitute the main pillars of innovation and successful business models adoption (Pisano 2015; Keiningham et al. 2020). Based on the above-mentioned points, the following questions arise:

- what the role of SO in developing goods-service innovations is;
- what the role of CX in developing goods-service innovations is;
- what the role of SO in developing visible goods is;
- what the role of CX in developing visible goods is;
- what the role of SO in developing human-based services for visible products is;
- what the role of CX in developing human-based services for visible products is;
- what the role of SO in developing automated services for visible products is;
- what the role of CX in developing automated services for visible products is.

Based on the study on the above questions by Makkonen et al. (2022), CX is the most significant issue compared to SO in especially in developing human-based and automated services. Hence, it is essential to assess and evaluate the service development form a CX perspective. The role and positioning of automated services within the modern world still remain an open issue. There, it is important to compare human-based services CX to automated services CX as it will provide guidelines from different context regarding the proper utilization of these two types of services.

In this paper, the theoretical discussion on product-service alignment is presented and the concepts of SO and CX are described. Moreover, the research questions, the methodology and the results are showcased and analyzed in detail. Finally, suggestions for future research direction are provided.

ALIGNING PRODUCTS AND SERVICES

Product Service Systems (PSS) consist of product and service components that together meet the needs and requirements of the customer. The product components can be mechanical, electronic, or software (Helo et al. 2017). The service components can change according to the life cycle phase. The design and implementation of a PSS takes place within the extended value network of the PSS provider (Brunner & Schneider 2021). The PSS consists of two intertwined networks, namely i) the production network, which consists of suppliers of parts for manufacturing and ii) the service network, which is responsible for providing service products.

Digital servitization of manufacturing is ‘the utilization of digital tools for the transformational processes whereby a company shifts from a product-centric to a service-centric business model and logic’ (Kowalkowski et al. 2017). Servitization is getting increased importance in today’s global economy due to the need of manufacturing companies to increase customer loyalty by adding value and sustainability to their products. Servitization motivates companies to maintain and to improve their competitive position, establishing more lasting relationships and closer collaborations with their customers. The manufacturing companies are challenged to move from considering independently their products and services and instead to consider them integrated. This requires organizational changes and methodologies for integrating development processes of products and services.

Kohtamäki et al. (2015) emphasized the shift toward service-orientation in developing and delivering traditional industrial products which had been co-created with customers as its main point value. As good service enables increased sales and profits for a company, it is of importance to comprehend what the main elements and essence of the core product are. This process can be significantly affected by applying the correct strategies.

Da Silva and Trkman (2014, p. 9) asserted that “theoretical grounding should be able to explain both the observed trends receiving scholarly attention as well as establish a clear distinction among existing terms within the literature”. Moreover, they stated that business models refer to the understanding of how business works and how value is created for different stakeholders; hence they refer to the transfer of the selected strategies into the every-day business activities (Da Silva & Trkman 2014).

Product innovations, customer relations, infrastructure management and financial issues constitute the main components of a business model (Osterwalder & Pigneur, 2002). In order to develop and adopt sustainable business models, it is essential to comprehend these components and apply them within the appropriate context. As customer satisfaction and relation are regarded as definitive components in connecting services to products, the approach to business model in this study, is predominantly CX driven.

CONNECTING STRATEGY AND CUSTOMER EXPERIENCE

Business models mainly derive from SO and focus on satisfying customers' needs and requirements. Hence, in order to achieve product-service alignment of high quality, both SO and CX along with their main components should be examined. Furthermore, a business model which followed both SO and CX perspectives was presented by Keiningham et al. (2020). The CX aspect of this specific model include i) Cognitive (How all needs are satisfied), ii) physical (How this service helps you), iii) sensory (What kind of feelings you have after using the service), iv) emotional (How good the atmosphere is in a service) and v) social (How services support interaction) elements. On the other hand, SO involves i) cost leadership strategy, ii) differentiation strategy, iii) differentiation focus strategy, iv) cost focus strategy and v) hybrid strategy.

OUR STUDY

The main factors addressed in this paper are human-based and automated service design with the aim of enhancing the overall development process and the end product. Automated services are anything that allows customers to solve potential problems without interacting with a human being. Automated support systems are available to provide support 24 hours seven day a week and thus they are more cost-effective than human customer support representatives. Moreover, particular emphasis is placed on the role and impact of CX in user-centered service design. These factors and CX variables are examined through analyzing students' viewpoints and attitudes. The specific aims of this study are:

- What service types and from what perspectives companies should be aware of when designing supporting services for products (goods) design, and
- What instructors especially should consider when teaching these issues to their students.

Based on the CX driven business model described in the previous section the major variables were:

- Cognitive CX in human-based service design;
- Physical CX in human-based service design;
- Sensory CX in human-based service design;
- Emotional CX in human-based service design;
- Social CX in human-based service design;
- CX in general in human-based service design;
- Cognitive CX in automated service design;
- Physical CX in automated service design;
- Sensory CX in automated service design;
- Emotional CX in automated service design;
- Social CX in automated service design;
- CX in general in automated service design;

In total, 52 master students, 9 females and 43 males who had mean working experience of 10 years, took part in this survey. Particularly, 40 of the students who participated were from three different higher education institutes in Finland while the other 12 were from a higher education institute in Greece. The data collection process involved the use of an online questionnaire which was uploaded on the Webropol platform as well as the use of a paper-based one. The respondents rated each item (variable) of attributes on a Likert scale of 1 to 5 where 1 mean "not at all important" and 5 meant "extremely important ".

Statistical analysis was made on SPSS.

DATA ANALYSIS

Table 1 (see next page) shows the means of the responses concerning the human-based services. Based on the results, the meaning of social interaction is defined as the key factor for supporting product development through human-based services.

Table 1. Human-based services and CX

Variable	Mean
Cognitive (How all needs are satisfied)	4.04
Physical (How this service helps you)	3.96
Sensory (What kind of feelings you have after using the	4.04
Emotional (How good the atmosphere is in a service)	3.98
Social (How services support interaction)	4.24
CX in general	4.31

Table 2 shows the means of the responses concerning the automated services. According to the results, cognitive and physical needs are determined as the key factors for supporting product development through automated services.

Table 2. Automated services and CX

Variable	Mean
Cognitive (How all needs are satisfied)	3.70
Physical (How this service helps you)	3.70
Sensory (What kind of feelings you have after using the service)	3.44
Emotional (How good the atmosphere is in a service)	3.53
Social (How services support interaction)	3.38
CX in general	4.06

Moreover, according to Kolmogorov test, students' responses data agreed with the normal distribution. For that reason, conducting statistical data analysis through T-test was deemed as an appropriate method. The related results are showcased in Table 3.

Table 3. Comparing human-based services to automated services

Variable	p
Cognitive (How all needs are satisfied)	.038
Physical (How this service helps you)	.110
Sensory (What kind of feelings you have after using the service)	<.001
Emotional (How good the atmosphere is in a service)	.007
Social (How services support interaction)	<.001
CX in general	.111

The results acquired emphasized the meaning of certain aspects in human-based service design. Special attention should be focused on atmosphere related variables (sensory and emotional) and social interaction when designing human-based services. In designing automated services cognitive and physical point of views are equally important. This means that in both the design of human-based and automated services, these arguments should be meticulously looked into.

DISCUSSION

The results of the study carried out by Makkonen et al. (2022), highlighted the importance of CX in the development of products and human-based services. The results of this current study provide guidelines for key areas which should be emphasized when creating services connected to products. When designing automated services all CX features expect physical CX need more attention in designing services for PSS. Especially, designers should emphasize sensory CX (What kind of feelings you have after using the service) and social CX (How services support interaction).

In addition to CX view presented in this paper, it is important to discuss customers' perspective in the context of value-creation, because in the long run maximizing is a crucial goal. The study by Osterwalder et al. (2009) provided a framework describing the main relative sources that create additional value. These sources include newness (value offerings that satisfy an entirely new set of needs), performance (acting more efficiently and effectively overall by doing things better with fewer defect, faster, with fewer resources), customization (tailoring products and services to the specific needs of individuals or customer segments), "getting the job done" (creating value to customers by helping them with particular things), design (aesthetic styling to fit with fashion trends, designing for modularity of or fewer components for easer assembly, designing for environmental friendliness, branding or status (customers may want to show society certain aspects of themselves), price (similar value products and services at a lower price), cost reduction (through online customer relationship management application, online recruitment or an online accounting software package), risk reduction (employing warranties, guarantees or service level agreements), accessibility (making products and services accessible to previously untapped customer segments), and convenience or usability (making things more convenient or easier to use). In this way we can have broader view to CX.

It is of great significance to look into the perspective of suitable technological frameworks when going over the field of automated services. As the meaning and scope of Industry 4.0 has expanded, it can constitute a useful context in which automated services can be examined. According to Erboz (2017), Industry 4.0 includes the following building blocks: big data and analytics, autonomous robots, simulation tools, horizontal and vertical system integration, industrial internet of things (IIoT), cloud computing, additive manufacturing, augmented reality as well as cybersecurity. Contemporary digital technologies are crucial factors in assisting companies in their trajectory towards a service-based sustainable business that facilitates information sharing across the service network. However, the role of different technologies and the identification of customers' perceived value need to be further investigated in different PSS settings.

Furthermore, the concept of a future Industry 5.0 should be considered as it provides essential elements for the utilization and development of Industry 4.0. According to the European commission, this shift towards Industry 5.0 can occur in four ways i) “adopting a human-centric approach for digital technologies including artificial intelligence”, ii) “up-skilling and re-skilling European workers, particularly digital skills”, iii) “realizing modern, resource-efficient and sustainable industries and transition to a circular economy”, and iv) “creating a globally competitive and world-leading industry, speeding up investment in research and innovation” (European Commission, 2021).

The limitation was the study was small data sample from Greece. Thus, it was not possible compare data from Finland to data from Greece.

FUTURE WORK

Future research work will involve more detailed analysis of CX elements and how they can be supported by different technologies in the context of Industry 4.0. Additionally, as the popularity of automated services increases and their implementation becomes more widely used, it is vital to pay special attention to the overall design and development process in the light of innovative frameworks, such as the one presented by Keiningham et al. (2020).

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DECISION SCIENCES INSTITUTE

Covariation in Student Software Preferences, Learning Styles, and Long-Term Interest: Implications for Business Analytics Course Design

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ABSTRACT

We conducted a study of a required graduate Business Analytics course with a sample of 56 students to understand the relationships among i) student perceptions of the topic, ii) preferences across AnalyticSolver, R and Python software, and iii) deep vs. surface learning styles. Analysis using hierarchical clustering on principal components showed six dimensions accounting for 51% of variability in the data. Participants who wanted a career as data analysts or operation managers showed the most interest in the topic. Most had a favorable view of Python followed by R and Analytic Solver. The majority of students demonstrated surface learning style.

KEYWORDS: Business Analytics, Data Mining Software, Learning Styles, PCA, Clustering

INTRODUCTION

Two central factors complicate the design of Business Analytics (BA) courses in modern MBA programs. First, the population of students they must serve is heterogeneous, reflecting a variety of backgrounds and long-term goals. This leads to varying degrees of interest across courses in the curriculum. Students also come with different portfolios of software skills and may have to learn new software required in certain courses. They also differ in their learning styles, with some highly motivated to master the material while others rely on rote memorization. Second, the roles that analytics serves in business are rapidly evolving, and this is reflected in the technical expectations for new hires. There is no universally adopted analytics toolkit, and course instructors must use their personal judgment – balancing student interests with industry needs – when deciding which software or methodologies to highlight.

To resolve these complexities, this paper profiles students across multiple BA-relevant dimensions. Specifically, we report the findings in a study of a required sole BA course in an MBA curriculum with 56 students that shows the relationships among i) student long-term interest in BA as career after completing the course, ii) preferences across three software environments – Analytic Solver (AS), R and Python – that were used in the course, and how these two factors were related to their iii) personal learning styles – Deep vs. Surface. The results of the study can be helpful for educators in designing teaching strategies and choosing appropriate data mining software tools to better match student learning styles to stimulate long-term interest in the subject and a career in BA.

LITERATURE REVIEW

During the last decade, data analytics has been playing an increasingly important role in a wide variety of business decisions (Gellman, 2014; Samuel, 2015). The job market has also been experiencing rising demand for employees skilled in analytics (Schroeder, 2021). Many business school graduate programs today offer at least one introductory course in BA. The Association to Advance Collegiate Schools of Business, an organization that sets standards for accreditation, has recently formally incorporated data analytics in their evaluation process (AACSB, 2020). This is to ensure that a student completing such programs has the knowledge, skills, and abilities to enter the BA job market and has acquired the mindset to continue to learn and adapt as technology evolves.

Building interest in BA career

The term BA covers a broad spectrum of activities. Some examples are: Data aggregation, Visualization, Data/Text mining, Predictive analytics, and Unsupervised learning (Hastie, Tibshirani, & Friedman, 2017; Ledolter, 2013; Shmueli, Bruce & Patel, 2016). Skills required for a successful career in BA include the ability to extract useful information from both structured and unstructured data gathered from multiple sources, analyze them using appropriate methods, and derive conclusions that benefit a company's business operations (Briggs, 2014; Murray, 2019). BA is a quantitative subject built on a variety of statistical tools. For a motivated student, the field can offer a high level of satisfaction and sense of accomplishment at the workplace through new discoveries on how various data are related, thereby offering potential solutions to business related challenges (Hollingsworth, 2017). The potential to find a job is higher in today's market for those who are interested in BA (Rawlings-Goss, 2019). A career as a BA is also monetarily rewarding, with salaries ranging from \$62,382 to \$143,837 depending on experience (Coursera, 2022). Generally, most MBA students have already an ongoing job and are looking for further growth. With appropriate guidance and support from the instructor, it is possible to kindle an intrinsic interest in the BA career (Cegielski & Jones-Farmer, 2016).

Selecting appropriate BA software tools

There are many options in choosing a data mining software for a BA Course, some of which are Excel based, while others require programming in Python, R, SAS or SQL (Huang, 2016; Murrary, 2019; Yadav & DeBello, 2019; Shende, Thakare & Byagar, 2020). In our college, while beginning the MBA program, all students had multiple years of prior exposure to Excel but none with Python and R. Hence, we adopted AS Solver (Frontline, 2022), an analytics suite with an Excel interface. We also introduced Python and R simultaneously. An earlier study had experimented with a similar approach using only Excel's PowerBI in conjunction with R in an MBA class; they found that students found the Excel interface easier compared to coding using R (Wang & Gu, 2018).

Both Python and R are open-source and free, which makes them equally appealing to students and universities. They are powerful BA tools with capabilities to slice and dice data for visualization and data analysis (Lander, 2017; Galea, 2018). They also have large libraries of packages with pre-coded algorithms that can perform statistical analyses. In this study, we used AS embedded in Excel as well as Python and R to do the same assignments throughout the course in understanding differences in student preferences among them.

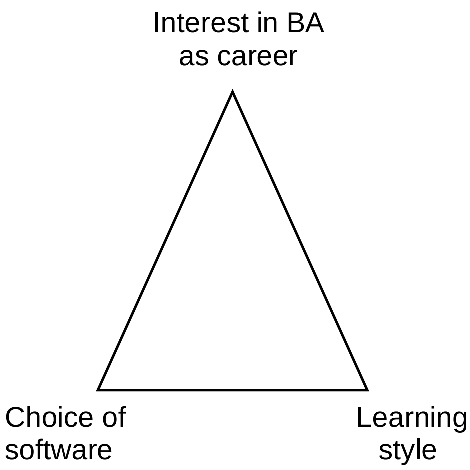
Deep vs. Surface learning

Even though the ideal goal of education is to develop expertise in a field of study to support lifelong learning, students use various strategies while learning that are influenced by teaching and assessment methods, their perceptions of task demands, and their own personal values and motives. Two different types of learning are currently accepted in literature: the surface and the deep approach (Biggs & Tang, 2007; Marton & Saljo, 1976; Marton & Saljo, 1984; Prosser & Trigwell, 1999). A deep learning strategy is directed at understanding the meaning of a task and to satisfy curiosity (Sankaran & Bui, 2001). A student using the deep approach will put in longer study hours, make detailed notes from the text and class notes, do exercises in addition to meeting minimum class assignments, and will study continually rather than cram (Vermunt & Vermetten, 2004). This approach may be considered the highest form of learning. In contrast, a surface learning strategy is directed to memorization without understanding and the goals are extrinsic such as getting good grades without having to fully master the material or simply due to emotional exhaustion and the fear of failure (Hu & Yeo, 2020). In this study, we measure the participant style of learning using the Revised Two Factor Study Process Questionnaire (Biggs, Kember & Leung, 2001).

MODEL

In this research, we modelled the concurrent relationships among three factors: i) Interest in BA as career, ii) Preferred software used in the course – AS, Python or R, and iii) Student learning style – Deep vs. Surface as shown Figure 1.

Figure 1: Model of Interest in BA, Software, and Learning Styles



We used a survey questionnaire in measuring each factor. Interest in BA as career was measured in terms of student disposition to work with quantitative / analytical problems and pursuing a career in the field. Student preferences towards each software choice - AS, Python or R - were measured using seven dimensions: i) Intuitiveness and ease of use, ii) Level of prerequisite knowledge, iii) Effort level in writing code, iv) Complexity of syntax, v) Time to code and run procedures, vi) Visual quality and appeal of output and vii) Ease of interpreting software error messages and fixing them. Learning styles - Deep vs. Surface - were measured using a study process questionnaire (Biggs, 2001). The complete questionnaire is available in Appendix A.

METHODOLOGY

Data was analyzed using hierarchical clustering on principal components (Husson, Josse, Le & Mazet, 2017). Clustering is useful in discovering knowledge in multivariate data sets by grouping similar observations. A variation of the method is Hierarchical Clustering on Principal Components (HCPC). As our model in Figure 1 relates a multidimensional dataset consisting of three sets of continuous variables measured on a Likert scale in the range 1 to 5, we first decided to perform Principal Component Analysis (PCA) and perform cluster analysis on the PCA results. The initial PCA step denoises the original, high-dimensional data which leads to a more stable clustering result. This approach is preferred for large data sets with multiple group-related variables. In analyzing our model, we used the data collected in the questionnaire in Appendix A consisting of 10 variables to measure Interest in BA as career, 35 variables to evaluate each of the three software (AS, Python, R) along seven dimensions and, 20 variables to measure Learning styles which makes choice of HCPC an ideal tool.

SAMPLE

The participants in the study were 56 students enrolled in a requisite Data Mining and Analytics course at the college of business of an AACSB-accredited large public university southwestern U.S. The course used the textbook titled Data Mining for Business Analytics (Shmueli, Bruce & Patel, 2016). While book focused on AS, an Excel based software, the instructor taught how to perform similar functions in programming mode using Python and R (Galea, 2018; Lander, 2017). There were five homework assignments over the semester that each student had to complete either individually or as part of a group up to four students. These assignments covered the topics of visualization, multiple linear regression, logistic regression, neural network and clustering. The instructor was available for guidance upon request from students to resolve technical and unexpected programming challenges while remotely connecting to the college IT lab. At the end of the semester, the students were asked to complete the three-part survey in Appendix A.

RESULTS

Table 1 shows that the first six dimensions capture 50.79% of the variance even when the eigenvalues are restricted at a high value of 6.650. Variances above 50% indicate that a reasonable structure exists (Berkeley, 2007).

Table 1: Contributions of the first 6 clusters

	eigenvalue	percentage of variance	cumulative percentage of variance
comp 1	19.714	14.081	14.081
comp 2	17.602	12.573	26.654
comp 3	10.799	7.714	34.368
comp 4	9.252	6.609	40.977
comp 5	7.088	5.063	46.040
comp 6	6.650	4.750	50.790

Figure 2 shows an alternative representation of the top three clusters in Table 1 using a silhouette diagram.

Figure 2: Silhouette graph of the top 3 clusters

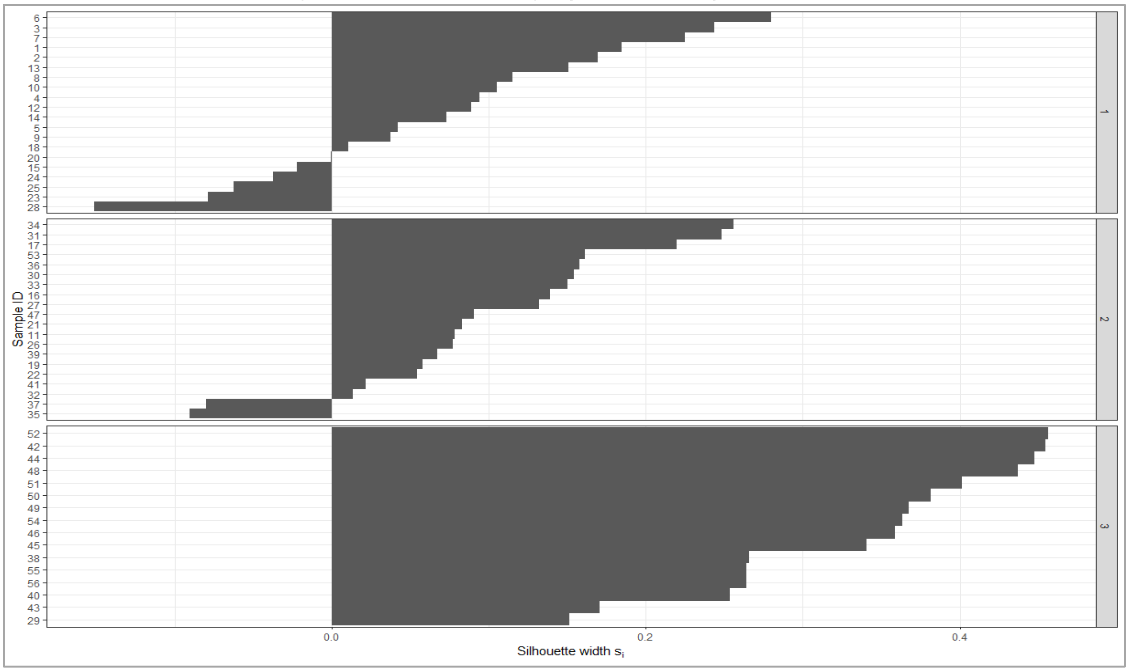
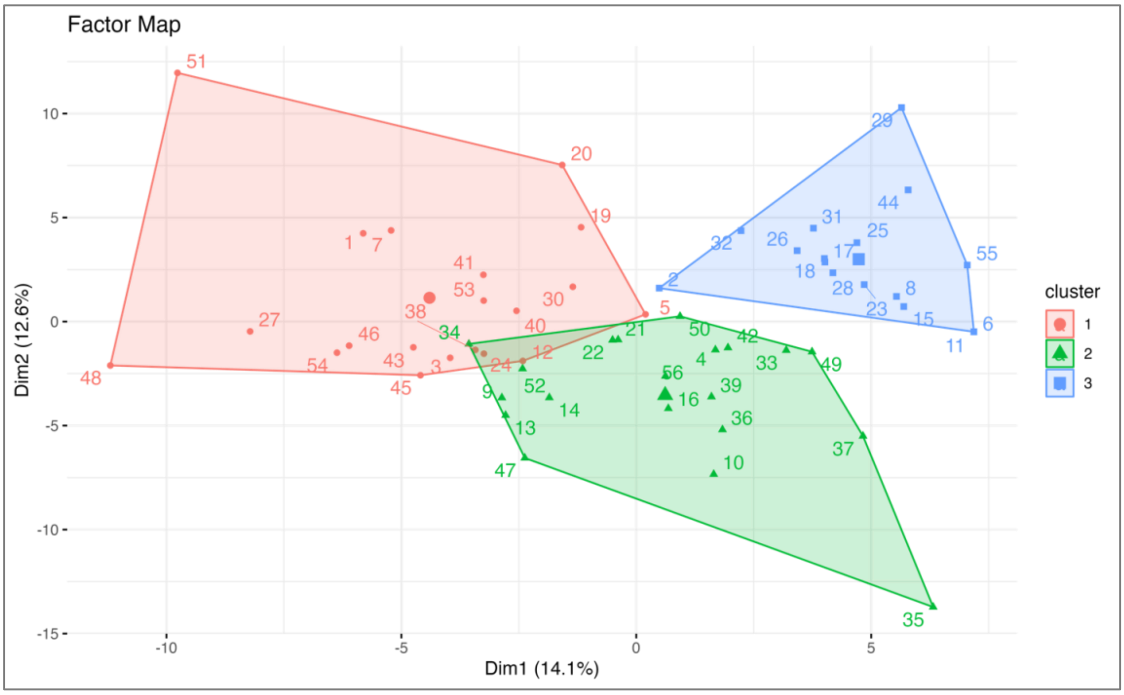


Figure 3 below shows the clear separation among the top three clusters even after restricting the projections to a two-dimensional display. While points 12, 24 and 34 appear overlapping, it is possible that it may not be the case if imagined across the six-component axes listed earlier in Table 1.

Figure 3: Projection of survey responses on factor map



DISCUSSION

In order to get additional insight into Figure 3, it would be useful to selectively compare individual data points in conjunction with their associated attributes like career (Interest in BA), software (Choice of software) and study (Learning style). For this, we can use Figure 4. Each numbered point on the figure represents one student, while text labels correspond to survey statements. Students are placed closer to statements for which they have high-valued responses. For example, the student represented by the data point #29 prefers R most in doing visualization, multiple regression, and neural network problems as indicated by the proximity to the variables Vzn_R, MLR_R and NN_R. Similarly, their proximity to Srf_Dp8 (refers to student's response to statement #8 in Part 3 of the survey) in Figure 4 indicates that the student uses a learning style that aids memorization by repeatedly going over the material even when it is not fully grasped. As for student #37, s/he comes prepared for class, likes to practice all three software but the preference is for Analytic Solver (which uses an Excel interface) when working with neural network, linear regression and logistic regression problems. Similarly, the data point #51 indicates a liking for Python for visualization, neural network, and clustering analysis. This student prefers a deep learning style and believes learning Python and R has more long term career value compared to Analytic Solver.

Figure 4: Concurrent projection of cluster attributes of individuals

Moreover, the question labels in Figure 4 support interpretation of the latent variation across responses. We divide discussion into three main directions, corresponding roughly to the directions that define the three observed clusters. First, we consider cluster 1. In this "northwestern" region, we find many R and Python questions with the suffixes `_1` and `_7`, meaning that students in this cluster found these languages “intuitive” and found it “easy to interpret [the] software’s error messages.” They also tended to give low scores for R and Python questions with the suffixes 2, 3, and 4; this can be seen because those questions lie on the opposite, “southeastern” corner. Not only did these students find R and Python easier to work with, they were more receptive to the learning technical, programming skills. In particular, they saw long-term value in learning R and Python relative to AS (Pg1_5) and appreciated the repeatability of programmed analytics environment (Pg1_6). In terms of learning style, these students tended to be more focused learners, prioritizing only what they believe is important (Srf_Dp_12) and having little patience with lecturers who covered topics that would not be examined (Srf_Dp_16). It is perhaps counterintuitive that these advanced R and Python learners exhibited these traits of surface learners. However, this learning style may support more efficient navigation of programming tasks, enabling these students to avoid becoming overwhelmed with syntactic details and instead focusing on analytical goals.

While cluster 1 included the natural R and Python learners, cluster 2 appears to consist of patient learners with a genuine interest in BA, but who find AS much easier to use. For example, they reported finding multiple linear and logistic regression in AS to be intuitive (MLR_AS_7, LR_AS_7) while R was considered complex across multiple tasks (Vzn_R_4, MLR_R_4). However, they were consistently deep learners, coming to each lecture with questions (Srf_Dp_17) and dedicating effort because they “find the material interesting” (Srf_Dp_13). This deep learning style is consistent with finding value in studying the same exercises across the three analytics environments (Pg1_4). In contrast to students in cluster 1, those in cluster 2 tended not see themselves focusing on BA in the long-run (Pg1_9). Their active exploration of BA, but acknowledged difficulty in learning more technical programming concepts, suggests that this cohort may be more likely to interact with or manage BA teams, without taking on an active data science-oriented role.

Next, consider cluster 3. Note that, in the “northeast” region of Figure 3, we find questions 2 and 4 for AS across multiple task categories (MLR_AS_2, LR_AS_2, Vsn_AS_4). High responses for questions 2 and 4 indicate a difficulty in following technical elements of AS. Students with these responses found the syntax and output of AS confusing, despite its Excel-based interface. Interestingly, these students were also impressed by the graphical outputs of R and python (LR_R_5, NN_R_5). These students also tended to have high scores for Srf_Dp_8, meaning that they often learn through memorization, even if they “do not understand.” Also, since questions Pg1_1 and Pg1_2 lie on the opposite “southwest” region of the figure, we can conclude that they do not “want to learn new quantitative/analytical skills” and do not “like using information technologies” in this context. This pattern of responses, which corresponds roughly with cluster 3, suggests that students who struggle with the point-and-click environment of AS also experience resistance to learning BA and rely on surface learning.

CONCLUSIONS

Our study has gathered student responses on three complementary aspects of the BA learning experience which are rarely considered together — strength of interest in technical analytics topics, attitudes towards exercises across several software environments, and gravitation towards deep vs. surface learning styles. By integrating these three views in the same analysis, we discovered patterns of covariation in the BA student population that were not a priori obvious. Specifically, we discovered three essential clusters, one which includes receptive and efficient learners who find programming natural, another consisting of patient, deep learners who are more comfortable in more point-and-click oriented environments, and a third cluster of students resistant to learning any analytics software and rely more strongly on memorization.

Nonetheless, we acknowledge that the sample size of our study is limited, and only reflects the experience in a single MBA program. While we believe that the course is representative of current practices in BA curriculum design, it would be interesting to replicate these findings in a programs with different dynamics.

Our results suggest that it may be beneficial for MBA programs to design tailored course streams for the alternative student profiles that we have identified — one stream should be to train students aspiring to become analysts, another can stress conceptual principles of BA over technical implementation, and a third that focuses on strengthening the foundation for quantitative learning. Our findings offer a challenge to educators in conceiving innovative approaches that delivers the course learning objectives that custom tailors to the student learning strengths and professional objectives instead of packaging course content in one size fits all standardized approach.

Alternatively, if it is not possible to split a course into three separate streams, our results suggest value in recognizing the diversity of learning goals and backgrounds and creating opportunities for students to share strengths with one another. For example, students in clusters 1 and 2 can exchange their technical implementation and critical thinking abilities through well-designed programming and discussion assignments. Moreover, in the long-run, we expect that a data-driven approach to course evaluation, revision, and design will be critical for MBA programs aiming to equip heterogeneous student populations with the analytics skills that will characterize the future of business.

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Appendix A

(All responses in this survey will be kept CONFIDENTIAL)

1-----------------------2-------------------------3-------------------4-----------------------5

Don't agree at all	Somewhat disagree	Neutral	Somewhat agree	Fully agree

Write the number (1 thru 5) for your response next to each statement based on the above scale:

1. I want to learn new quantitative/analytical skills and understand how they work. ____
2. I like using information technologies in solving quantitative/analytical problems. ____
3. I want to continue learning more in the DMBA area._____
4. Repeating same exercises using the three different software tools like Excel Analytic Solver, R and Python gave me a practical feel of the differences among these software tools. _____
5. Knowledge R or Python has more long-term market value compared to Analytic Solver. _____
6. With R and Python, one can save the programs and do re-runs (repeatability) easily compared to Analytic Solver. _____
7. I have used Excel for the last ____ number of years. (1yr=1, 2yrs=2, 3yrs=3, 4yrs=4, ≥5yrs=5)
8. Since my job doesn't require knowledge of DMBA, I don't see a need to learn R or Python at this time. _____
9. DMBA is not an area of interest I want to specialize. ____
10. I am planning to pursue a career as data scientist. _____

Compare your experience of using Analytic Solver, R and Python

1	2	3	4	5
Don't agree at all	Somewhat disagree	Neutral	Somewhat agree	Fully agree

Rate statement in each row between 1 to 5 by filling the cells in the last 3 (gray) columns

Visualization	Analytics Solver	R	Python
Creating graphs is intuitive			
Requires deep knowledge of software vocabulary/syntax/packages			
Level of effort required in creating graphs is high			
Complexity in each step/coding/syntax is high			
Graphs are high quality, professional and visually appealing			
It takes too much time to create write code, create graphs			
It is easy to interpret software's error messages and fixing them			

Multiple Linear Regression (MLR)	Analytics Solver	R	Python
Performing MLR is intuitive			
Requires deep knowledge of software vocabulary/syntax/packages			
Level of effort required in creating/running MLR procedure is high			
Complexity of each step/coding/syntax in generating outputs is high			
Visual quality/appeal of the result output tables is high			
It takes too much time overall to write code, run the MLR procedure			
It is easy to interpret software's error messages and fixing them			

Logistic Regression	Analytics Solver	R	Python
Performing LR is intuitive			
Requires deep knowledge of software vocabulary/syntax/packages			
Level of effort required in creating/running LR procedure is high			
Complexity of each step/coding/syntax in generating outputs is high			
Visual quality/appeal of the result output tables is high			
It takes too much time overall to write code, run the LR procedure			
It is easy to interpret software's error messages and fixing them			

Neural Network (NN)	Analytics Solver	R	Python
Performing NN is intuitive			
Requires deep knowledge of software vocabulary/syntax/packages			
Level of effort required in creating/running NN procedure is high			
Complexity of each step/coding/syntax in generating outputs is high			
Visual quality/appeal of the result output tables is high			
It takes too much time overall to write, run the NN procedure			
It is easy to interpret software's error messages and fixing them			

Clustering (CLS) (k-means & Hierarchical)	Analytics Solver	R	Python
Performing either type of clustering is intuitive			
Requires deep knowledge of software vocabulary/syntax/packages			
Level of effort required in creating/running the procedure is high			
Complexity of each step/coding/syntax in generating outputs is high			
Visual quality/color/appeal of the result output tables/graphs is high			
It takes too much time overall to write, run the clustering procedures			
It is easy to interpret software's error messages and fixing them			

The following is a standardized survey on understanding various study approaches students have taken in the past. It is being borrowed from published literature. Ref: Biggs, J. et al., Revised Two Factor Study Process Questionnaire, British Journal of Educational Psychology (2001).

The following questionnaire asks about your perspectives on various types of study approaches. There is no right or wrong way. It all depends on what works best for oneself. Therefore, answer the following questions as honestly as you can. If you think your answer to a question would depend on the subject being studied, then give the answer that would apply to the subject(s) most important to you. [note: your responses are confidential].

Please enter the appropriate number between 1 and 5 as per the guideline shown below:

This item is never or only rarely true for me	1
This item is sometimes true for me	2
This item is true of me about half the time	3
This item is frequently true of me	4
This item is always or almost always true of me	5

1. I find that at times studying gives me a feeling of deep personal satisfaction. _____
2. I find that I have to do enough work on a topic so that I can form my own conclusions before I am satisfied. _____
3. My aim is to pass the course while doing as little work as possible. _____
4. I only study seriously what's given out in class or in the course outlines. _____
5. I feel tht virtually any topic can be highly interest once I get into it. _____
6. I find most new topics interesting and often spend extra time trying to obtain more information about them. _____
7. I do not find my course(s) very interesting so I keep my work to the minimum. _____
8. I memorize some things, going over and over them until I know them by heart even if I do not understand them. _____
9. I find that studying academic topics can at times be as exciting as a good novel or movie.

10. I test myself on important topics until I understand them completely. _____
11. I find I can get by in most assessments by memorizing key sections rather than trying to understand them. _____
12. I generally restrict my study to what I consider important; I think it is unnecessary to do anything extra. _____
13. I work hard at my studies because I find the material interesting. _____
14. I spend a lot of my free time finding out more about interesting topics that have been discussed in different classes. _____
15. I find it is not helpful to study topics in depth. It confuses and wastes time, when all you need is a passing acquaintance with topics. _____
16. I believe that lecturers shouldn't expect students to spend significant amounts of time studying material everyone knows won't be tested. _____
17. I come to most classes with questions in mind tht I want answers for. _____
18. I make it a point to look through the suggested readings that go with the lectures. _____
19. I see no point in learning the material which is unlikely to be in the test. _____
20. I believe the best way to pass tests is to try to remember answers to most likely questions. _____

Demographics:

For the following questions, identify the number in parenthesis that corresponds to your answers and type them in the 2nd column. If you are uncomfortable answering any or all of the following questions, please ignore them. It is presented here only as a way to explore on my part how course content can be best fitted to match student background, goals and aspirations in the future.

1. Number of semesters I have attended CSUN	
2. I am an international student : Yes (1), No (0)	
3. English is my second language : Yes (1), No (0)	
4. I work currently: Full time (1), Part-time (2), Not applicable (3)	
5. What would be your dream job?	
6. Are you the first in your family to go to college? Yes (1), No (0)	

Thanks for completing the survey.

DECISION SCIENCES INSTITUTE

Deadline Effect in Stroke Patient Care: Paradox of Patient Arrival Times

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ABSTRACT

Stroke is a highly time-sensitive medical emergency and earlier treatment results in a better therapeutic outcome. Drawing on Goal Setting Theory and Expectancy Theory, we examine the existence of deadline effect in stroke care and identify a circumstance that mitigates such deadline effect. We define the deadline effect as a variable task processing rate because of time pressure associated with a task completion deadline. The use of Tissue Plasminogen Activator (TPA) is a standard treatment for ischemic stroke patients. However, it should be administered within 4.5 hours of symptom onset (i.e., golden hours). The existence of the 4.5-hour treatment window creates a deadline. Stroke care clinicians may slow down their course of action if a patient arrives at hospital after the onset of symptoms earlier than others so that enough time remains until the deadline, which implies inconsistent care. Using an accelerated-failure-time model as our main model specification while addressing potential patient selection bias, we find that when the time from onset of symptoms to patient arrival at the hospital door, i.e., Onset-to-Door time, is shorter (longer), the hospital stroke clinicians spend a longer (shorter) time conducting pre-TPA infusion tasks, i.e., Door-to-Needle time or in-hospital time before TPA is longer (shorter). We call this specific phenomenon "serial deadline effect." However, the *Target:Stroke* initiative, a goal-driven national initiative in the U.S. to improve stroke care quality, has significantly mitigated this deadline effect. That is, the hospital stroke clinicians tend to spend their care time relatively consistently regardless of the time spent in the front-end time segment of the process. Our key results are robust to other various confounding factors and model specifications. Importantly, we further find in post-hoc analyses that the *Target:Stroke* initiative has achieved such mitigation of the deadline effect without revealing adverse effects on other health outcome measures. Our findings provide important practical implications to hospital clinicians whose ultimate goal is to provide consistent patient care; properly set goals can result in a consistent processing rate in addition to performance improvement for hospital organizations.

KEYWORDS: Stroke Patient Care, Deadline Effect, Time Pressure; Goal Setting Theory; Expectancy Theory; Healthcare Operations

DECISION SCIENCES INSTITUTE

Decoding the DNA of Swiss Manufacturing – A taxonomy of competitive capabilities at the example of the Swiss watchmaking industry

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ABSTRACT

In today´s changing and competitive business environment, companies must identify and adjust their manufacturing capabilities to remain successful. In the past, manufacturing companies relocated capacities from high- to low-cost environments. Recent events, however, resulted in a call for reshoring. To successfully reshore, companies must consider competitive capabilities. We follow the taxonomy development approach from Nickerson et al. (2013) to determine the key capabilities of successful companies in high-cost environments. Due to high labor costs in combination with global success, we investigate the Swiss watchmaking industry. Our findings are a first milestone to decode the structure of the Swiss manufacturing landscape.

KEYWORDS: Competitive Capabilities, Swiss Manufacturing, High-cost Environment; Watchmaking Industry, and Taxonomy Development

INTRODUCTION

Per capita, Switzerland is among the top performer of value added in manufacturing (Ferdows, 2021). In 2021, Switzerland had the third highest manufacturing value added per capita worldwide (UNECE, 2022). As a result, Switzerland outperforms even “Europe’s manufacturing powerhouse” Germany in terms of per capita manufacturing value added (i.e., two times as much) (UNECE, 2022). Additionally, Switzerland is among the most competitive countries worldwide (IMD World Competitiveness Center, 2021; Schwab & Zahidi, 2021).

However, Switzerland has one of the highest average wages of the OECD countries (OECD Better Life Index, 2022). As a result, the high salaries, as well as the exchange rate, are seen by practitioners as the main barriers to the successful execution of manufacturing activities for four consecutive years (Friedli, et al., 2020). This phenomenon is not new: Globalization has resulted in a large number of relocations of manufacturing facilities from high-cost to low-cost environments (Wiesmann, et al., 2017; Sansone, et al., 2020). High-income country manufacturing firms were striving for a cost advantage (Sansone et al., 2020), as manufacturing is generally one of the most cost-intensive activities (Thakur-Weigold, 2021).

However, due to recent change events (e.g., Covid-19 pandemic, trade war between China and the USA) and to shorten supply chains the relocation (i.e., reshoring) of manufacturing activities grew (Edh Mirzaei, et al., 2021). To successfully reshore and sustain a long-term competitive

advantage, such decisions need careful consideration incorporating competitive capabilities (e.g., quality) (Wiesmann et al., 2017).
The Swiss watchmaking industry is particularly successful in the global competition. 50% of the total market value is generated by the Swiss watch industry (Jaberg & Turuban, 2020). As such, Switzerland is the leading exporter of watches in terms of value with a total amount of 20.5 billion Swiss francs in 2019 (FHS - Federation of the Swiss Watch Industry, 2020). Almost 70% of the total value exported from Switzerland is from the high-end segment (i.e., watches for more than CHF 3,000) (FHS - Federation of the Swiss Watch Industry, 2020). However, due to “Swissness”-regulations in order to use the label “Swiss made”, the majority (i.e., 60%) of the manufacturing costs must be accrued in Switzerland (Der Bundesrat, 2022). Additionally, technical development must take place in Switzerland (Der Bundesrat, 2022).
The objective of this paper, hence, is to develop a comprehensive understanding of the key competitive capabilities of Swiss watchmaking companies to guide managers in their decisions and actions as well as to contribute to the understanding of the advantages that might arise from high-cost environments. Due to its global success and the simultaneous obligation to produce in Switzerland, the Swiss watchmaking industry is especially suited for this research. Moreover, the high export share “signals the presence of competitive advantage” (Porter, 1998). The research question for this study is therefore as follows:
RQ: *What are the competitive capabilities that allow Swiss watchmaking companies to create and sustain a competitive advantage in the watch industry?*
In order to answer the research question, we develop a taxonomy. The approach is suited for our study since taxonomies provide a structure and organization of a knowledge base, hence, supporting scholars and practitioners in understanding complex issues (Nickerson et al., 2013; Lösser, et al., 2019). For a structured method, we follow the well-used approach from Nickerson et al. (2013).
The remainder of the paper is organized as follows: After the introduction, we discuss the relevant literature on competitive capabilities in high-cost environments. Subsequently, we introduce the applied research methodology. Later, the final taxonomy is presented, and lastly theoretical and practical implications, limitations, and possible future research avenues are discussed.

RESEARCH BACKGROUND

Competitive capabilities in manufacturing

Globalization has resulted in a large number of manufacturing facilities moving from high-cost to low-cost environments in the last three decades (Sansone et al., 2020; Ancarani, et al., 2021). Due to recent change events (such as the global crisis of 2008 or the Covid-19 pandemic), this trend was reversed, leading to reshoring initiatives of developed economies’ manufacturers (Ancarani et al., 2021). As a result, recent research has aimed to gain insights into the factors that determine the attractiveness of high-cost environments (Ancarani et al., 2021). According to Ancarani et al. (2021) “[…] a crucial research theme lies in the identification of the competitive priorities underscoring firms’ location initiatives in [developed economies].”
Competitive capabilities result in developing or maintaining individual sources of competitive advantage (Leong, et al., 1990; P. T. Ward, et al., 1998; P. T. Ward & Duray, 2000; Ancarani et al., 2021). They guide the location decisions of manufacturing facilities to reap the benefits of different countries (Buckley & Casson, 1976; Dunning, 1980; Ferdows, 1997; Da Silveira, 2014; Ancarani et al., 2021). The development of competitive capabilities follows a hierarchical sequence that begins with the development of a business strategy (Koufteros, et al., 2002). Driven by business strategy, a firm sets competitive priorities which could include for example enhancing innovation or reducing costs. These priorities are the basis from which a company can develop

the appropriate manufacturing competencies to reach its objectives and subsequently create the appropriate competitive capabilities (Koufteros et al., 2002). “Competitive capabilities compare a firm’s ability to meet customer expectations to its competitor’s ability to do the same” (Koufteros et al., 2002). In the manufacturing literature they are broadly expressed as low cost, flexibility, quality, delivery, and innovation (Leong et al., 1990; Miller & Roth, 1994; P. T. Ward et al., 1998; P. T. Ward, & Duray, 2000; Ancarani et al., 2021).

Related taxonomies

The academic literature provides some studies addressing the development of taxonomies of key capabilities in the manufacturing sector. Miller and Roth (1994) identified capabilities based on previous studies and included additional ones intuitively. They identified 11 capabilities for large manufacturers in North America. The findings of Kathuria (2000) include four competitive priorities for small manufacturers in America. Frohlich and Dixon (2001) replicated the study from Miller and Roth (1994) and highlighted 9 competitive capabilities for the general manufacturing industry in America, Western Europe, and Asia Pacific. Another application of the study from Miller and Roth (1994) was carried out by Zhao et al. (2006) with a focus on companies from the Tianjin region in China. Sum et al. (2004) identified 5 operations priorities with a focus on small and medium manufacturing companies from Singapore. Christiansen et al. (2003) focused their work on Denmark. They conducted an ad-hoc literature review and identified 9 competitive priorities. Luz Martín-Peña and Díaz-Garrido (2008) operationalized priorities detected in several studies with a focus on the general manufacturing industry in Spain. Lastly, Grant et al. (2013) replicated the study from Miller and Roth (1994) in Ireland for the general manufacturing industry. Despite the variety of studies investigating competitive capabilities, not all of them investigate high-cost environments. Additionally, Switzerland as one of the most suited countries (see INTRODUCTION) was not the subject of investigation of either one. Finally, manufacturing capabilities can evolve over time and differ depending on the focus area (Frohlich, & Dixon, 2001; Zhao et al., 2006; Grant et al., 2013). As a result, different criteria in the manufacturing industry need to be examined periodically due to a rapidly changing world (Grant et al., 2013). However, all studies have conducted their evaluation based on nearly identical generic capabilities that were rarely challenged. Moreover, the studies were conducted at least 9 years ago, potentially being outdated.

METHODOLOGY

To address our research question, we adopted the taxonomy development approach from Nickerson et al. (2013). The approach is widely applied and accepted in information systems research (Lösser et al., 2019; Deitermann & Friedli, 2021; Gelhaar, et al., 2021; Kundisch, et al., 2021). The approach provides a rigorous method (Kundisch et al., 2021) and is divided into three stages and seven steps (see Figure I) (Nickerson et al., 2013; Kundisch et al., 2021). During the first stage, a meta-characteristic and ending conditions are defined in accordance with the purpose of the taxonomy. The meta-characteristic is “the most comprehensive characteristic” (Nickerson et al., 2013). Ending conditions, defined in the first stage, guide the termination of the iterative method. Nickerson et al. (2013) provide a comprehensive list of objective and subjective ending conditions. The second stage consists of the development of dimensions and characteristics. Depending on the availability of information on the objects of study and the researcher´s knowledge, two approaches exist: empirical-to-conceptual (E2C) or conceptual-to-empirical (C2E). With a lack of available data and information, Nickerson et al. (2013) recommend starting with the C2E approach. Subsequently, the characteristics, descriptions of the dimensions and logical consequences of the meta-characteristic, are defined. The C2E approach consists of the identification of dimensions without the examination of the actual object. The E2C approach guides the researcher in order to identify subsets of objects and common characteristics. The last stage of each iteration is the alignment of the taxonomy with the ending conditions.

Meta-characteristics:

Our contribution aims to a) guide business leaders in the Swiss watchmaking industry to be and stay competitive and b) enhance the scientific knowledge on competitive capabilities in the manufacturing industry in high-cost environments with a special focus on Switzerland and the watchmaking industry. Therefore, we defined "competitive capabilities in high-cost environments" as the meta-characteristic for our taxonomy.

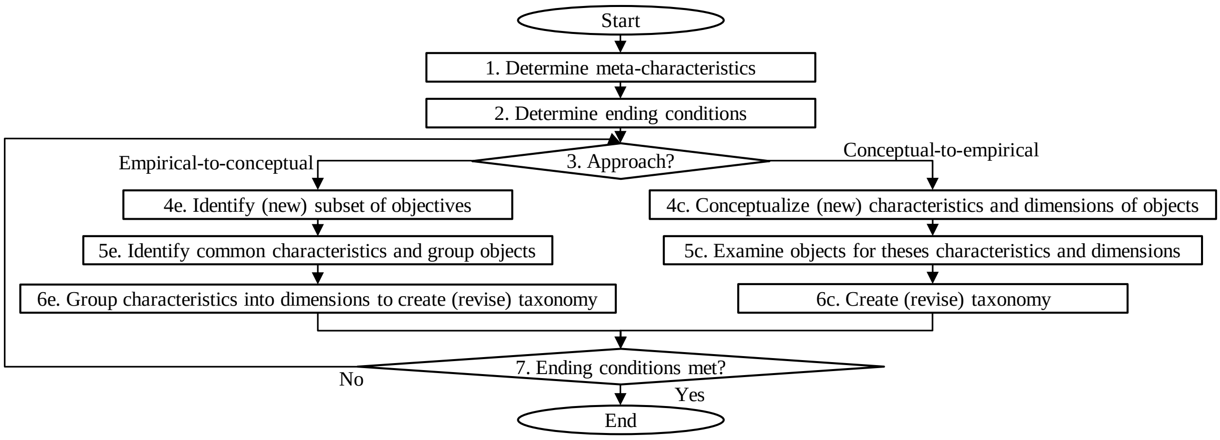

Figure I: The taxonomy development method (Nickerson et al., 2013)

Ending conditions:

We applied the subjective and objective ending conditions provided by Nickerson et al. (2013) since they provide a rigorous approach to evaluating the taxonomy. In order to differentiate the degree of importance between different capabilities, we added one objective ending condition: "The taxonomy structure must be a hierarchical criteria model".

First iteration (C2E):

To generate a comprehensive overview and understanding of the domain of interest, we conducted a systematic literature review (SLR). SLRs provide a vital and qualified mean to consolidate and progress the current knowledge base in an individual area (Cooper, 1988; Baker, 2000; Rowley & Slack, 2004; Ritchey, 2006), hence, it is suited for our procedure. To ensure "more transparency, reliability, and reproducibility of the findings" (Thomé, et al., 2016) we followed the approach from vom Brocke et al. (2009).

Due to the limited literature describing the Swiss industry sector, we broadened the scope of the SLR to global manufacturing in high-cost environments. Based on an initial understanding of the literature, we defined the search strings "capabil*" AND "competitive" AND "manufacturing" AND "high-cost". The choice of the last keyword follows the reasoning of Ketokivi et al. (2017). They consider "high-cost" to be equivalent to a high GDP per capita, which in turn has a direct and positive link to wage levels. The search was conducted using the databases Web of Science, Scopus, and Google Scholar. We applied the keywords to all fields in the first two databases. Since the search via Google Scholar led to a great number of results, we limited the scope to the ones that contain the keyword "manufacturing" in their title. This narrowed the results down to the most important. To ensure a high-quality level, we included only journal publications from the 15 top-ranked peer-reviewed journals in the field of "Management Science and Operations Research" (Scimago, 2022). Additionally, we limited the scope of relevant articles to publications between

2010 and 2021. This is due to the fact that markets change over time and frameworks and factors need to be evaluated and updated frequently to reflect the current competitive environment (Sansone et al., 2020). The search yielded a total of 78 articles. After the inclusion of articles found via backward and forward search, the sample included 87 articles. The removal of duplicates and irrelevant articles led to a final list of 17 articles.

Based on the identified literature we derived the following dimensions: quality, cost, flexibility, innovation, sustainability, time, and relationship. Noteworthy is the work from Sansone et al. (2020), which provides a comprehensive basis for this study. Additionally, we identified 26 competitive capabilities. However, we eliminated 8 capabilities, as they are only mentioned in a single article or miss a customer focus. This resulted in 18 hierarchical ranked manufacturing-related capabilities, according to the average position in which they have been ranked by different authors. If a capability was not mentioned by an individual author, we assigned the lowest score. In a subsequent step, we merged the capabilities product- and process quality, as well as product- and process sustainability since they are almost equally relevant to customers. Additionally, we allocated the capabilities to dimensions based on the literature findings.

Second Iteration (E2C):

During the second iteration, we conducted semi-structured interviews with 6 different company representatives (see Table 1). All participants have diverse working experiences in the Swiss watchmaking industry and worked on average 22 years in the operation and production management of their company. We chose the companies and interview partners based on two criteria: (1) their location – the headquarter must be based in Switzerland and the majority of the product value is manufactured in Switzerland; and (2) their price segmentation – the products are either mid-price or high-end. Since the Swiss watchmaking industry is known for being highly confidential, we did not include any more criteria.

The price-range categorization is based on the general understanding of the industry. End products with an average price above 3,000 CHF are considered "high-end" and average prices between 500 CHF and below 3,000 CHF are considered "mid-range". To classify the size of the company, we followed the European Union standard (<250 employees ≙ small; ≥250 employees ≙ large).

Table 1: Descriptive details of the company sample

Company	Role of the interviewee	Experience in the watchmaking industry (years)	Headquarter	% Value produced in Switzerland	Price range	Structure	Size
A	Head of Production	15	Switzerland	100%	High-end	Horizontal	Large
B	COO & Director of Product	15 & 15	Switzerland	>60; <100%	High-end	Horizontal	Large
C	COO	23	Switzerland	100%	High-end	Vertical	Large
D	COO	33	Switzerland	>60; <100%	Mid-price	Horizontal	SME
E	COO	37	Switzerland	>60; <100%	Mid-price	Horizontal	SME
F	Operations and Planning Manager	8	Switzerland	100%	High-end	Vertical	SME

The interviews were conducted in 2021 and 2022 via Zoom or face-to-face, lasted between 45 to 90 minutes, were recorded and transcribed, and finally analyzed following the approach from Thomas (2006). The participants were asked to evaluate the relative importance of the list of capabilities for their customers now and in the future. We used a Likert scale ("1 = not important" to "7 = very important") and let the participants explain their ranking. Furthermore, the participants were asked to state additional capabilities or remove irrelevant capabilities.

Based on the interviews we derived an average importance score of individual manufacturing capabilities for both today and the future. Subsequently, the individual capability scores were merged in order to determine the importance of the dimensions. We added the dimension “image”, since “brand image” incorporating “create emotion”, “history”, and “exclusivity” were repeatedly mentioned.

Third iteration (E2C):

Since the second iteration led to a new dimension and new capabilities, we conducted a third iteration. To reduce errors due to possible contrasting perspectives as a result of different structures and firm sizes, we interviewed experts, who are not directly involved in the watchmaking manufacturing process. Nevertheless, the interviewees are highly experienced and have huge expertise in the watchmaking industry. Two experts have over 40 years of experience in white labeling (i.e., companies that produce finished watches for other brands). A third one is the president of an association representing the Swiss watchmaking industry. He not only shared his view but also those of his three division chiefs (legal, economic, and administrative). The experts evaluated our results, commented on the ranking of the different capabilities, and were asked to add elements if necessary. We interviewed the industry experts for 30 minutes and the president of the association shared his and his colleague’s findings via an extensive e-mail.

The experts approved the taxonomy´s dimensions and capabilities. Despite not being mentioned in the literature, the experts highlighted the importance of the dimensions “image”, “quality”, and “innovation” for the Swiss watchmaking industry. Moreover, they highlighted the dimension “sustainability”, which they expect to become even more important in the future. One expert additionally added a capability “corporate social responsibility”, referring to environmental, social, economic, and ethical issues.

Ending conditions:

After the third iteration, the ending conditions were fulfilled as follows: 1) All papers from the sample of the literature review and all empirical data have been examined. 2) No object was merged with a similar object or split into multiple objects in the last iteration. 3) Each capability of each dimension could be classified with at least one object. 4) No new dimension was added in the last iteration. However, we added one capability. 5) Neither were dimensions or capabilities merged or split in the last iteration. 6) Every dimension is unique and not repeated. 7) Every capability is unique within its dimension. 8) Each combination of capabilities is unique and not repeated. 9) The taxonomy is concise because no unnecessary capabilities or dimensions were included. 10) The taxonomy allows differentiating of every object from each other (robustness). 11) It allows classifying all objects (comprehensive). 12) The taxonomy is extendible as new dimensions and capabilities can easily be added. 13) The taxonomy is explanatory, as it provides valuable and non-redundant information for the characterization of the manufacturing capabilities of Swiss watchmakers. 14) The taxonomy is a hierarchical criteria model.

All ending conditions are fulfilled, with the exception of condition four, which is partially fulfilled. Due to a) the effort to conduct a fourth iteration, b) the discretion and hesitation of interview partners in the Swiss watchmaking industry, c) the successful validation of the taxonomy, and d) the fact that only a single capability was added, we did not conduct an additional iteration.

TAXONOMY TO DESCRIBE STRATEGIC CAPABILITIES

The developed taxonomy serves as an answer to the research question of this study, as it develops a comprehensive understanding of key competitive capabilities and can guide executives. It consists of eight dimensions and 19 capabilities (i.e., characteristics) (see Figure 2).

The dimension *image* was ranked as the most important with a mean value of 6.5 for today. Moreover, all experts agreed that this dimension will also be crucial for the future and ranked it first with a mean value of 7.0. The dimension encompasses four capabilities: brand image, high pricing, traceability and product origin, and corporate social responsibility. Although creating a strong brand image is also mentioned in the general manufacturing literature for high-cost countries, its importance appears to be far less decisive than in the Swiss watchmaking sector. One expert stated: “Swiss watchmaking companies do not merely sell objects that indicate time, but rather objects that create emotions. […] They primarily sell dreams, something inaccessible, a notion of perfection that you cannot find in a machine tool”. In the process of image creation the “Swiss Made” label, which refers to Swiss expertise and exceptional quality (Goodman, et al., 2010), also plays a crucial role. The capability of offering high-priced products supports the brand image and is a key success factor for Swiss watchmakers. One expert mentioned: “Just like if you find a Ferrari at CHF 50'000, it will seem a little strange”. The third capability is called traceability and product origin. It refers to the “ability to prove the authenticity of one's product as well as the origin of the different materials [, which] is crucial, and this capability will become even more important in the years to come”, as one expert explained it. Lastly, corporate social responsibility concerns the environmental, social, economic, and ethical issues in the company’s activities. It plays a key role in the image dimension and according to one expert becomes even more relevant due to current events (e.g., Ukraine war).

Ranking today	Ranking future	Trend	Dimension	Characteristics			
1	1	→	Image	Brand image	High pricing	Traceability and product origin	Corporate social responsibility
2	3	↓	Quality	Product/process quality	Delivery reliability	Customer service	Customer experience
3	2	↑	Innovation	Product innovation	Technology innovation	Process innovation	Market innovation
4	6	↓	Relationship	Partner relationship			
5	5	→	Sustainability	Product/process sustainability			
6	7	↓	Time	Delivery time	Time to market		
7	4	↑	Flexibility	Volume flexibility	Product flexibility		
8	8	→	Costs	Cost efficiency			

Figure 2: Key dimensions of the mid- to high-end segment of the Swiss watchmaking industry

The second most critical dimension today with a mean value of 5.1 is *quality*. It is predicted to gain more relevance in the future (mean value of 6.1). The dimension includes four capabilities: product/process quality, delivery reliability, customer service, and customer experience. Companies offering high-priced products generally are forced to offer a particularly high product quality to compete effectively (Pal, et al., 2018). While image prevails largely over other factors, it remains of high importance for the companies surveyed to offer a product that is qualitatively in line with its brand image as well as its selling price. One expert stated: “The product quality must be irreproachable, otherwise the brand’s reputation would collapse”. Switzerland’s unique expertise, supported by excellent educational institutions as well as by other industries, such as microtechnology (Goodman et al., 2010) allows the sector to benefit from a savoir-faire that ensures superior quality of products. Additionally, the quality of service provided to customers such as reliable delivery, customer service, and customer experience are important capabilities for Swiss watchmakers. One company representative explained: “It is not a warranty; it is a service […] [that] high-end Swiss watchmaking companies ensure that parts sold 30 years ago are still available today”.

The third most critical dimension with a mean value of 4.6 is *innovation*. The innovation related capabilities are expected to become more essential in the future (main value of 6.3) Although innovation is not part of the list of factors developed by Miller and Roth (1994), it has been widely accepted in the recent manufacturing literature (Da Silveira, 2014; Pal et al., 2018; Friedli et al., 2020; Sansone et al., 2020). The dimension is of particular importance for small countries, which do not possess significant natural resources (Roper & Arvanitis, 2012). Four capabilities are included in this dimension: technology innovation, process innovation, market innovation, and product innovation. The importance of individual capabilities of this dimension appeared to be different for the experts. The capability product innovation was ranked highest (i.e., 7.0) by two experts, while others had a different opinion. One expert stated: “Most of the existing models have not significantly changed throughout the years (....). Although there are plenty of different time displays that have been developed over time, 90% of them contain hands and are round”. In general, the Swiss watch industry cannot be compared to companies like Apple, which revolutionized the watch market by seizing more than half of the world market share in only 5 years with the invention of smartwatches (Morgan Stanley, 2018; Deloitte, 2020). We identified varying opinions on the importance of innovation-related capabilities based on the interviews. Small and mid-range companies ranked the capabilities lower than large companies. Nevertheless, the dimension is also important to keep the “Swiss made” label.

Relationship was ranked as the fourth most important dimension with a mean value of 5.3. The third iteration resulted in the dimension to be less important in the future. One expert mentioned: “While supplier partners are key to the industry, seller partners will gradually lose relevance for the industry since an increasing number of brands are selling their products through a direct sales channel”. This is supported by a Deloitte study, where 33% of the executives interviewed expect single-brand stores to be the most important sales channel in the years to come in the watchmaking industry (Deloitte, 2020). The dimension encompasses only one capability: partner relationship. Despite this dimension not being widely considered in the manufacturing literature, it is important to gain a competitive advantage (Pal et al., 2018). The Swiss watchmaking industry is particularly dependent on external relationships due to the complex and highly segmented structure of its supply chain (Deloitte, 2020). One expert admitted: “Without a personal friendship with our movement provider, we could not be where we are”. As a result, the proximity of different stakeholders - also called “clusters” - plays a crucial role in these partnerships.

The fifth most critical dimension with a mean value of 3.5 for today is *sustainability*. The dimension only recently gained considerable attention in recent studies (c.f. Sansone et al. (2020)). For the future, different perceptions exist: While some experts believe that the dimension will become crucial in the coming years as customers increasingly seek sustainability, others remain skeptical. An expert states that “[t]he sustainable aspect is mainly of interest to the Western market (…). While European customers are willing to have the smallest package possible, customers from the Middle East are still willing to buy the biggest one, otherwise, they think the watch is worthless.” While companies need to meet their customer’s expectations, the sustainable trend does not yet seem to have reached the primary Swiss watch importing markets (FHS - Federation of the Swiss Watch Industry, 2020). The dimension includes the capability product/process sustainability. It focuses primarily on the environmental impacts of companies (e.g., materials used, emissions generated, etc.). In terms of maintenance, Swiss mid-range and high-end watches can be considered sustainable since mechanical watches can be repaired indefinitely. However, the materials used for the products combined with the production process are still not environmentally friendly. “The sector uses a significant amount of hydrocarbon for the production (…) and also a lot of energy” as one expert explains.

Time was ranked as the sixth most critical dimension with a mean value of 4.5. For the future, time was ranked as the seventh most critical dimension, as the various participants do not perceive it to become a major factor in the success of Swiss watchmaking. The dimension includes the capabilities “delivery time” and “time to market”. In contrast to, for example, the apparel industry, the Swiss watchmaking industry aims to produce exclusive and long-lasting products, which are only slightly influenced by trends. An expert stated that “it takes between 3 to 4 months to produce an existing model and about a year for a new product - from conception to market introduction." Moreover, customers are willing to wait for the product: "A customer who really wants to have the exclusive product of his dreams is inclined to wait." Additionally, Swiss watchmakers are more concerned about the quality of the product and will not sacrifice the quality in order to be faster. "We should not rush before releasing a product, we should study it and test it" revealed one expert.

The seventh most critical dimension having a mean value of 4.4 for today is *flexibility*. For the future, the interviewees perceive the dimension to become more important (i.e., rank four). As one expert explains it: "In the automotive sector, people can already customize their cars for a while. (…) As long as the customer pays, we should do whatever he wants." The dimension encompasses two capabilities: volume flexibility and product flexibility. In terms of volume, Swiss watchmaking companies cannot be described as flexible in comparison to large Asian competitors that produce in greater quantities and have a broad pool of low-cost labor (FHS - Federation of the Swiss Watch Industry, 2020). Since the Swiss watchmaking industry produces in a "make-to-stock" approach, the product flexibility is limited. However, locating the production closer to customers and producing in a "make-to-order" approach would result in the loss of the "Swiss made" label, which is one of their key capabilities (i.e., brand image).

The least critical dimension is *costs* with a mean value of 4.2. It remains relatively unimportant for the future. Nevertheless, the dimension still contributes to the success of Swiss watchmaking companies. One expert explains: "In any industry, the objective is to ensure quality (...) but also to be profitable." The dimension incorporates the capability cost efficiency, which is relevant for the Swiss watchmaking industry. One expert stated: "We try to have a competitive price positioning compared to our competitors and to be as affordable as possible for what we manufacture." However, the "make-to-stock" strategy that characterizes the Swiss watchmaking industry generally results in a high level of inventory. One expert revealed that "some companies even have a stock level of 140%, which means they can cover 1.4 years of turnover with their stock."

CONCLUSION

To answer the research question we followed the taxonomy development of Nickerson et al. (2013). We used the existing knowledge base and interviews to enhance the existing knowledge. In order to generate highly relevant results, we conducted our research in the mid- to high-end Swiss watchmaking industry. The industry is especially suited as it produces in a high-cost environment and is highly successful on the global market. The results reveal the key factors for the success of Swiss watchmaking companies today and perceptions for the future. The taxonomy incorporates eight dimensions and 19 capabilities and allows to draw several conclusions.

In terms of **scientific contributions**, our work contributes to a better understanding of the research area of key manufacturing capabilities. First, it supports existing research by identifying quality as one of the key capabilities for manufacturers in high-cost environments, while costs are less relevant. Second, the study gives valuable insights into the key capabilities in the highly discreet Swiss watchmaking industry. Third, this study is a first contribution to the understanding of the competitive capabilities globally successful Swiss manufacturers aim to achieve. As a result, the study contributes to the understanding of the success of Swiss manufacturers, who are successful in the global marketplace despite having one of the highest labor costs worldwide.

As for **managerial contributions**, the developed taxonomy provides a better understanding of the key capabilities, which globally successful Swiss watchmakers pursue today and perceive in the future. As a result, the structured view of different manufacturing capabilities can guide practitioners to implement successful operating strategies. Additionally, our findings provide insights for policymakers in high-cost environments about the strategic orientation of successful manufacturers. Hence, the insights and the taxonomy can provide a reference point for politicians to adjust legislation.

As for all studies, our contribution is subject to **limitations**. Due to the discretion of the Swiss watchmaking industry, our sample was limited to 12 experts contributing. This resulted in a limited number of iterations, leading to the last iteration not meeting all ending conditions fully. Nevertheless, we were able to validate the taxonomy. Additionally, our taxonomy is a time-bound snapshot that needs to be updated regularly. due to the evolving nature of manufacturing capabilities over time (Frohlich, & Dixon, 2001; Zhao et al., 2006; Grant et al., 2013). Finally, despite being based on scientific literature and interviews, the data itself is open to interpretation. This can result in other researchers deriving other characteristics depending on their personal influences and preferences.

Based on the limitations possible **future research avenues** can be derived. Additional research could consider further luxury sectors with similarities to the Swiss watchmaking industry to overcome the confidentiality issue and augment the study. Moreover, despite our research giving valuable insights into the Swiss watchmaking industry, broadening the scope to Swiss manufacturers in general can lead to further insights into the competitiveness of successful companies in high-cost environments.

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DECISION SCIENCES INSTITUTE
Digital Business Ecosystems for Digital Spare Parts

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ABSTRACT

The idea of Digital Spare Parts (DSP) is to replace centralized conventional manufacturing with decentralized additive manufacturing. Design and manufacturing files of spare parts are stored and transmitted digitally in order to digitize formerly physical inventories or reduce delivery times. DSP could also help improve the resilience and adaptability of supply chains by serving decentralized and on-site additive manufacturing capabilities as an alternative or substitute to conventional manufacturing processes. However, studies into the contributions of DSP focus mostly on single process steps or different supply chain configurations rather than the ecosystem level. Therefore, this paper investigates how DSP can support the development of a more resilient and adaptable supply chain and ecosystem.

KEYWORDS: Digital Spare Parts, Decentralized Manufacturing, Additive Manufacturing, Resilient Supply Chain, Digital Business Ecosystems

INTRODUCTION

Digital platforms such as iTunes or Spotify have created very successful digital business ecosystems as they connect producers and consumers in electronic marketplaces (Kretschmer et al., 2020; Zutshi & Grilo, 2019). The idea of digital business ecosystems has also inspired business model innovation for technologies such as additive manufacturing (Baumann & Leerhoff, 2022). For example, via digital platforms such as Thingiverse, consumers can share product designs and build objects at home (Zutshi & Grilo, 2019). Similarly, manufacturers can use digital platform ecosystems to make spare parts for their products available to customers, for example, by accessing a network of 3D printing service providers.

Compared to conventional manufacturing, additive manufacturing processes enable local on-demand manufacturing at the point of use (Walter et al., 2004). The idea of Digital Spare Parts (DSP) is to replace centralized conventional manufacturing of spare parts with decentralized additive manufacturing. Companies digitally store and transmit design and manufacturing files of spare parts are in order to digitize formerly physical inventories or reduce delivery times (Knofius et al., 2016). In this context, digital platforms for trading licenses could support the implementation of the DSP concept and business model, hence exploiting the resource value of information (Wunck & Baumann, 2017).

Research on the implementation of the DSP concept so far has mostly focused on individual supply chain configurations or individual spare parts design, while DSP platform ecosystems have not been studied in depth (e.g., Ballardini et al., 2018; Chekurov et al., 2018; González-Varona et al., 2020). Similarly, practical applications are still in their infancy. This paper, therefore, analyzes the literature on digital business ecosystems in additive manufacturing of spare parts to derive a framework to capture their scope. It evaluates the framework through expert interviews and adds the challenges of implementing the DSP concept as an element of the supply chain.

The remainder of the paper is organized as follows: After introducing the research questions, we describe the research design, followed with a systematic literature review. In the section on digital business ecosystems for DSP, we condense the framework and investigate different supply chain models. We discuss these findings in depth to capture the scope of platform ecosystems for additive manufacturing of spare parts derived from the literature with findings from expert interviews. The paper concludes with a summary of the results before addressing the limitations of our study.

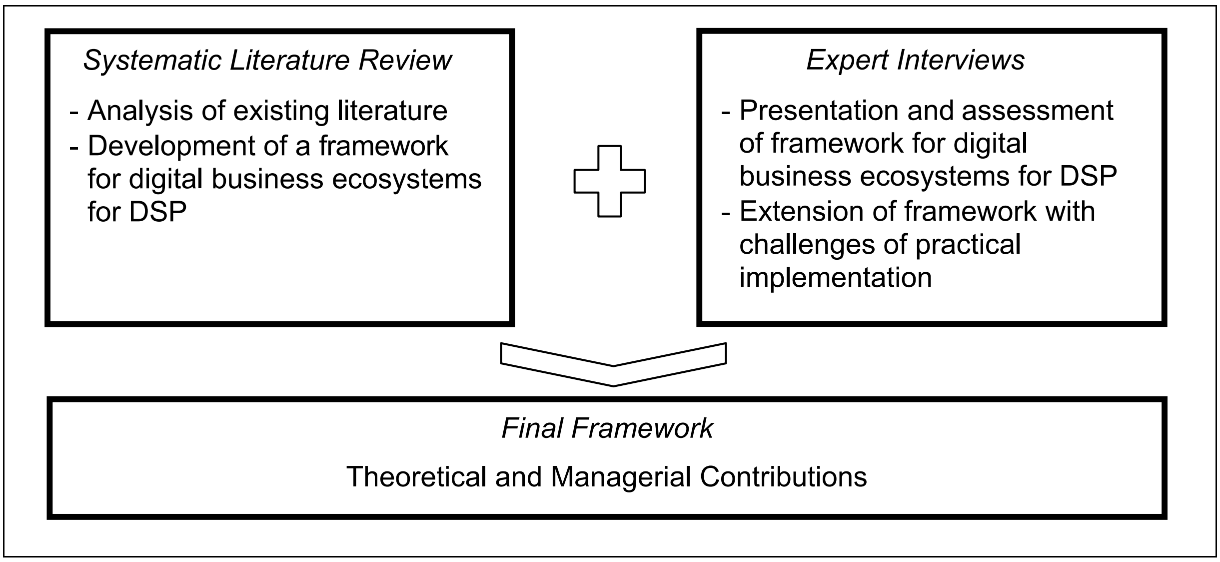
RESEARCH QUESTIONS

Digital business ecosystems in additive manufacturing are still a newly emerging phenomenon. Our paper, therefore, addresses the following research questions:
(1) What are the relevant categories that define the scope of digital business ecosystems for additive manufacturing of spare parts?
(2) What are the practical challenges of implementing digital business ecosystems for spare parts that are additively manufactured?

METHODS

The research design combines a systematic literature review and expert interviews to create a framework with theoretical and managerial contributions for the implementation of the DSP concept (see Figure 1).

Figure 1 – Methodology



A systematic literature review was used to identify the relevant literature in the field of digital platform ecosystems for DSP. We searched nine databases: Scopus, ACM Digital Library, IEEE Xplore, Web of Science, EBSCO, Wiley Online Library, ProQuest, Emerald Insight, and WISO.

The search terms were divided into two blocks. The first block targeted the topics of spare parts and additive manufacturing. We searched for combinations of the term “spare part” with “digital” or “additive manufacturing,” “rapid manufacturing,” or “3d-printing”. This search was supplemented with “rapid repair,” “additive repair,” and a combination of the term “spare part management” with “additive manufacturing,” “rapid manufacturing,” and “3d-printing.” The second block covers the digital business ecosystem. This includes the terms “business model,” “business environment,” “digital ecosystem,” “supply network,” “distributed manufacturing,” “sustainable manufacturing,” “supply chain,” and “inventory.” We linked the terms within the blocks with an OR, and the blocks themselves with an AND.

We included a contribution if it was a document-type article, conference paper, or book chapter, and if the contribution established a connection to the topic area of additive manufactured spare parts and (digital) business ecosystems or a related topic (such as supply networks or distributed manufacturing). We excluded a contribution if it was not written in English or German, had no named author, consisted only of an abstract or a presentation, had not been peer-reviewed, or covered only a technical topic of additive manufactured spare parts.

From an initial set of 304 articles, 77 papers relevant to the topic area remained. Based on the content analysis of the articles, we derived categories for a framework to capture the scope of platform ecosystems for additive manufacturing of spare parts. In order to assess and extend our framework, we created an interview guide and conducted semi-structured interviews with experts from original equipment manufacturers (OEMs), maintenance service providers, and platform operators.

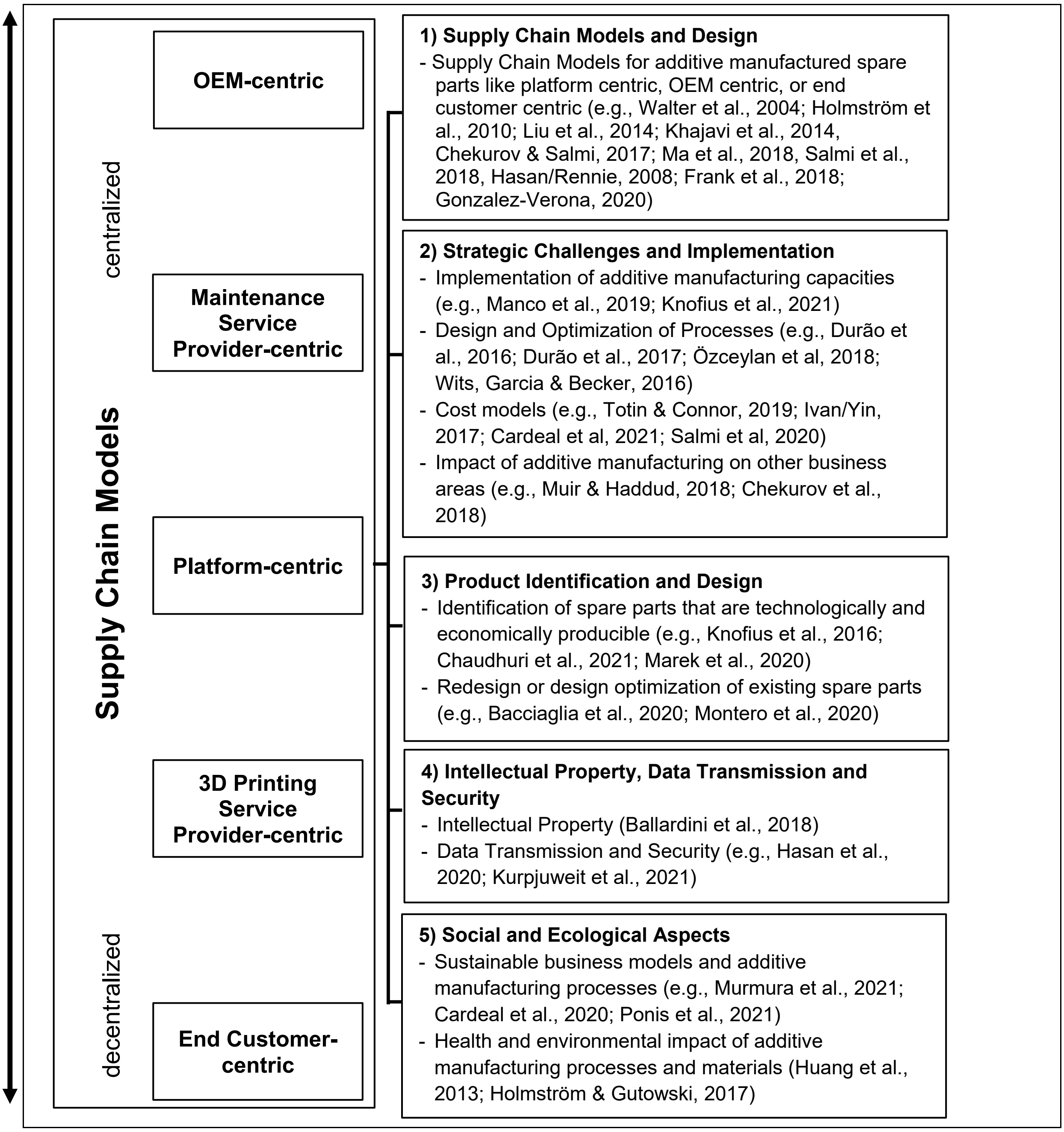
FINDINGS OF THE SYSTEMATIC LITERATURE REVIEW

(1) Supply Chain Models and Design

Contributions assigned to this category deal with the fundamental design of the supply chain for additive manufacturing of spare parts. While at the beginning scholars limited the consideration superficially to the distinction between centralized and decentralized additive manufacturing (e.g., Walter et al., 2004; Holmström et al., 2010; Liu et al., 2014; Khajavi et al., 2014), in later contributions researchers undertook increasingly different scenario analyses of various supply chain configurations. In these considerations, researchers investigated different degrees of increasingly decentralized additive manufacturing of spare parts by different actors in the supply chain such as OEMs, repair stores, or even spare parts distributors (Chekurov & Salmi, 2017; Ma et al., 2018). A paper outside our literature review described five different supply chain configurations as a framework (Salmi et al., 2018): OEM-centric, maintenance service provider-centric, platform-centric, 3D printing service provider-centric, and end customer-centric. These configurations range from a centralized (OEM) to a decentralized (end customer) manufacturing approach (see Figure 2).

Platforms for the implementation of a decentralized additive manufacturing approach are becoming increasingly important. Thus, a wide variety of contributions describe platforms as the center of activities of additive manufactured spare parts, for example, as providers of end-to-end (E2E) solutions or digital storage options (in the form of a digital warehouse), or even as a gateway to a network of different 3D printing service providers (e.g., Hasan & Rennie, 2008; Frank et al., 2018; Gonzalez-Verona, 2020).

Figure 2 – Summary of Findings



(2) Strategic Challenges and Implementation

We assigned contributions to the second category that deal with strategic challenges and the implementation of additive manufacturing capacities. One topic here is the pure implementation of additive manufacturing processes. Contributions deal with general aspects such as technology selection, production planning, installation of additive manufacturing capacities in the supply chain, or an additional or alternative source of spare parts in addition to conventional manufacturing processes (e.g., Manco et al., 2019; Meisel et al., 2016; Sgarbossa et al., 2021; Knofius et al., 2021).

In addition, authors of some papers specifically address the design and optimization of business processes related to additive manufacturing of spare parts. For example, researchers described and presented processes for the introduction of additive manufacturing processes for the implementation of different independence levels in additive manufacturing or also for the management of print jobs (e.g., Darwish et al., 2020; Wits et al., 2016; Durão et al., 2016; Durão et al., 2017; Özceylan et al., 2018).

Cost models represent another topic area. Here, various authors deal, for example, with the question of whether a purely digital business model can be profitable or whether additive manufacturing of spare parts is more economical than manufacturing with conventional processes (e.g., Totin & Connor, 2019; Ivan & Yin, 2017; Cardeal et al., 2021). Another question is at which locations additive manufacturing capacities should be implemented in the supply chain in order to keep the overall costs for the supply chain and logistics as low as possible (Brito et al., 2019). The contributions in this topic area should, therefore, be seen as complementary to the rest of the topic areas. For example, one contribution in addition to topic area 3 deals with the creation of a cost model that can evaluate the cost benefits of redesigning a spare part for additive manufacturing (Minguella-Canela et al., 2018).

The last topic area deals with influences of additive manufacturing on other business areas. For example, the contributions examine the influence of additive manufacturing on customer satisfaction or the barriers to the introduction and implementation of the DSP concept (e.g., Muir & Haddud, 2018; Chekurov et al., 2018).

(3) Product Identification and Design

In the additive manufacturing of spare parts, we identified product identification and product design as the third topic area. On the one hand, this involves the identification of spare parts suitable for additive manufacturing in terms of technological feasibility and economic efficiency (e.g., Knofius et al., 2016; Chaudhuri et al., 2021; Marek et al., 2020). On the other hand, some contributions deal with product design by photogrammetry and reconstruction of spare parts or even design adaptation of already existing 3D models for optimization for additive manufacturing processes (e.g., Bacciaglia et al., 2020; Montero et al., 2020).

(4) Intellectual Property, Data Transmission, and Security

The fourth topic area deals with the intellectual property of DSP, data transmission, and data security. However, with regard to the topic of licensing law, we found only one paper through the literature review that focusses on this topic (Ballardini et al., 2018). The authors specifically investigate the impact of additive manufacturing processes on the European business and legal framework. The result is that new regulations are necessary for dealing with DSP or CAD files, as patent law has so far been interpreted in connection with physical goods and not their digital representations.

In addition, a large number of contributions address the topic of blockchain as a technology with regard to data transmission and security. On the one hand, researchers describe the approach of "smart contracts", but also various opportunities, challenges, effects, and barriers of this technology in use with additive manufacturing processes or with DSP (e.g., Hasan et al., 2020; Kurpjuweit et al., 2021).

(5) Social and Ecological Aspects

The contributions in this category address social and/or ecological aspects related to additive manufacturing of spare parts. Individual contributions look at the sustainability of additive manufacturing processes or of business models. For example, investigators consider the extension of product life cycles, avoidance of overproduction, and material waste of additive manufactured spare parts (e.g., Murmura et al., 2021; Cardeal et al., 2020; Ponis et al., 2021). However, some researchers are also considering and analyzing the general consideration of health and environmental impacts of additive manufacturing processes and materials (e.g., Huang et al., 2013; Holmström & Gutowski, 2017).

SUPPLY CHAIN CONFIGURATIONS FOR DIGITAL SPARE PARTS

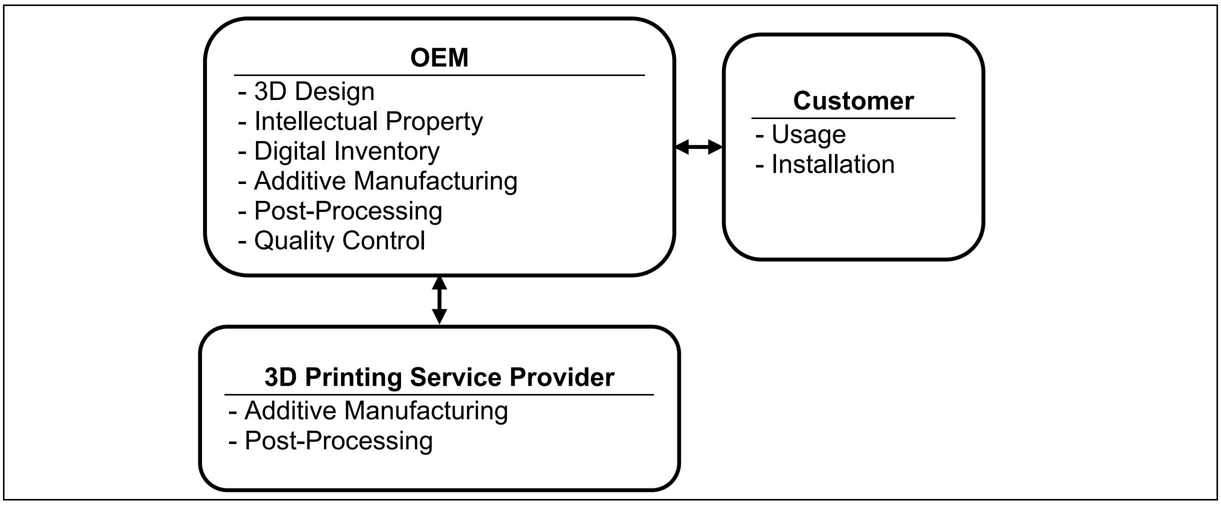
Through the interviews we conducted, we analyzed the supply chain configurations of an OEM, a maintenance service provider, and a platform operator.

OEM-Centric Supply Chain Model

The first case study deals with the OEM-centric supply chain configuration of a rail vehicle manufacturer from Germany (see Figure 3). The company has customers from the rail sector—in addition to state railroads, also operators of, for example, streetcars or metros. The manufacturing processes used are fused deposition modeling (FDM), selective laser melting (SLM), and wire arc additive manufacturing (WAAM). In addition to the spare parts business, the company used additive manufacturing processes for the maintenance of rail vehicles. As an OEM, the company also manufactures its own spare parts, on the one hand, and third-party spare parts, on the other, using additive manufacturing processes. In the latter case, the OEM assumes the role of the maintenance service provider.

In addition to its own additive manufacturing capacities, the company makes use of the manufacturing or reworking capacities of external service providers. Ultimately, however, as an OEM, it holds a central position in the supply chain.

Figure 3 – OEM-Centric Supply Chain Model

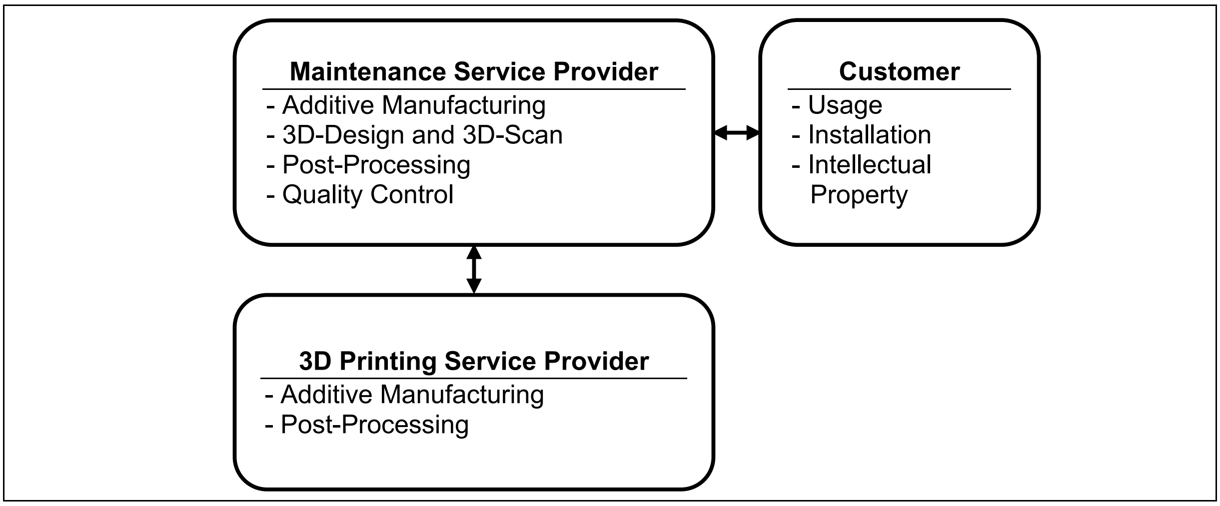


Maintenance Service Provider-Centric Supply Chain Model

The second case study deals with a maintenance service provider-centric supply chain model (see Figure 4). As a maintenance service provider, the company manufactures prototypes, small series, and spare parts in cooperation with its customers and on their behalf. In addition, it offers consulting services to help decide together with the customer whether conventional or additive manufacturing makes sense. The company's customers come from a wide range of industries, such as rail and automotive. It manufactures using SLM, FDM, and multi-jet fusion (MJF) processes. In the case of manufacturing capacities not being available, external service providers are also used.

In the maintenance service provider centric model it is usually the customers who owns the license. If a spare part is newly designed for a customer, the company obtains an assurance that it owns the license to it. However, in the case of a spare part without a license being held by the direct customer, the OEM of the original part is typically not involved in the process. This is because the maintenance service provider sometimes carries out part of the new design and component optimizations and as a result the spare part usually undergoes changes in relation to its design or utility model.

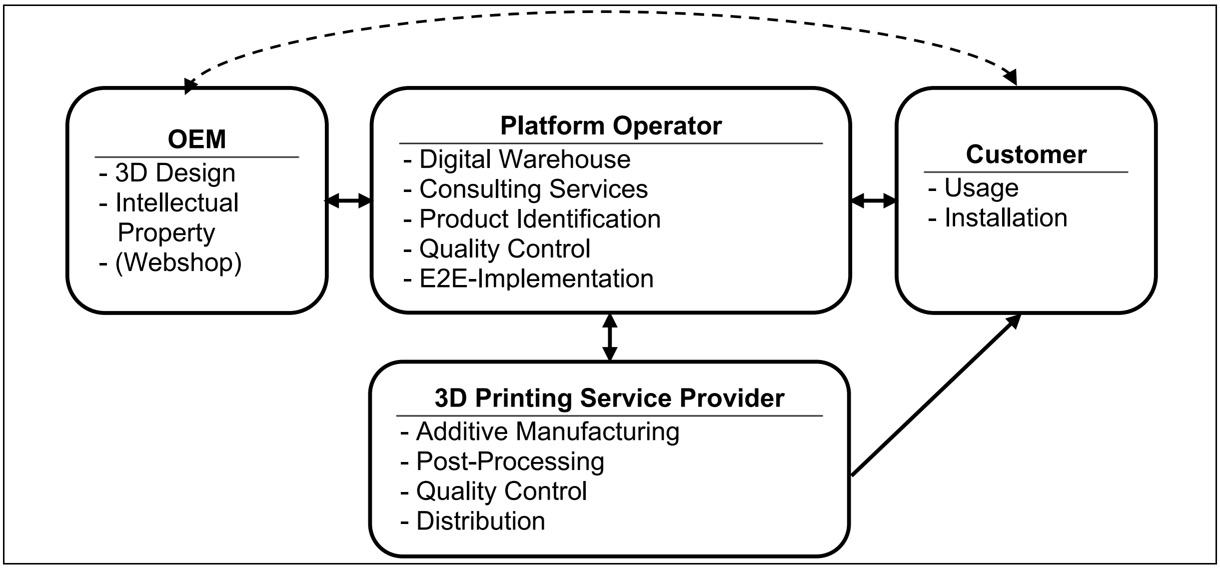
Figure 4 – Maintenance Service Provider-Centric Supply Chain Model



Platform-Centric Supply Chain Model

The platform operator works together with the manufacturer, which provides the design and the 3D models, holds the license for the spare part, and sometimes offers the spare parts through its own webshop to the end customer. The company offers various services for spare part manufacturers and end customers. These include, for example, the storage of DSP (digital warehouse), consulting services, E2E implementation, and quality control of the additively manufactured spare parts (see Figure 5). For the additive manufacturing of the spare parts, a network of 3D printing service providers manufactures the spare parts on demand and take care of post-processing, quality control, and distribution. The end customer then receives the additively manufactured spare parts. The goal of the platform operator is to include as many 3D printing service providers as possible in the network so that, when an order is placed, a service provider that is geographically as close as possible to the customer can be commissioned with the production.

Figure 5 – Platform-Centric Supply Chain Model



With regard to practical challenges that make the introduction and implementation of the DSP concept difficult, we divided the interview guide into two sections, which first relate to technological aspects and second to the entire ecosystem. In the case of technological challenges and hurdles respondents, for example, mentioned the fact that 3D models are sometimes not yet available for the spare parts to be manufactured additively. Since additive manufacturing is mostly interested in spare parts whose designs may date back 30–40 years, 3D models have not yet been created for these spare parts. This means that a 3D model has to be created either on the basis of technical drawings (if available) or, for example, by means of a 3D scan. This creates considerable additional work for the additive manufacturing of spare parts and results in their manufacturing becoming economically unattractive. Respondents also mentioned the difficulty of identifying spare parts suitable for additive manufacturing. Overall, these points can be summarized as a lack of automation of the additive manufacturing process. In addition, insufficient materials or manufacturing processes are also still an obstacle to additive manufacturing of spare parts.

When considering the entire digital business ecosystem respondents mentioned a lack of mindset change. In practice, individual actors are sometimes still rather critical of additive manufacturing processes. For example, some customers have so far shown little willingness to see additive manufacturing processes as an alternative or supplement to conventional manufacturing processes. This means that the implementation of a digital supply chain beyond company boundaries across the entire ecosystem has been difficult to date. In this context, however, respondents also mentioned that the 3D printing market is perceived as too fragmented by customers or even OEMs. The large number of technologies, manufacturing processes, or even materials makes it difficult for new actors to enter the ecosystem around additive manufacturing. Consequently, platform operators need to bring the actors in the ecosystem up to speed with regard to digitization and to make the IT systems compatible for data exchange on DSP in order to implement a digital supply chain. However, not only the pure data exchange on DSP is relevant, but also the exchange of protocols about the print job. These protocols are required for quality assurance or for clarifying liability issues. There is also a need for further action on the part of other players such as legislators. Open liability issues for additively manufactured (spare) parts or also with regard to data distribution across national borders make the implementation of the DSP concept more difficult.

DISCUSSION

This paper investigated the additive manufacturing of spare parts under the so-called DSP concept. The digital files of the spare parts that are required for production, are being digitally transmitted and then the information is used to additively manufacture the spare part.

Research Question 1

With regard to the first research question, it can, thus, be stated that five different categories can be identified in the literature that are necessary for an overall consideration of the digital business ecosystem. Although, digital platforms represent only one of several possible configurations when considering the supply chain, the interviews and the consideration of a practical example for a platform operator clearly show that problems and challenges from the various categories are mostly independent of a specific supply chain configuration. In the interviews, it became apparent that the respondents often named the challenges, which are identified in the scientific literature, independently of the specific supply chain configuration. Overall, however, our findings comfirm the relevant categories that define the scope of digital platform ecosystems and provide a framework for further development.

Research Question 2

In terms of the practical challenges of introducing digital business ecosystems and the DSP concept, it can be stated that, in addition to previously identified technological challenges such as the unavailability of 3D models or the time-consuming manual preparation and post-processing, additional issues such as a lack of mindset shift represent challenges for digital ecosystems and platforms. Consequently, convincing stakeholders such as customers to join the ecosystem or to perceive additive manufacturing as a valid alternative to conventional manufacturing processes is difficult. Nevertheless, platform operators are trying to align their service offering to counteract these obstacles. They are expanding their core business around additive spare parts manufacturing or the storage and transfer of DSP and include consulting services and the service of E2E implementation.

Implications for Ongoing Supply Chain Disruptions

To solve current supply chain problems and disruptions, the DSP concept and additive manufacturing of spare parts can be supportive at least in the respect that the required parts can also be produced locally to the point of use independent of, for example, transnational shipping blockades. Only the manufacturing files need to be transferred digitally. For example, at the beginning of the COVID-19 pandemic, the sudden demand for personal protective equipment for medical personnel was met by using additive manufacturing capabilities from private individuals and other entities to produce this protective equipment. This allowed production to be as local as possible to the point of use. This overcame the manufacturing and delivery difficulties of conventional manufacturing processes. However, it should be critically noted here that the materials, machines, or even spare parts required for additive manufacturing can also be affected by the supply difficulties.

CONCLUSION

Through detailed analysis of the papers retrieved through the systematic literature review, we found five categories that are central to business ecosystems for additive manufacturing of spare parts: (1) supply chain models and design; (2) strategic challenges and implementation; (3) product identification and design; (4) intellectual property, data transmission, and security; and (5) social and ecological aspects. The expert interviews confirmed the relevance of the categories. In terms of current implementation challenges, the experts highlighted the missing partnerships among various actors of the business ecosystem and a general skepticism about additive manufacturing processes that prevent the implementation of a digital supply chain. From the interviews, it is also apparent that the 3D printing market is still fragmented, which represents a high barrier to entry for new market actors. In addition, most manufacturers refrain from making direct interactions between customers and the 3D printing service providers available, and if they do, it is only to a very limited extent. The ongoing lack of interaction on various levels, thus, hinders innovation and development opportunities of the entire ecosystem.

This paper elucidates the development and current state of digital business ecosystems for additive manufacturing of spare parts in both research as well as practical application. The novel framework captures the scope of the topic area through five categories that span platform concepts, data and digital technology, strategies and implementation, and social and ecological aspects. The framework is not only an important step to guide future studies and research designs, but practitioners could adopt the findings for the conceptualization and implementation of platform ecosystems for additive manufacturing of spare parts.

However, there are some limitations. During the systematic literature review, it was noted that the number of articles on some topics, such as licensing law or data transmission, was significantly lower than on other topics, even though these topics are assigned a fairly high level of importance in practice. At this point, it can be assumed that the search strategy, for example, did not cover these topics well and could have been too narrowly defined. It should also be critically noted that only three interviews were conducted in total. A higher number of interviews would have made the results more reliable and would have allowed additional perspectives from the various supply chain configurations and business ecosystems to be described.

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Dinner at Your Doorstep: Service Innovation Through the Gig Economy in Food Delivery Platforms

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ABSTRACT

Online food delivery (OFD) platforms utilize a three-sided marketplace connecting the restaurants, gig-drivers, and consumers. However, it is still unclear how various parties are affected by the three-sidedness of the platforms. In this paper, we study the OFD platforms' optimal choices in a setting where they compete on both price and service quality. We show that conventional insights from two-sided platforms do not completely carry over to OFD markets. We also show that the introduction of minimum wage regulation may hurt consumers. As a result, our results provide meaningful insights into balancing the interests of the restaurants, gig-drivers, and consumers.

KEYWORDS: online food delivery, on-demand platform, gig economy, and multi-sided markets

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Do sustainability practices impact customers' attitude towards brand?

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ABSTRACT

Sustainability initiatives are embedded in business models of most firms. In service firms, sustainability initiatives need to be carefully implemented due to customers' involvement in production of services. Customers' participation in the sustainability practices may increase inconvenience or cost of the service product. Therefore, this research posits proposition that sustainability practices impact customers' attitude towards a brand. Then we provide a roadmap to empirically investigate the impact of sustainability practices on brand attitude.

KEYWORDS: Sustainability, Brand Attitude, Brand loyalty, Brand awareness, Service Sector, Survey Research

INTRODUCTION

Sustainability is increasingly becoming core of business models in all types of firms. Manufacturing firms can implement sustainability practices within their current practices freely. However, service firms are cautious to alter or redesign their service processes because customers are involved production of services. When a hotel plans to go green and want to use less water by asking their customers to reuse their towels, a customer is stuck in dilemma of inconvenience vs their responsibility towards environment. When a transportation company charges environmental fees, the customer ends up paying higher prices. When a grocery retailer asks customers to bring back water bottles, grocery bags and packaging materials to recycle them, the extra time, transportation, and inconveniency factor may form mixed attitude towards the brand in the minds of the customers.

Sustainability reporting from the companies allow customers to investigate companies' strategies and action plans associated to environmental and social sustainability. More than just providing a disclosure to their stakeholders about their goals and practices, companies have used sustainability reporting as a marketing platform to create greater brand awareness because it can create brand recognition and brand recall – the two types of brand awareness as identified by Percy & Rossiter (1992). Firms also use green marketing programs that encourage green product consumption and attempt to influence customers' purchase intension by improving brand recognition (Lin et al., 2017).

A company earns brand equity when their customers place greater confidence on their brands compared to its competitors' (Chen, 2010; Lassar et al., 1995). Customers are willing to pay premium price for the brand that has earned brand equity in their industry. Brand awareness created due to sustainable practices can lead to the higher brand equity. However, companies deploy environmental and social practices to enhance their service products' environmental and social performance (Chen, 2010). This can create customer confidence on the company's brand which further enhances positive attitude towards the brand.

The central research question for this paper is how sustainability practices impact brand awareness and brand attitude. Although there is some research done for investigating relationships between sustainability practices, brand awareness and brand equity there is lack of research that investigate the relationships from reported sustainability data and measured data from customers of service companies alone. This research proposes a research model that postulates the relationships of the forementioned three constructs. In the following sections, we provide in-depth literature review, present research model, propose a roadmap of research method that can be used to test the relationships postulated in the research model and present implications of this research.

LITERATURE REVIEW

Although, brand attitude reflects a potential consumer's involvement with the purchase decision and motivation to purchase, brand awareness is also an integral part of customers' intent to purchase and repurchase a product (Rossiter, 2014; Percy & Rossiter, 1992). To identify research gaps and current state of research, this study explores two interfaces of literatures: (1) sustainability and brand awareness (2) sustainability and brand attitude.

Sustainability and brand awareness

Brand awareness literature has been important factor in marketing for developing brand attitude to motivate purchase and repurchase intentions. Recently, green branding has made companies focus on drawing customers' attentions towards their sustainability initiatives. Companies producing tangible goods are already realizing the benefits of producing substantiable products by getting higher performance outcomes (Hong et al., 2019; Jagani & Hong, 2022). Due to environmental factors, stakeholders', and government pressures, it has become imperative that service companies also follow the path of implementing sustainability practices to deliver service products that are environmentally and socially sustainable. Green brand awareness has focused mainly on creating brand awareness by advertising on sustainability practices regardless of product type – service or goods (Zubair Tariq, 2014; Chang & Chen, 2014**;** Huang et al., 2014). Sustainability practices in service firms, unlike in manufacturing firms, alter service process which can give rise to mixed customer reactions due to change in their roles and need for retraining. This calls for research that focuses on service industry that studies the impact of sustainability practice on brand awareness.

Sustainability and brand attitude

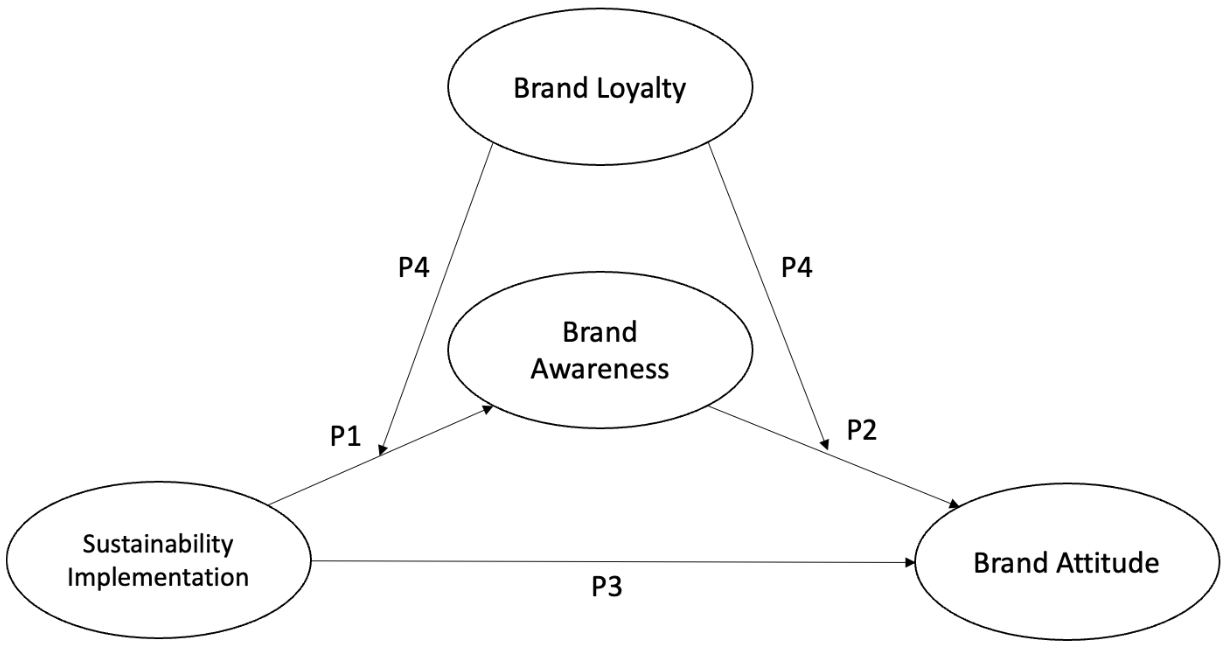
Brand attitude is directly and positively related with brand image (Faircloth et al., 2001). Brand attitude influences repurchase decisions of customers (Hartmann & Apaolaza-Ibáñez, 2012). Yoo & MacInnis, (2005) suggests that feelings and emotions form attitude toward brand. Sustainability initiatives are such a feeling that invokes sensitivity towards environment and society. Although, there are several studies (Hartmann et al., 2005; Olsen et al., 2014; Huang et al., 2014; Mehdikhani & Valmohammadi, 2021) that attempt to identify the impact of sustainability practices on the brand attitude, there is absence of empirical studies that focus on service sector. Therefore, we present a research model with relationship between sustainability practices, brand awareness and brand attitude.

Customers' dedication and commitment towards a brand creates brands loyalty that influences purchase intention directly. Therefore, it becomes important to investigate the moderating role of brand loyalty on mediating effect of brand awareness. This research proposes that brand loyalty as an important moderating mediator variable.

DEVELOPMENT OF PROPOSITIONS

Based on the motivation, literature review and current research need, we develop a research model postulating the relationships between sustainability implementation, brand awareness, brand attitude and brand loyalty using strong theories supporting the associations between the constructs. The research model is presented in Figure 1.

Figure 1: Research model



Sustainability implementation in this study is defined as the translation of strategic position of the firm regarding sustainability. In other words, this implementation comprises of a set of actionable practices that realize the intent of a company pertaining to social, environmental, and governance sustainability. Such practices are known to be a positive predictor of brand awareness which is conceptualized as the overall familiarity of customer with a specific brand (Keller & Swaminathan, 2020). For instance, Brønn & Vrioni, (2001) argue that companies can improve their brand image by making sustainability a fundamental corporate value and communicating it to their patrons. In another research, He & Li, (2011) state that implementation of sustainability practices by a service firm positively influence the familiarity of customers with its brands. Lichtenstein et al., (2004) in an empirical study demonstrates that sustainability-oriented actions of the firm have a direct and positive effect on its customers' level of identification and awareness of with its brands. The positive association between sustainability implementation and brand awareness has been established in other studies (Marin et al., 2009; Aquino & Americus, 2002; Mattera et al., 2012). Therefore, this study posits that sustainability implementation practices are positive associated with brand awareness.

P1: Sustainability implementation is positively associated with brand awareness.

Brand awareness has been conceptualized in the literature from different perspectives. It has been defined as the level of familiarity current and prospective customers have with the organizations and its products or services (Gustafson & Chabot, 2007; Keller & Swaminathan, 2020), the capability of a buyer to recognize and identify a brand within a category with sufficient specificity to make a purchase (Percy & Rossiter, 1992), and the accessibility of the brand in customers' memory (Chandon, 2003). Regardless of these different variations in definition, many studies concur that brand awareness is a predictor of brand attitude (Rossiter, 2014) which is theorized as positive or negative personal evaluations, emotions, feelings, and behavioral tendencies towards a specific brand (Kotler, 2018) the tendencies that have been ingrained in customers' psyche (Shin et al., 2014), or consumers' overall impressions of a brand-named product or service (Mitchell & Olson, 1981; Keller & Swaminathan, 2020). Drawing on this line of theory in the literature, this study propose that brand awareness and brand attitude are positively associated.

P2: Brand awareness is positively associated with brand attitude.

Analogous to the positive association between sustainability implementation i.e., actions of the firm that translates its strategic intent for sustainability, and brand awareness, extant literature holds that such actions are also a predictor of brand attitude (Wu & Wang, 2014) which is conceptualized as customers' feelings and sentiments about the firm's brands (Kotler, 2018). Companies that participate in sustainability initiatives lay the groundwork for how customers evaluate products and services (Boonpattarakan, 2012). Plans that translate sustainability-oriented strategy into an actionable agenda, i.e., sustainability implementation encourages consumers to actively engage with the brand (Pivato et al., 2008), and creates a positive sentiment towards the brand among customers (Alexander et al., 2014). Consumers have a more positive perception towards brands of corporations that actively address environmental, social, and governance issues pertaining to sustainability (Sen et al., 2006). Sustainability related efforts could promote the consumers' opinion about the company and its brands and therefore enhance its brand attitude (Lii & Lee, 2012). Therefore, this study proposes that sustainability implementation is positively associated with brand attitude.

P3: Sustainability implementation is positively associated with brand attitude.

Brand loyalty is conceptualized as the tendency and commitment of customers towards the brand and could manifest itself in actions such as repeated purchase of the same brand (Mellens et al., 1996). Brand loyalty is also defined as consumers' dedication and favorable attitude about purchasing the same brand in the future (Liu, 2007), or a biased cognitive reaction towards a specific brand which is demonstrated over time (Berkowitz, 1978). Literature shows that brand loyalty shows a positive and strong association with brand attitude and awareness (Gómez et al., 2006). In general, customers have different attitudes towards a specific brand, however those who posit stronger brand loyalty also have greater attitude and awareness towards the brand (Rajumesh, 2014). There is also a significant connection between being loyal to a brand and affective attitudes towards a brand, i.e., mindsets, thoughts, judgements, and sentiments (Barsky & Nash, 2002).

Some studies suggest that the positive relationship between sustainability related actions of a company and its brand related outcomes, e.g., brand attitude, could become stronger in presence of greater brand loyalty (Chen, 2010; Park & Kim, 2016). Following this line of reasoning, this study argues that the strong link between brand loyalty and brand attitude could alter the magnitude of correlation between sustainability implementation and brand awareness, as well as the relationship between sustainability implementation and brand equity. In other words, consumers who are more loyal towards a specific brand, could potentially evaluate its sustainability related activities more approvingly. Consequently, with greater loyalty to purchase a specific brand repeatedly, the association between sustainability implementation and brand awareness/attitude could be stronger. Therefore, this study proposes that brand loyalty moderates the relationship between sustainability implementation and brand awareness/attitude.

P4: Brand loyalty moderates the relationship between sustainability implementation, brand awareness, and brand attitude.

PROPOSED RESEARCH METHOD

To analyze the research question and postulates in the research model, data from single source will not be sufficient due to the need of information from different sources (company and customer) simultaneously. The sustainability practices can be accurately measured from the company reported documents like sustainably reports while brand awareness, brand loyalty and brand attitude can be truly captured from survey of the company’s customers. Therefore, our first stage will be a careful examination of sustainability reports. This will enable us to understand different sustainability practices conducted by the sample of companies. We plan to select a sample of prominent service organizations who report their sustainability practices through annual sustainability reports. Then, we will provide a subjective quantification of these practices on a scale of 1 to 10 based on number of sustainability practices, and importance of those practices.

In the next stage, we will conduct a large-scale survey of customers of all the service organizations that we identified in stage 1. Due to availability of strong existing research on brand awareness, brand loyalty and brand attitude, we will adopt the Likert Scale items from literature and modify them in sustainability context.

Finally, we plan to use structural equation modeling and Andrew Hayes process model 58 (Hayes, 2017) to analyze the research model and test our propositions.

RESEARCH IMPLICATIONS AND CONCLUSION

This study proposes that brand awareness and brand attitude are associated with sustainability implementation which is a translation of firm’s strategic intent pertaining to sustainability matters into actionable practices. From a theoretical perspective, this article underlines the essential significance of sustainability in branding theory, with a focus on the constructs of brand attitude and brand awareness. Existing research shows that sustainability is critical in customers' brand evaluations and is at the center of modern brand management ideas (Armstrong et al., 2011). The link between what real measures firms take in relation with sustainability, and how customers perceive those measures is rather murky and imprecise. There is a misalignment between a company's environmental initiatives and how its customers perceive and evaluate its brands (Grubor & Milovanov, 2017).

Through conceptual research, this study fills this theoretical gap by investigating the direct and indirect effects of sustainability initiatives on brand awareness and brand attitude and proposes a conceptual model. This research opens the path for future studies that will use primary and secondary data to empirically test the proposed conceptual model.

To conclude, this paper investigates how sustainability practices impact brand attitude in the context of service firms. The simultaneous production and consumption nature of service products and customers' involvement in production of service products call for a careful implementation of sustainability practices in service firms. The effect of sustainability implementation can be both, positive and negative, because of mixed perceptions the customers assimilate due to distinct service requirements. The proposed research methods will provide better theoretical and practical understanding of role of sustainability practices in creating brand awareness and customers' attitude towards a brand.

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DECISION SCIENCES INSTITUTE

Does Corruption influence Performance more or does Performance influence Corruption more? The Role of Country-level Governance

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ABSTRACT

This study investigates whether corruption has a greater influence on country-level performance or whether the latter has a greater influence on the former. Using a multisource panel dataset of 130 countries over the period 2010-2019, this study employs simultaneous equation modelling. We find strong evidence of bi-directional associations among corruption, country-level governance and country-level performance; however, they suggest that country-level performance has a greater influence on corruption than the performance-corruption framework in developed and worldwide countries. This finding supports the economic well-being perspective compared with the ‘grabbing/helping hand’ theories of corruption.

KEYWORDS: Corruption Risk; Country-level Performance; Country-level Governance; Panel Data; Simultaneous Equation Modelling

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Eco-efficiency Assessment of the US States: A DEA-Based Malmquist Productivity Index Analysis

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ABSTRACT

This study quantitatively evaluates eco-efficiency in the 50 states of the US using three inputs (capital stock, labor force, and energy consumption), one desirable output (real GDP), and one undesirable output variable (CO2 emissions). The output-oriented CCR and BCC models evaluate the states' technical and pure technical efficiency. In addition, Malmquist Productivity Index (MPI) evaluates the states' total productivity, technological, and efficiency changes from 2014 to 2019. The DEA results indicate that 56% of the states operate inputs and output at the most optimal scale. Delaware, Hawaii, Maryland, New York, and Virginia are designated CRS. Fifteen states are classed as IRS, which might considerably increase their production by expanding their input variables. Thirty states are classed as DRS, suggesting that their production level improves less than the proportion growth in their inputs. In addition, 60% of the states have excess energy consumption, and 80% have excess CO_2 emissions. The MPI results indicate that 43 states have improved productivity by 5.02% and efficiency by 7.29% from 2014 to 2019. Among these 43 states, Montana improved productivity and efficiency by 14.99% and 22.94%. Finally, only 18 states are found to have enhanced technological efficiency. The findings of this study will enable policymakers to understand the latest relative eco-efficiency assessments of the states in the US.

KEYWORDS: Data Envelopment Analysis (DEA), Eco-efficiency, Malmquist Productivity Index

INTRODUCTION

Global warming is the average temperature increase in Earth's surface, air, and oceans. It was first recognized by Fourier (1827), and Arrhenius (1897) developed the earliest model for the relationship between the temperature of the ground and carbon dioxide concentration. However, its perceived effects on humans have become measurable within the last five decades. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the average global surface temperature has increased by 1°C since 1850 because of an irrepressible increase in the concentration of greenhouse gasses. According to the previous report of the IPCC, if we successfully keep the concentration of greenhouse gasses constant, the global average surface warming would be about 0.2°C for a decade, which may lead to severe problems in ecosystems worldwide. According to the scenario projections in this report, when the warming increases by 2°C, approximately 25% of the plant and animal species will be in danger of extinction. In addition, crop productivity will decrease, leading to food scarcity in many regions.

Millions of people will have health problems because of an increase in malnutrition. Moreover, severe weather conditions will increase deaths, diseases, and injuries. Climate change also results in significant rising sea levels, leading islands in Asia, Africa, and the Caribbean to become vulnerable to storm surges, inundation, and erosion. A rising sea level is also the cause some islands will even vanish. Shortly, climate change will cause many severe problems if global warming is not restrained.

Not surprisingly, global warming and climate change became countries' most critical environmental and political issues. First, in 1997 a total of 192 countries signed the Kyoto Protocol, which delimits the production of GHG emissions to fight global warming and climate change. However, it was not a complete success because the world's three major GHG polluters, including the United States, which accounts for more than half of global GHG emissions, did not establish binding objectives. As a result, 196 parties signed the Paris Agreement in 2015 to limit the increase in global average temperature to less than 1.5 degrees Celsius above pre-industrial levels. According to the agreement, the United States must cut its GHG emissions by 25% by 2025 compared to 2005 levels. As a result, the energy and emission efficiency of states in the United States is critical to accomplishing this target. Furthermore, any increase in state energy and emission efficiency leads to long-term economic development for individual states and the United States. In addition, the states' eco-efficiency is critical in meeting their Renewable Portfolio Standards (RPS) requirements. RPS has been mandated by 30 states across the US and the District of Columbia (DC), requiring a specific target of in-state electricity production provided by renewable energy sources by a specific year. For example, Hawaii (HI) targeted that renewable energy sources will provide 100% of electricity production by 2045, Vermont (VT) targeted 75% by 2032, and California (CA) targeted 50% by 2030.

In this study, linear programming problems are modeled to quantitatively evaluate the eco-efficiency of the 50 states of the US using three inputs (capital stock, labor force, and energy consumption), one desirable output (real GDP), and one undesirable output variable (CO2 emissions). The output-oriented CCR (Charnes, Cooper, and Rhodes (1978)) and BCC (Banker, Charnes, and Cooper (1984)) models are implemented to evaluate the states' technical efficiency and pure technical efficiency. In addition, Malmquist Productivity Index (MPI) evaluates the states' total productivity, technological, and efficiency changes from 2014 to 2019. Lastly, the findings of this study will enable policymakers to understand the latest relative eco-efficiency assessments of the states in the US.

The remainder of this paper is organized as follows: Section 2 provides a brief literature review of DEA-related articles in the energy sector and the wind industry. Section 3 presents an overview of the DEA framework for the output-oriented CCR and BCC models. In addition, this section provides the MPI method briefly. Section 4 describes the data in detail with input and output variables selection. Section 5 reports the DEA and MPI results. Finally, Section 6 provides a summary and some concluding remarks.

LITERATURE REVIEW

Data Envelopment Analysis (DEA) is a very popular management tool for evaluating and improving the efficiency of both manufacturing and service operations. It was developed by Charnes et al. (1978).

This research assesses eco-efficiency in the 50 states of the United States utilizing three input variables (capital stock, labor force, and energy consumption), one desirable output variable (real GDP), and one undesirable output variable (CO_2 emissions). Capital stock and labor force are two critical components in all stages of production. The level of aggregate output may be measured using (real) GDP (real GDP). Energy consumption is an essential input variable in the manufacturing process and should be accounted for in the model to assess energy efficiency. Finally, because carbon dioxide (CO_2) emissions negatively result from manufacturing activities, they are critical for environmental efficiency and long-term economic growth. Table 1 summarizes the DEA applications in detail on this topic, considering these input and output variables. Please see Demiral and Sağlam (2021) for a thorough review of these studies.

Table 1: Summary of DEA applications in the literature

Reference	Measure	DMUs	Period	Methods
Zhou and Ang (2008)	Energy efficiency	21 OECD countries	1997-2001	DEA
Zhou et al. (2010)	Total-factor emission efficiency	Top 18 CO_2 emitters	1995-2004	MPI
Yeh et al. (2010)	Energy efficiency	China and Taiwan	2002-2007	DEA
Choi et al. (2012)	Energy efficiency	China's 30 Provinces	2001-2010	SBM
Wang et al. (2013)	Energy and environmental efficiency	China's 30 Provinces	2006-2010	DEA-window
Apergis et al. (2015)	Energy efficiency	OECD countries	1985-2011	SBM, MCMC-GLMM
Iftikhar et al. (2016)	Energy and emission efficiency	26 major economies	2013-2014	SBM
Moutinho et al. (2017)	Environmental efficiency	26 European countries	2001-2012	DEA, QR
Moutinho et al. (2018)	Eco-efficiency	16 Latin American countries	1994-2013	MPI
Park et al. (2018)	Environmental and emission efficiency	US's 50 states	2004-2012	SBM
Wang et al. (2020)	Eco-efficiency	17 European countries	2013-2017	SBM
Demiral and Sağlam (2021)	Eco-efficiency, Eco-productivity	US's 50 states	2018	DEA, SBM

This research builds on Demiral and Sağlam's (2021) prior work by utilizing a macroeconomic panel data set from 2014 to 2019. This study quantitatively evaluates eco-efficiency in the 50 states of the US using three inputs (capital stock, labor force, and energy consumption), one desirable output (real GDP), and one undesirable output variable (CO_2 emissions). The output-oriented CCR (Charnes, Cooper, and Rhodes (1978)) and BCC (Banker, Charnes, and Cooper (1984)) models are implemented to evaluate the states' technical efficiency and pure technical efficiency. In addition, Malmquist Productivity Index (MPI) evaluates the states' total productivity, technological, and efficiency changes from 2014 to 2019. Lastly, the findings of this study will enable policymakers to understand the latest relative eco-efficiency assessments of the states in the US.

MODEL DEVELOPMENT

Data Envelopment Analysis (DEA)

DEA is a non-parametric, multi-factor relative efficiency measure for evaluating and improving the effectiveness of both manufacturing and service operations. Charnes et al. (1978) introduced the DEA framework to calculate the relative efficiency score by dividing the weighted sum of outputs and a weighted sum of inputs to obtain decision-making units (DMU). Equation 1 formulates the scenario where we have N number of maximized DMUs, which are achieved by s number of output and m number of input variables:

$$\begin{aligned} \textit{Max.} \quad & E_k = \frac{\sum_r^s u_r y_{rk}}{\sum_i^m v_i x_{ik}} \\ \textit{s.t.} \quad & \frac{\sum_r^s u_r y_{rj}}{\sum_i^m v_i x_{ij}} \le 1, \forall j \\ & u_r, v_i \ge 0, \forall i, r. \end{aligned} \tag{1}$$

where E_e is the maximized efficiency score which belongs to the e^{th} DMU.

The Output-Oriented CCR Model

The output-oriented model's objective is to maximize output variable(s) while keeping the current level of inputs fixed. The output-oriented CCR model can be formulated as a linear programming problem under the constant returns to scale (CRS) assumption. The relative technical efficiency score of the kth DMU (ζ_k) can be computed as follows:

$$\begin{aligned} \textit{Max.} \quad & \zeta_k + \varepsilon \left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^- \right) & \\ \textit{s.t.} \quad & \zeta_k y_{rk} - \sum_{j=1}^{n} y_{rj} \lambda_j - s_{rk}^+ = 0 & r = 1,2,\dots,s; \\ & x_{ik} - \sum_{j=1}^{n} x_{ij} \lambda_j - s_{ik}^- = 0 & i = 1,2,\dots,m; \\ & \lambda_j, s_i^-, s_r^+ \ge 0; & j = 1,2,\dots,n;\ i = 1,2,\dots,m;\ r = 1,2,\dots,s. \end{aligned} \tag{2}$$

where s_r^+ and s_i^- represent non-negative slack variables for output and input constraints, respectively. x_{ij} represents the amount of ith input variable that jth DMU consumes; y_{rj}

represents the amount of rth output variable that jth DMU produces, and lastly λ_j represents structural variables.

The Output-Oriented BCC Model

The output-oriented BCC model can be formulated by adding a convexity constraint to Equation 2. The relative pure efficiency score of the kth DMU (ξ_k) of BCC model under variable returns to scale (VRS) assumption can be formulated as Equation 3:

$$
\begin{aligned}
\textit{Max.} \quad & \xi_k + \varepsilon\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^-\right) & \\
\textit{s.t.} \quad & \xi_k y_{rk} - \sum_{j=1}^{n} y_{rj}\lambda_j - s_{rk}^+ = 0 & r = 1,2,\ldots,s; \\
& x_{ik} - \sum_{j=1}^{n} x_{ij}\lambda_j - s_{ik}^- = 0 & i = 1,2,\ldots,m; \\
& \sum_{j=1}^{n} \lambda_j = 1 & \\
& \lambda_j, s_i^-, s_r^+ \geq 0; & j = 1,2,\ldots,n;\ i = 1,2,\ldots,m;\ r = 1,2,\ldots,s.
\end{aligned}
\tag{3}
$$

The output-oriented CCR and BCC models are adopted from Charnes et al. (1978), Bankers et al. (1984), and Sağlam (2017a, 2017b, 2018, 2019).

The Malmquist Productivity Index (MPI)

Caves et al. (1982) developed the Malmquist productivity index (MPI) based on Malmquist (1953). The MPI measures total-factor production, technical improvement, and the change in the efficiency of DMUs over time. Färe et al. (1994) proposed a DEA-based MPI by combining Farrell's (1957) efficiency measurements and Caves et al. (1982) productivity measurements and separating them into two components: the first measures efficiency changes, and the second measures technical changes.

Hence, MPI for DMU_k is formulated as Equation (4)

$$
\begin{aligned}
MPI_k &= \sqrt{\frac{D_k^t(x_k^{t+1}, y_k^{t+1})}{D_k^t(x_k^t, y_k^t)} \times \frac{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})}{D_k^{t+1}(x_k^t, y_k^t)}} \\
MPI_k &= \underbrace{\frac{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})}{D_k^t(x_k^t, y_k^t)}}_{\substack{Efficiency\ Change \\ (EC_0)}} \times \underbrace{\left[\frac{D_k^t(x_k^t, y_k^t)}{D_k^{t+1}(x_k^t, y_k^t)} \times \frac{D_k^t(x_k^{t+1}, y_k^{t+1})}{D_k^{t+1}(x_k^{t+1}, y_k^{t+1})}\right]^{1/2}}_{\substack{Technological\ Change \\ (TC_0)}}
\end{aligned}
\tag{4}
$$

The MPI can be written as the product of efficiency and technological change: MPI=EC×TC. MPI>1 denotes productivity growth, MPI=1 denotes no productivity change, and MPI<1 denotes productivity decline from t to t+1 for the associated DMU.

DATA DESCRIPTION

This study evaluates eco-efficiency in the 50 states of the US using three inputs (capital stock, labor force, and energy consumption), one desirable output (real GDP), and one undesirable output variable (CO_2 emissions). Capital stock and labor force are two fundamental components in all manufacturing phases. The aggregate output level can be assessed by (real) gross domestic product (real GDP). Energy consumption is an essential input variable in the manufacturing process and should be considered in the model to evaluate energy efficiency. Finally, carbon dioxide (CO_2) emissions are an unfavorable byproduct of manufacturing operations, making them essential for environmental efficiency and long-term economic development. Table 2 shows the Pearson correlations between pre-determined input and output variables from 2014 to 2019.

Table 2: Pearson Correlations between input and output variables (p-values are given in parentheses)

	Capital Stock	Labor Force	Energy Consumption	GDP	CO_2 Emission
Capital Stock	1.000	0.976 (0.000)	0.850 (0.000)	0.995 (0.000)	0.811 (0.000)
Labor Force		1.000 (0.000)	0.869 (0.000)	0.984 (0.000)	0.834 (0.000)
Energy Consumption			1.000	0.836 (0.000)	0.986 (0.000)
GDP				1.000	0.791 (0.000)
CO_2 Emission					1.000

Input Variables

In this study, we consider three input variables for the DEA models: (1) capital stock, (2) labor force, and (3) energy consumption. Table 3 presents the related data for these input variables.

Capital Stock:

There is a strong correlation between capital stock and real GDP (0.995). El-Shagi and Yamarik (2019) calculated the capital stock data set based on the different states' sectoral composition and the capital stock, investment, and depreciation estimations. The average US capital stock value (in 2009 Dollars) was about $20.77 trillion between 2014-2019. In 2019, California had the highest capital stock ($3.35 trillion), about 15% of the total US capital stock value. New York and Texas are runner-up states that exceed the $1 trillion thresholds. Vermont has the lowest capital stock value at $34.79 billion.

Labor force:

As discussed above, there is a strong correlation between capital stock and real GDP (0.985). The US Bureau of Labor Statistics provides monthly employment data sets for the individual states, and the annual labor force is calculated by the simple average of 12-month employment levels. In 2019, the US employed 156.68 million people, with an average unemployment rate of about 4 percent. The states' average employment rate is about 3.13 million, and Wyoming and Alaska have the lowest employment rates.

Energy Consumption:

Energy consumption is also an important input variable in the manufacturing process and should be considered in the model to evaluate energy efficiency. As seen in Table 2, there is a strong correlation between energy consumption and CO2 emissions. The US Energy Information Administration (EIA) provides the corresponding data set. According to the EIA, the United States' primary energy consumption hit a historical high of 101.1 quadrillion BTU (British thermal units) in 2019. According to the EIA, 80 percent of consumed energy is obtained from burning fossil fuels, the primary source of CO_2 emissions. The average energy consumption is about two quadrillions BTU, which ranges between 0.14 and 14.23 quadrillion BTU, consumed by Vermont and Texas, respectively.

Output Variables

This study considers a desirable and undesirable output variables in the data set: (1) real GDP and (2) CO_2 Emissions, respectively. Table 3 presents the related data for these output variables.

Real GDP:

The real gross domestic product (GDP) is the most critical output variable to measure the states' eco-efficiency. The data set is collected from the Bureau of Economic Analysis. As seen in Table 2, there is a strong correlation between the GDP and all the input variables. The US's total real GDP is $18.80 trillion, and it ranges from $0.03 and $2.8 trillion, which Vermont and California generated, respectively. New York (NY) and Texas (TX) are runner-up states that exceed the $1 trillion real GDP thresholds with $1.49 trillion and $1.76 trillion. The US state's average real GDP is about $376 billion, and 14 states have exceeded this value.

CO_2 Emissions:

Table 2 shows a strong correlation between CO_2 emissions and all the other input variables, especially with energy consumption. Hence, this output contributes significantly to precisely assessing states' eco-efficiency and ecologically sustainable manufacturing performance. The data set is derived from the EIA's US States Energy Portal. According to the EIA, the states' average CO2 Emission is about 103.12 million metric tons, ranging from 6.02 and 683.23.06 million metric tons, which Vermont and Texas produced, respectively.

Table 3: Descriptive Statistics of input and output variables in the period 2014–2019						
		Capital Stock	Labor Force	Energy Consumption	Emission	GDP
2014	Mean	395.04	2,919,776.52	1,962.25	108.28	332,590.67
	StDev	493.45	3,226,726.57	2,095.35	108.71	417,697.17
	Min	35.43	293,319.67	140.04	5.89	28,510.10
	Median	260.13	1,945,569.79	1,483.13	79.07	186,937.50
	Max	2,753.34	17,310,885.42	12,635.57	661.88	2,316,331.20
2015	Mean	403.28	2,963,595.11	1,944.07	105.28	343,146.95
	StDev	509.21	3,278,682.13	2,109.73	106.91	436,475.44
	Min	35.30	290,985.33	140.30	6.13	28,876.60
	Median	255.00	1,949,337.71	1,496.92	76.28	192,550.95
	Max	2,863.01	17,663,106.08	12,766.65	655.14	2,437,366.90
2016	Mean	410.93	3,010,661.03	1,943.51	103.55	348,979.36
	StDev	522.84	3,334,724.70	2,140.63	106.53	447,387.38
	Min	34.01	284,308.17	134.89	5.91	29,206.30
	Median	256.20	1,970,600.96	1,497.23	76.70	198,768.45
	Max	2,980.58	17,979,883.00	12,994.81	656.81	2,519,133.60
2017	Mean	418.36	3,056,137.09	1,949.28	102.81	357,248.45
	StDev	545.24	3,390,241.63	2,164.34	107.36	463,083.16
	Min	33.85	280,890.33	133.99	5.83	29,312.40
	Median	255.97	1,999,159.17	1,504.16	77.71	206,112.90
	Max	3,136.73	18,256,390.17	13,180.17	664.93	2,628,314.60
2018	Mean	427.61	3,094,329.81	2,020.25	105.84	367,899.03
	StDev	561.76	3,435,949.44	2,269.42	110.04	478,082.91
	Min	34.37	280,078.42	138.56	5.85	29,565.40
	Median	264.28	2,007,206.42	1,534.02	80.54	214,146.20
	Max	3,228.93	18,460,134.75	14,017.43	684.69	2,708,966.90
2019	Mean	437.52	3,133,560.86	2,002.39	103.12	376,087.13
	StDev	578.58	3,476,949.69	2,279.79	108.99	492,091.10
	Min	34.79	281,754.92	136.86	6.02	29,806.20
	Median	265.90	2,009,528.92	1,563.35	80.73	220,135.25
	Max	3,349.58	18,620,413.58	14,227.42	683.23	2,800,505.40

RESULTS AND DISCUSSIONS

DEA Results

This study quantitatively evaluates eco-efficiency in the 50 states of the US using three inputs (capital stock, labor force, and energy consumption), one desirable output (real GDP), and one undesirable output variable (CO_2 emissions). The output-oriented CCR (Charnes, Cooper, and Rhodes (1978)) and BCC (Banker, Charnes, and Cooper (1984)) models are implemented to evaluate the states' technical efficiency and pure technical efficiency. Figure 1 presents the average eco-efficiency scores obtained from the output-oriented CCR model, and Figure 2 presents the average eco-efficiency scores obtained from the output-oriented BCC model from 2014 to 2019.

The output-oriented CCR model indicates that there are only three states: Alaska, Delaware, and New York, reaching the maximum eco-efficiency score of 1.000 for all these six years. The average eco-efficiency score is 0.816, which ranges between 0.619 and 1.000. In addition, according to the output-oriented CCR model, 24 states' eco-efficiency score exceeds 0.80, and 11 states exceed 0.90. On the other hand, Arkansas, Montana, New Mexico, and West Virginia have the lowest eco-efficiency scores, less than 0.7, during the research focus period.

The output-oriented BCC model indicates ten states: Alaska, California, Delaware, Florida, Hawaii, New York, Rhode Island, Vermont, Virginia, and Wyoming, reaching the maximum eco-efficiency score of 1.000 for all these six years. The average eco-efficiency score is 0.858, which ranges between 0.640 and 1.000. In addition, according to the output-oriented BCC model, 32 states' eco-efficiency score exceeds 0.80, and 18 exceed 0.90. Similarly, Arkansas, Montana, and West Virginia have the lowest eco-efficiency scores, less than 0.7, and New Mexico barely exceeded the 0.7 thresholds during the research focus period.

The dual problem of the output-oriented CCR model provides states' current level of returns to scale information. For a given DMU, returns to scale are identified as increasing returns to scale (IRS) if the sum of the dual weights is less than 1, and it is identified as decreasing returns to scale (DRS) if the sum of the dual weights is greater than 1. Only five eco-efficient states: Delaware, Hawaii, Maryland, New York, and Virginia, are designated as CRS, indicating that they operate at the most excellent level of productive efficiency in 2019. On the other hand, IRS is assigned to fifteen states, implying that they might considerably increase their production by expanding their input variables. Thirty states are classed as DRS, suggesting that their production level improves less than the proportion growth in their inputs.

The scale efficiency scores for the output-oriented models are calculated by the ratio of the technical efficiency of the CCR model and the pure technical efficiency of the BCC model. The mean scale efficiency score is 0.965. A total of five states, Delaware, Hawaii, Maryland, New York, and Virginia, are scale efficient, and 47 states' scale efficiency scores exceed 90%. This result shows that 95% of the states are either scale efficient or very close to fulfilling scale efficiency.

The slack of the output-oriented CCR model indicates excess input and undesirable output variables. According to the slacks of capital stock, only four states have excess capital stock: Alaska, California, North Dakota, and Wyoming. The rest of them have zero-slack value for the capital stock. Only ten states have an excess labor force, with an average of 143 thousand employees, which can be reallocated between the other states to improve the productivity of each state.

60% of the states have an excess energy consumption, with an average of 676.4 billion BTU. The excess energy consumption should be reduced to increase states' current level of eco-efficiency performances. Similarly, 80% of the states have excess CO_2 emissions, averaging 39.3 metric tonnes. There are only ten states that have no excess emissions. The excess CO_2 emissions should be reduced to increase states' current level of eco-efficiency performances.

Figure 1: Average eco-efficiency scores obtained from output-oriented CCR model (2014-2019)

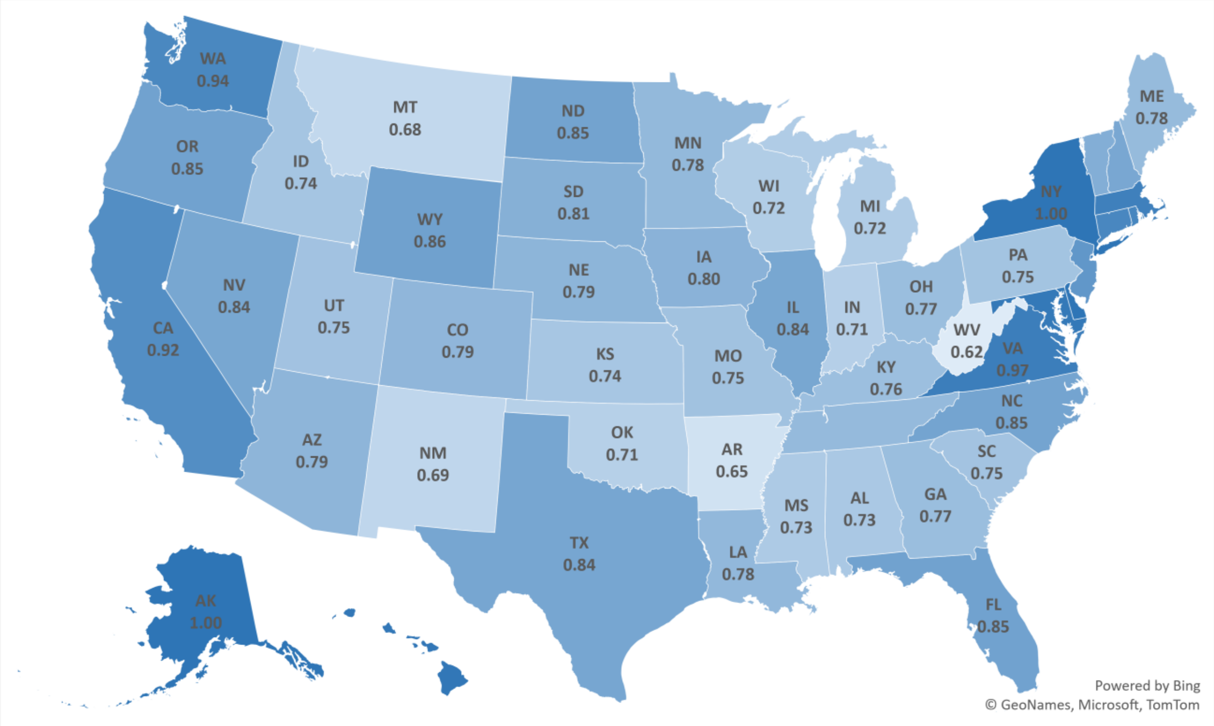
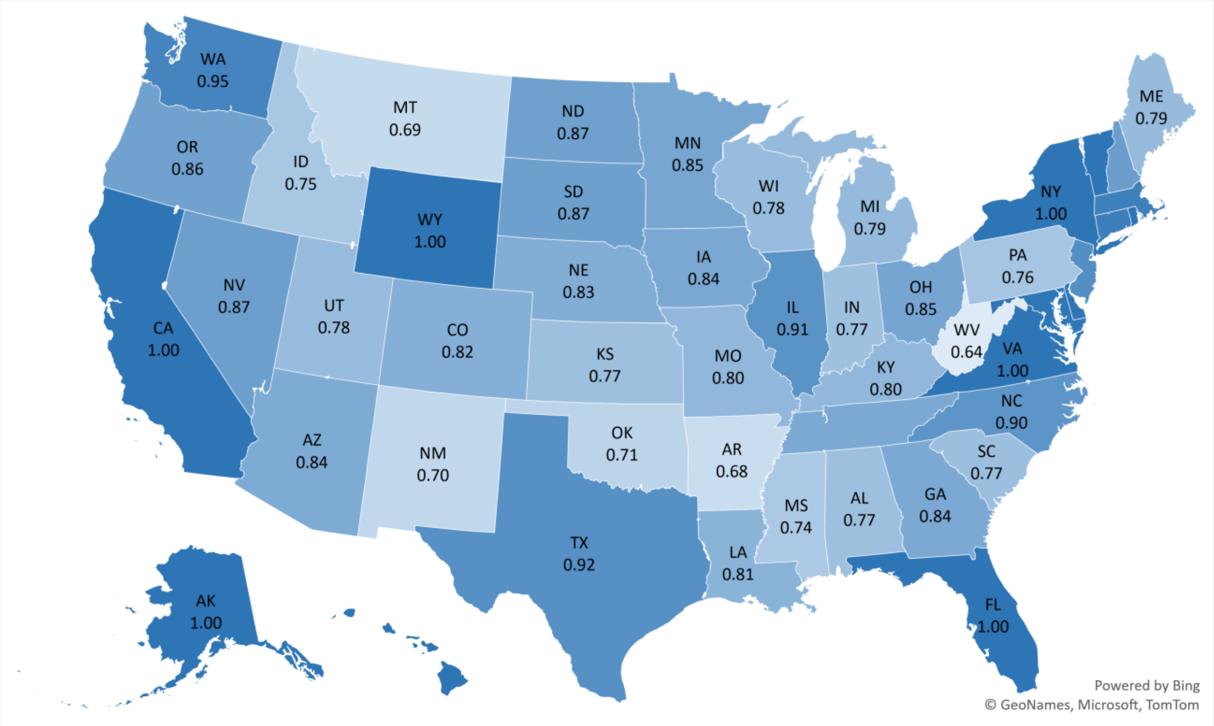


Figure 2: Average eco-efficiency scores obtained from output-oriented BCC model (2014-2019)



MPI Results

Equation 4 calculated the states' MPI results, efficiency change, and technological change from 2014 to 2019. Tables 4, 5, and 6 present year-on-year productivity, efficiency, and technological change for the 50 states from 2014 to 2019.

From 2014 to 2015, 41 states improved productivity by 1.1%. Among the 41 states, Montana improved productivity the most (4.1%). On the other hand, nine states have recessed productivity; Indiana recessed the most (−3.0%). Similarly, 35 states have improved efficiency with an average of 0.5%; Montana improved efficiency the most (3.8%). However, fifteen states have recessed efficiency. Among them, North Dakota recessed the most (−3.3%). Finally, 48 states are found to have improved technological efficiency, and only two states, Arkansas and Indiana, recessed technological efficiency.

From 2015 to 2016, only 23 states improved productivity. Vermont improved productivity the most (4.9%). On the other hand, 27 states have recessed productivity, and North Dakota recessed the most (−6.5%). Forty-one states have improved efficiency with an average of 3.9%. Among them, Kansas improved efficiency the most (8.1%). However, fifteen states are found to have recessed efficiency. North Dakota recessed the most (−6.7%) again. Only seven states were found to have improved technological efficiency during this period, and 43 states recessed technological efficiency. Arkansas, Georgia, Minnesota, and Ohio recessed the most (−5.7%).

From 2016 to 2017, 44 states are found to have improved productivity. Among them, Connecticut improved productivity the most (5.2%). However, only six states are found to have recessed productivity. In addition, 33 states have improved efficiency with an average of 1.3%. Among them, Connecticut improved efficiency the most (6.0%). However, 17 states are found to have recessed efficiency. During this period, 36 states were found to have improved technological efficiency, and 14 states recessed technological efficiency.

From 2017 to 2018, 40 states improved productivity with an average of 1.9%. North Dakota improved productivity the most (5.7%). On the other hand, ten states have recessed productivity. Among them, Delaware recessed the most (−4.6%). Similarly, 44 states have improved efficiency with an average of 3.8%. Among them, Arkansas improved efficiency the most (10.6%). However, only six states are found to have recessed efficiency. Among them, Rhode Island recessed the most (−2.7%). Furthermore, only 12 states are found to have improved technological efficiency, and 38 states recessed technological efficiency. During this period, Tennessee recessed the most (−6.2%).

From 2018 to 2019, 26 states have improved productivity by 1.6%. Among the 26 states, Maryland improved productivity the most (6.6%). On the other hand, 24 have recessed productivity; South Dakota recessed the most (−4.5%). However, only eight states have improved efficiency; Nebraska improved efficiency the most (2.7%). Forty-two states have recessed efficiency. Among them, Vermont recessed the most (−7.1%). Finally, 45 states are found to have improved technological efficiency. Among them, Vermont improved technological efficiency the most (7.3%). However, only five states recessed technological efficiency.

From 2014 to 2019, 43 states improved productivity by 5.02%. Among these 43 states, Montana improved productivity the most (14.99%). Connecticut, Kansas, and Nebraska exceeded the 10% thresholds. On the other hand, only seven states have recessed productivity. Among them, Delaware recessed the most (−6.42%). Forty-three states have improved efficiency by 7.29%. Among these 43 states, Montana improved efficiency the most (22.94%). However, only seven states have recessed efficiency. Among them, North Dakota recessed the most (−7.64%). Finally, only 18 states are found to have improved technological efficiency. New York improved technological efficiency the most (9.23%). However, 32 states recessed technological efficiency. During this period, Arkansas recessed the most (−10.51%).

SUMMARY AND CONCLUSION

This study quantitatively evaluates eco-efficiency in the 50 states of the US using three inputs (capital stock, labor force, and energy consumption), one desirable output (real GDP), and one undesirable output variable (CO_2 emissions). The output-oriented CCR and BCC models evaluate the states' technical and pure technical efficiency. In addition, Malmquist Productivity Index (MPI) evaluates the states' total productivity, technological, and efficiency changes from 2014 to 2019.

The DEA results indicate that 56% of the states operate inputs and output at the most optimal scale. Delaware, Hawaii, Maryland, New York, and Virginia are designated as CRS, indicating that they operate at the most excellent level of productive efficiency in 2019. On the other hand, IRS is assigned to fifteen states, implying that they might considerably increase their production by expanding their input variables. Thirty states are classed as DRS, suggesting that their production level improves less than the proportion growth in their inputs. In addition, 60% of the states have excess energy consumption, and 80% have excess CO_2 emissions.

The MPI results indicate that, from 2014 to 2019, 43 states have improved productivity by 5.02% and efficiency by 7.29%. Among these 43 states, Montana improved productivity and efficiency by 14.99% and 22.94%. Finally, only 18 states are found to have improved technological efficiency. New York improved technological efficiency the most (9.23%). However, 32 states recessed technological efficiency. During this period, Arkansas recessed the most (−10.51%).

In conclusion, it is hoped that the findings of this study will enable policymakers to understand the latest relative eco-efficiency assessments of the states in the US.

Table 4: Year-on-year MPI changes for the US states from 2014 to 2019

State	14-15	15-16	16-17	17-18	18-19	Average	Cumulative	% Growth
Alabama	0.996	0.984	1.026	1.015	0.993	1.003	1.012	1.22%
Alaska	1.012	0.995	1.000	1.016	1.017	1.008	1.040	4.00%
Arizona	1.010	0.993	1.026	1.008	0.987	1.005	1.024	2.37%
Arkansas	0.990	0.996	1.032	1.042	0.996	1.011	1.057	5.66%
California	1.024	1.005	1.014	1.011	1.027	1.016	1.083	8.25%
Colorado	1.027	1.019	1.029	1.002	0.999	1.015	1.078	7.81%
Connecticut	1.025	1.040	1.052	0.970	1.019	1.021	1.108	10.81%
Delaware	1.006	0.948	1.006	0.954	1.022	0.987	0.936	-6.42%
Florida	1.008	1.008	1.012	1.009	1.014	1.010	1.051	5.14%
Georgia	1.004	0.988	1.006	1.017	0.995	1.002	1.011	1.07%
Hawaii	1.019	1.008	1.004	1.016	0.996	1.009	1.044	4.35%
Idaho	1.005	1.010	1.011	1.030	1.013	1.014	1.070	7.01%
Illinois	1.004	0.992	1.010	1.006	0.992	1.001	1.005	0.52%
Indiana	0.970	0.992	1.015	1.013	1.001	0.998	0.990	-1.03%
Iowa	1.035	0.983	1.005	1.017	0.993	1.007	1.032	3.25%
Kansas	1.025	1.035	1.013	1.020	1.003	1.019	1.100	10.04%
Kentucky	1.007	0.987	1.006	1.014	0.995	1.001	1.007	0.73%
Louisiana	0.987	0.993	1.014	1.010	1.016	1.004	1.022	2.15%
Maine	0.986	1.007	1.032	1.034	1.013	1.014	1.074	7.37%
Maryland	0.995	0.994	1.028	0.999	1.066	1.016	1.082	8.20%
Massachusetts	1.011	1.011	0.989	1.005	0.999	1.003	1.014	1.44%
Michigan	1.005	0.985	1.006	1.017	0.992	1.001	1.004	0.45%
Minnesota	1.004	1.007	1.009	1.020	0.998	1.008	1.038	3.82%
Mississippi	1.008	0.995	1.029	1.020	1.000	1.010	1.052	5.23%
Missouri	1.007	0.995	1.020	1.022	0.985	1.006	1.028	2.84%
Montana	1.041	1.013	1.043	1.041	1.004	1.028	1.150	14.99%
Nebraska	1.030	1.004	0.996	1.031	1.046	1.021	1.111	11.13%
Nevada	0.999	0.999	1.000	1.000	0.981	0.996	0.980	-2.02%
New Hampshire	1.033	1.029	1.019	0.996	0.991	1.013	1.068	6.82%
New Jersey	1.014	1.013	1.007	0.984	1.014	1.006	1.032	3.17%
New Mexico	1.020	0.999	0.999	0.987	1.001	1.001	1.005	0.54%
New York	1.016	1.022	1.018	1.000	1.032	1.018	1.092	9.23%
North Carolina	1.002	0.987	1.024	1.002	0.990	1.001	1.005	0.51%
North Dakota	0.976	0.935	1.005	1.057	1.007	0.996	0.976	-2.36%
Ohio	0.975	0.993	1.005	1.013	1.009	0.999	0.994	-0.56%
Oklahoma	1.018	0.978	0.995	1.024	1.027	1.008	1.042	4.21%
Oregon	1.035	1.008	1.002	1.014	1.008	1.013	1.067	6.74%
Pennsylvania	1.014	1.002	1.011	1.014	1.025	1.013	1.067	6.70%
Rhode Island	1.022	1.034	1.005	0.975	1.010	1.009	1.046	4.61%
South Carolina	1.003	0.992	1.020	1.026	0.996	1.008	1.039	3.87%
South Dakota	1.011	1.001	1.024	1.028	0.955	1.004	1.018	1.76%
Tennessee	1.011	0.982	1.003	1.006	0.985	0.998	0.987	-1.26%
Texas	1.039	0.996	1.005	1.014	1.005	1.012	1.060	6.00%
Utah	1.019	1.019	1.015	1.016	0.993	1.012	1.064	6.36%
Vermont	1.002	1.049	1.011	0.997	0.997	1.011	1.056	5.60%
Virginia	1.008	1.018	1.018	0.999	0.998	1.008	1.042	4.19%
Washington	1.023	0.989	1.017	1.019	0.990	1.008	1.038	3.76%
West Virginia	1.018	0.981	0.996	1.019	0.974	0.998	0.988	-1.23%
Wisconsin	1.012	1.006	1.003	1.030	1.010	1.012	1.063	6.26%
Wyoming	1.039	0.979	1.008	1.025	1.007	1.012	1.058	5.81%

Table 5: Year-on-year efficiency changes for the US states from 2014 to 2019

State	14-15	15-16	16-17	17-18	18-19	Average	Cumulative	% Growth
Alabama	0.992	1.025	1.004	1.064	0.990	1.015	1.076	7.58%
Alaska	1.000	1.000	1.000	0.998	1.001	1.000	1.000	-0.04%
Arizona	0.999	1.023	1.019	1.010	0.983	1.007	1.034	3.41%
Arkansas	0.990	1.057	1.033	1.106	0.987	1.035	1.181	18.07%
California	1.013	0.998	1.010	1.010	0.995	1.005	1.027	2.70%
Colorado	1.026	1.046	1.029	1.019	0.988	1.021	1.111	11.12%
Connecticut	1.006	1.020	1.060	0.974	1.001	1.012	1.060	6.05%
Delaware	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.00%
Florida	0.996	1.048	1.003	1.025	0.999	1.014	1.073	7.34%
Georgia	1.001	1.048	1.011	1.052	0.973	1.017	1.085	8.55%
Hawaii	1.008	1.019	1.000	1.000	1.000	1.005	1.028	2.76%
Idaho	0.991	1.064	0.991	1.044	0.988	1.016	1.078	7.85%
Illinois	1.004	1.035	1.017	1.023	0.978	1.012	1.059	5.86%
Indiana	0.970	1.049	1.025	1.040	0.986	1.014	1.069	6.88%
Iowa	1.031	1.024	0.983	1.078	0.987	1.021	1.105	10.53%
Kansas	1.024	1.081	1.020	1.041	0.989	1.031	1.162	16.23%
Kentucky	1.003	1.028	0.984	1.059	0.992	1.013	1.067	6.66%
Louisiana	0.986	1.026	1.019	1.023	1.002	1.011	1.057	5.73%
Maine	0.982	1.054	1.008	1.053	0.988	1.017	1.085	8.55%
Maryland	0.983	1.021	1.019	1.000	1.000	1.005	1.023	2.30%
Massachusetts	1.001	1.014	0.993	1.012	0.968	0.998	0.988	-1.17%
Michigan	1.001	1.027	1.009	1.072	0.976	1.017	1.085	8.46%
Minnesota	1.002	1.068	1.019	1.051	0.980	1.024	1.124	12.42%
Mississippi	1.004	1.036	1.007	1.039	1.013	1.020	1.102	10.25%
Missouri	1.004	1.036	0.998	1.071	0.981	1.018	1.090	9.05%
Montana	1.038	1.055	1.023	1.100	0.998	1.043	1.229	22.94%
Nebraska	1.030	1.054	1.002	1.050	1.027	1.033	1.173	17.25%
Nevada	0.992	1.040	0.990	1.031	0.981	1.007	1.034	3.38%
New Hampshire	1.022	1.056	1.010	0.997	0.937	1.004	1.018	1.85%
New Jersey	1.002	1.038	1.003	1.008	0.994	1.009	1.046	4.61%
New Mexico	1.017	1.001	0.998	0.985	0.989	0.998	0.990	-0.96%
New York	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.00%
North Carolina	0.998	1.038	1.002	1.031	0.975	1.009	1.042	4.25%
North Dakota	0.967	0.933	0.998	1.035	0.992	0.985	0.924	-7.64%
Ohio	0.971	1.053	1.015	1.040	0.994	1.015	1.073	7.34%
Oklahoma	1.014	0.965	0.980	1.016	1.014	0.998	0.989	-1.14%
Oregon	1.023	1.034	0.992	1.015	0.963	1.005	1.026	2.55%
Pennsylvania	1.011	0.996	1.009	1.011	1.011	1.008	1.039	3.91%
Rhode Island	1.012	1.049	1.006	0.973	0.985	1.005	1.024	2.37%
South Carolina	1.000	1.034	0.998	1.064	0.998	1.019	1.097	9.66%
South Dakota	1.007	1.043	1.003	1.080	0.948	1.016	1.079	7.86%
Tennessee	1.007	1.023	0.983	1.072	0.975	1.012	1.059	5.92%
Texas	1.037	0.998	1.004	1.016	0.992	1.009	1.048	4.76%
Utah	1.008	1.052	1.012	1.048	0.981	1.020	1.102	10.23%
Vermont	0.990	1.079	1.000	0.996	0.929	0.999	0.988	-1.22%
Virginia	1.004	1.062	0.995	1.020	1.000	1.016	1.082	8.16%
Washington	1.011	1.009	1.012	1.035	0.972	1.008	1.039	3.90%
West Virginia	1.015	0.971	0.993	1.013	0.962	0.991	0.954	-4.65%
Wisconsin	1.006	1.048	0.999	1.088	0.993	1.027	1.137	13.70%
Wyoming	1.028	0.979	1.002	1.004	0.992	1.001	1.004	0.38%

Table 6: Year-on-year technological efficiency changes for the US states from 2014 to 2019								
State	14-15	15-16	16-17	17-18	18-19	Average	Cumulative	% Growth
Alabama	1.004	0.960	1.022	0.954	1.002	0.988	0.941	-5.91%
Alaska	1.012	0.995	1.000	1.018	1.015	1.008	1.040	4.04%
Arizona	1.011	0.970	1.007	0.998	1.004	0.998	0.990	-1.01%
Arkansas	1.000	0.943	0.999	0.942	1.009	0.978	0.895	-10.51%
California	1.011	1.007	1.004	1.001	1.031	1.011	1.054	5.40%
Colorado	1.001	0.974	1.000	0.984	1.011	0.994	0.970	-2.98%
Connecticut	1.018	1.019	0.993	0.996	1.019	1.009	1.045	4.49%
Delaware	1.006	0.948	1.006	0.954	1.022	0.987	0.936	-6.42%
Florida	1.012	0.962	1.008	0.984	1.015	0.996	0.980	-2.05%
Georgia	1.004	0.943	0.995	0.967	1.023	0.986	0.931	-6.89%
Hawaii	1.010	0.989	1.004	1.016	0.996	1.003	1.015	1.55%
Idaho	1.013	0.949	1.020	0.986	1.026	0.999	0.992	-0.77%
Illinois	1.000	0.959	0.994	0.983	1.014	0.990	0.950	-5.04%
Indiana	0.999	0.946	0.991	0.974	1.015	0.985	0.926	-7.40%
Iowa	1.004	0.960	1.022	0.944	1.006	0.987	0.934	-6.59%
Kansas	1.000	0.957	0.993	0.981	1.015	0.989	0.947	-5.33%
Kentucky	1.004	0.960	1.022	0.957	1.002	0.989	0.944	-5.56%
Louisiana	1.001	0.968	0.995	0.988	1.014	0.993	0.966	-3.38%
Maine	1.004	0.956	1.023	0.983	1.025	0.998	0.989	-1.08%
Maryland	1.012	0.973	1.008	0.999	1.066	1.012	1.058	5.76%
Massachusetts	1.010	0.996	0.996	0.993	1.032	1.005	1.026	2.64%
Michigan	1.004	0.959	0.998	0.948	1.017	0.985	0.926	-7.39%
Minnesota	1.002	0.943	0.990	0.970	1.018	0.985	0.923	-7.65%
Mississippi	1.004	0.960	1.022	0.982	0.988	0.991	0.955	-4.55%
Missouri	1.004	0.960	1.022	0.954	1.004	0.989	0.943	-5.70%
Montana	1.004	0.960	1.020	0.946	1.006	0.987	0.935	-6.47%
Nebraska	1.000	0.953	0.994	0.982	1.018	0.990	0.948	-5.22%
Nevada	1.008	0.961	1.010	0.970	1.000	0.990	0.948	-5.23%
New Hampshire	1.010	0.974	1.008	1.000	1.058	1.010	1.049	4.88%
New Jersey	1.012	0.976	1.003	0.976	1.019	0.997	0.986	-1.38%
New Mexico	1.002	0.998	1.001	1.001	1.012	1.003	1.015	1.52%
New York	1.016	1.022	1.018	1.000	1.032	1.018	1.092	9.23%
North Carolina	1.004	0.951	1.023	0.972	1.016	0.993	0.964	-3.58%
North Dakota	1.010	1.002	1.008	1.021	1.015	1.011	1.057	5.71%
Ohio	1.004	0.943	0.990	0.974	1.015	0.985	0.926	-7.36%
Oklahoma	1.004	1.013	1.015	1.008	1.013	1.011	1.054	5.41%
Oregon	1.012	0.975	1.010	0.999	1.046	1.008	1.041	4.08%
Pennsylvania	1.003	1.006	1.003	1.002	1.013	1.005	1.027	2.68%
Rhode Island	1.010	0.986	0.999	1.002	1.026	1.004	1.022	2.19%
South Carolina	1.004	0.960	1.022	0.964	0.998	0.989	0.947	-5.28%
South Dakota	1.004	0.960	1.022	0.952	1.007	0.989	0.943	-5.66%
Tennessee	1.004	0.960	1.021	0.938	1.010	0.987	0.932	-6.78%
Texas	1.003	0.997	1.000	0.998	1.013	1.002	1.012	1.19%
Utah	1.011	0.968	1.004	0.970	1.012	0.993	0.965	-3.51%
Vermont	1.012	0.973	1.011	1.001	1.073	1.014	1.069	6.91%
Virginia	1.004	0.959	1.023	0.980	0.998	0.993	0.963	-3.68%
Washington	1.011	0.980	1.005	0.985	1.018	1.000	0.999	-0.13%
West Virginia	1.003	1.011	1.003	1.006	1.012	1.007	1.036	3.58%
Wisconsin	1.006	0.960	1.005	0.946	1.017	0.987	0.935	-6.54%
Wyoming	1.011	1.000	1.006	1.021	1.015	1.011	1.054	5.41%

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Effect of data sharing in the supply chain on product quality: Mediating roles of JIT delivery and supplier integration

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ABSTRACT

Supply chain integration, especially supply chain quality integration, is critical to improving the quality of products. Past research suggested many factors that relate to the quality of products. However, we do not exactly know the relationships, especially the causal relationships, among them. Based on the literature review, we picked up three factors, i.e., data sharing, JIT delivery, and supplier integration, related to product quality. We presumed a causal sequence of these factors with three hypotheses and analyzed them with data in hand. We also checked the mediation effects of JIT delivery and supplier integration.

KEYWORDS: Data sharing, Product quality, Supply chain quality integration, JIT delivery, and Empirical study

INTRODUCTION

World competition among companies and plants in the manufacturing industry is becoming fiercer today. The quality of the product is critical to being selected by consumers and the market. It is well known that "there is a relationship between integration and performance" (Van Donk and Van der Vaart, 2004) Different companies and plants within a supply chain need to cooperate and coordinate to realize product quality. It is a matter of supply chain integration (SCI). Today, product quality depends on SCI.

Supplier integration has a more vital link to internal integration and information systems than customer integration (Ganbold et al., 2021). "Performance improvement and competitive advantage can be achieved by cooperative relations with suppliers" (Al-Abdallah et al., 2014). Therefore, we focus on supplier integration specifically in this study.

Research Motivation

Our goal in this article is to find the driving factors of product quality in the supply chain context. Today, product quality depends on supply chain quality integration (SCQI). SCQI includes many factors or aspects, but the relationships among these factors are not transparent. Huo et al. (2019) wrote that “although the contingent effects of SCQI on quality-related performance have been studied, SCQI patterns and their relationships with performance remain unknown.” Are there any sequences or causal relationships among them? Besides, many external conditions may affect these SCQI factors. However, we do not have enough empirical evidence that reports these relationships. "Although the antecedents and consequences of quality management have been well studied, previous research has not examined them in the supply chain context" (Huo et al., 2014). Of course, we can imagine many cause-and-effect relationships among them. Therefore, we tried to find a sequence of the cause-and-effect relationships among these factors based on a literature review and an empirical study.

The paper is organized as follows. In the next section, we will discuss the relevant concepts and relationships among them as a literature review. We also present our research hypotheses and model there. The third section will present our data for our empirical analysis. In the fourth section, we will show results of the preliminary measurement analysis for key constructs, which will be followed by results of hypothesis testing in the fifth section. In the sixth section, we will study mediation effects of JIT delivery and supplier integration more deeply, taking in account direct and indirect effects among the constructs. Finally, we will present our conclusions, where we shall interpret our findings, discuss academic and managerial implications and research limitations, and suggest avenues for future research.

LITERATURE REVIEW

Supply Chain Quality Integration

Our goal in this article is finding affecting factors and their sequences to SCQI. Zhao et al. (2008) defined supply chain integration (SCI) as “the degree to which an organization strategically collaborates with its main supply chain partners and manages intra- and inter-organization processes to achieve effective and efficient flows of products, services, information, money, and decisions, with the objective of providing maximum value to its customers” (p.7). Many studies have been conducted about SCI. Van Donk & Van der Vaart (2004) defined five dimensions of SCI: (1) physical flow, (2) planning and control, (3) organization, (4) flow of information, and (5) product development. We would like to insist that these dimensions interweave with each other.

A part of SCI, supply chain quality integration (SCQI) or supply chain quality management (SCQM), is critical for manufacturing companies. Zhang et al. (2019) defined SCQI as “the degree to which an organization's internal functions and external supply chain partners strategically and operationally collaborate with each other to jointly manage intra- and inter-organizational quality-related relationships, communications, processes, etc., with the objective to achieve high levels of quality-related performance at low costs.” SCQI includes intra- and inter- (supplier and customer) integration of quality improvement activity in internal and external supply chain contexts (Robinson & Malhotra, 2005; Akyuz & Erkan, 2010). On the other hand, SCQM is conceptualized as the integration between quality management (QM) and supply chain management (SCM) (Lin & Gibson, 2011; Kaur et al., 2019; Alkalha et al., 2019). Robinson & Malhotra (2005) defined SCQM as "the formal coordination and integration of business processes involving all partner organizations in the supply channel to measure, analyze and continually improve products, services, and processes in order to create value and achieve satisfaction of intermediate and final customers in the marketplace."

While enormous studies have been made on quality management (QM) so far, QM problems turn out to be SCQI problems because of the increased criticality of SCI. "Along with the globalization of production, supply chains have become crucial sources of quality issues (Flynn & Zhao, 2015; Foster, 2008; Robinson & Malhotra, 2005)" (Zhang et al., 2019). SCQI consists of internal, supplier, and customer integration to attain quality improvement (Huo et al., 2014).

SCQI has many benefits. It is necessary not only to supply quality products to customers but also to improve "all quality-related performance (i.e., product quality, cost, delivery, and flexibility)" (Huo et al., 2014). Huo et al. (2014) wrote that quality and SCQM preventive measures could avoid many product recall incidents.

Data Sharing

Firms in a supply chain must share data to realize SCQI. A supply chain must share many different types of information, including logistics, business, strategic, tactical, and so on (Lotfi, et al., 2013). Data sharing among stakeholders is necessary for suppliers and buyers to realize JIT delivery. They have motivations to share data, e.g., to minimize inventory holdings. It is necessary for suppliers and logistics partners to share data to deliver products and materials just in time. IT systems for data sharing facilitate the success of JIT by providing precise information on future materials requirements (Banker et al., 2006; Valamede & Akkari, 2020). Data sharing benefits both buyers and sellers (Lotfi et al., 2013).

Data sharing relates to the fourth dimension (i.e., the flow of information) of SCI (Van Donk & Van der Vaart, 2004). ICT and EDI are typical tools for data sharing. As they are no more than tools, proactive use or how to use them are critical for data sharing. Why and how to share the data and information in the SCI context is essential. Besides, use-case of ICT range widely. Companies and plants use ICT tools for almost all activities and dimensions for data sharing.

Let us think of it from a resource-based view (RBV) (Barney, 1991). Because ICT tools and EDI services are ubiquitous or available quite easily, their simple introduction cannot prove a competitive advantage. Unless we focus on the applications and processes, we may fail to find the values of data sharing in SCQI.

JIT Delivery

"JIT delivery is a delivery full on time. Delivery full-on-time is the most widely used performance indicator in measuring delivery performance. It is defined as the percentage of time a company delivers the orders in the right quantities and at the right time to its customers. Delivery performance is of particular importance for the suppliers. For decreasing their manufacturing costs, manufacturers impose JIT delivery on their suppliers" (Ulusoy, 2003). JIT delivery from suppliers is proof of the JIT supply chain (Yang, 2021). JIT delivery by suppliers relates to the first (physical flow) and third (organization) dimensions of SCI by Van Donk & Van der Vaart (2004). Moreover, the second dimension (planning and control) of SCI by Van Donk & Van der Vaart (2004) is necessary to realize JIT delivery. "In a JIT supply chain, suppliers are responsible for knowing their customers and end consumers of their products" (Yang, 2021). Suppliers and buyers need to share both sides of data to realize it. Suppliers can achieve JIT delivery by receiving updated data on the production schedule in the buyer plant.

Today, companies and plants employ ICT for JIT delivery to accelerate coordination and adapt to the volatile demand and rapid change in the market. Ganbold et al. (2021) wrote that JIT delivery from suppliers is "well integrated with the internal cross-functional applications such as ERP systems." Data sharing with ICT is a prerequisite of JIT delivery today. Therefore, we have
H1: Data sharing with suppliers is a prerequisite to JIT delivery from suppliers.

Supplier Integration

Menguc et al. (2014) insisted on the strategic importance of supplier integration for firms in their new product development. Van Donk & Van der Vaart (2004) showed JIT as an example of the third dimension (organization) of SCI. However, JIT delivery is also a prerequisite for physical flow, such as vendor-managed inventories (VMI), packaging customization, and standard equipment or containers. Usually, JIT buyers request vendors for packaging customization and standard equipment or containers. Packaging customization is a “buyer focus” (Van Donk & Van der Vaart, 2004), which makes integration easy. Moreover, “typical integrative activities are those that aim at standardization as a means to smooth information and material flow across the chain” (Van Donk & Van der Vaart, 2004). Otherwise, buyer plants must adapt to vendor-specific packages and containers, adding one more step to handling these purchased materials. It decreases work efficiency on the buyer side. JIT is also necessary for suppliers to improve efficiency in VMI operations.

The discussion illuminates supplier integration into the buyer process and the importance of JIT delivery to realize operational efficiency. VMI, packaging customization, and standard equipment or containers request suppliers’ adaptation, and it is the supplier integration into the buyer’s system. In JIT delivery, “vendors are integrated into the production system by a pull system making frequent deliveries as needed” (Ahmad et al., 2003). Therefore, we propose
H2: JIT delivery from suppliers is a prerequisite to supplier integration.

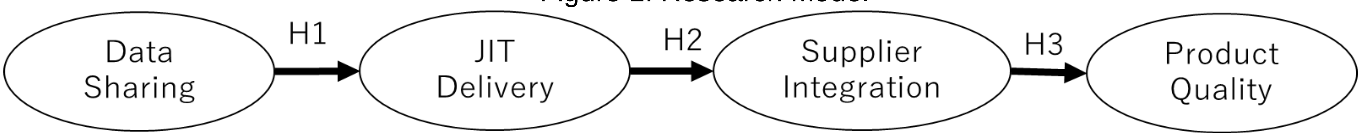
Product Quality

Product quality is our goal factor to explain. The goal of SCQI is improving “high levels of quality-related performance “(Zhang et al., 2019). Supplier integration for quality is SCQI. Devaraj et al. (2007) suggested that supplier integration had a positive effect on quality performance. It improves product quality besides other quality dimensions such as distribution quality. Therefore, we simply propose
H3: supplier integration improves product quality.

First Research Model

Using the constructs and hypotheses suggested in the previous section, we can draw Figure 1 as our research model, where we propose the cause-and-effect sequence. It implicitly supposes pure or full mediation effects. Of course, we can add more direct effects to make them various partial mediation models. We will discuss it later. Therefore, Figure 1 is our first research model.

Figure 1: Research Model



DATA

We employed the fourth-round dataset of the High-Performance Manufacturing (HPM) survey project (Schroeder & Flynn, 2001; Shimada & Ang, 2014). The project collected various data from plants in three manufacturing industries (Table 2) in 13 advanced countries (Table 1). The fourth round of the HPM project data collection started in 2014. It is the latest version available. Table 1 shows the demographics of respondents. The dataset includes 306 plants in thirteen countries/regions. A regional team visited the representatives of companies and plants and asked them to respond to a set of standardized questionnaires in each country/region. The original questionnaires had been made in English, and regional team members in each country/region translated them into their language before the distribution. If a company had multiple plants, the company was requested to select one plant for the data collection.

Table 1: Data distribution by country and region

Country/Region	Count	%	Country/Region	Count	%
Brazil	24	7.8	Japan	22	7.2
China	30	9.8	Korea	26	8.5
Spain	25	8.2	Sweden	9	2.9
Finland	17	5.6	Taiwan	30	9.8
Germany	28	9.2	United Kingdom	13	4.2
Israel	26	8.5	Vietnam	25	8.2
Italy	29	9.5	Missing	2	0.7
			Total	306	100

Table 2 shows the sample size by industry. We selected plants in the electric/electronics, machinery, and transportation industries. The transportation industry includes both assembly and parts manufacturers.

Table 2: Data distribution by industry

Industry	Count	%

Electric/Electronics	114	37.3
Machinery	110	35.9
Transportation	80	26.1
Missing	2	0.7
Total	306	100.0

The following four tables (Table 3 to Table 6) list questions that we employed to measure each construct. The respondents are different depending on the questions. Accountants responded to questions for Data Sharing in Table 3, upstream supply chain management responded to questions for JIT Delivery in Table 4 and for Supplier Integration in Table 5, and downstream supply chain management responded to questions for Product Quality in Table 6.

Within questions for data sharing (Table 3), we included questions about inventory data. Inventory data is one of typical data that are shared within supply chain. Supply chain companies share inventory data to avoid going out of stock and stock repetition (Lotfi et al., 2013). We also added just in time question. Data (knowledge) sharing is a base of Just-in-time (JIT) supply chain (Yang et al., 2021).

Table 3: Questions for Data Sharing

VARIABLES	QUESTIONS: Respondents are Accounting Management
DTSH01	Inventory holdings are minimized across the supply chain.
DTSH02	Supply chain-wide inventory is jointly managed with suppliers and logistics partners (e.g., UPS, FedEx)
DTSH03	Distribution networks are configured to minimize total supply chain-wide inventory costs.
DTSH04	Production and delivery schedules are shared across the supply chain.
DTSH05	Performance metrics are shared across the supply chain.
DTSH06	Supply chain members collaborate in arriving at demand forecasts.
DTSH07	Inventory data are visible at all steps across the supply chain.

Table 4: Questions for JIT Delivery

VARIABLES	QUESTIONS: Respondents are Upstream Supply Chain Management
JITD01	Our suppliers deliver to us on a just-in-time basis.
JITD02	We receive daily shipments from most suppliers.
JITD03	Our suppliers are linked with us by a pull system.

Table 5: Questions for Supplier Integration

VARIABLES	QUESTIONS: Respondents are Upstream Supply Chain Management
SINT01	Our manufacturing plans/solutions are supply chain aligned.
SINT02	Supply chain partner input is used in developing manufacturing plans and solutions.
SINT03	Our supply chain partners' plans /solutions are manufacturing aligned.
SINT04	Manufacturing inputs is used in developing our supply chain partners' plans and solutions.

Table 6: Questions for Product Quality

VARIABLES	QUESTIONS: Respondents are Downstream Supply Chain Management
QUAL01	Quality is the most important criterion used by our customers in selecting us as a supplier.
QUAL02	Our customers can rely on us for quality products.
QUAL03	We are selected by our customers because of our reputation for quality.

PRELIMINARY MEASUREMENT ANALYSIS

Exploratory Factor Analysis

We conducted an exploratory factor analysis (EFA) with all question items (variables) to explore “the underlying factor structure without prior specifications of the number of factors and their loadings” (Venkatraman,1989). We employed SPSS version 28 for the calculation. Table 7 shows the result with 17 question items in total. Since we assumed that the extracted factors correlate, we ran EFA with a Promax rotation based on maximum likelihood factor analysis (MLFA). We found four distinct factors with eigenvalues greater than 1.0. They account for 65.11% of the variance in total.

We employed a Kaiser-Meyer-Olkin (KMO) test to determine the sampling adequacy of data to be used for our EFA. The result of the KMO test of sample adequacy was .833. Kaiser & Rice (1974) wrote that >.9 is marvelous, >.8 is meritorious, >.7 is middling, and >.6 is mediocre. Bartlett’s test of sphericity had an approximate Chi-square of 1361.12 at a significance level of 0.001. It checked whether the matrix of correlations is significantly different from an identity matrix. It supported that the data was approximately multivariate normal and suitable for factor analysis (Jacks et al., 2018; Zach, 2019).

We tested for possible common method bias (variance) with Harman’s single-factor test (Podsakoff et al. 1986). According to this approach, common method bias would be present if a single factor accounts for most of the variance extracted from the exploratory factor analysis (EFA). The first factor accounts for 28.72% of the total variance only. Therefore, we do not need to look at the common method bias as a significant concern.

Table 7: Result of EFA

Variables	Data Sharing	JIT Delivery	Supplier Integration	Product Quality
DTSH01	0.648	0.028	-0.057	-0.03
DTSH02	0.598	-0.009	0.07	0.058
DTSH03	0.790	0.038	0.016	-0.012
DTSH04	0.753	0.012	-0.008	-0.061
DTSH05	0.795	-0.112	-0.01	0.03
DTSH06	0.703	0.023	-0.016	0.05
DTSH07	0.615	0.02	0.075	-0.056
JITD01	-0.008	-0.08	0.923	0.137
JITD02	0.019	0.034	0.574	-0.073
JITD03	0.046	0.089	0.581	-0.073
SINT01	0.05	0.776	-0.04	0.058
SINT02	0.01	0.820	0.043	0.03
SINT03	0.015	0.861	0.021	-0.036
SINT04	-0.073	0.817	0	-0.007
QUAL01	-0.106	0.008	0.168	0.572
QUAL02	0.035	0.048	-0.007	0.674
QUAL03	0.046	-0.011	-0.149	0.852

Confirmative Factor Analysis

Next, based on the results of the EFA, we conducted confirmative factor analysis (CFA) with Amos version 25. It evaluates the unidimensionality and reliability of each construct. We selected the ML (maximum likelihood) method. Karini & Meyer (2019) wrote that “when the sample size is large, and data are normally distributed, the ML method provides the most accurate estimation with the smallest standard errors.” Table 2 shows the result. We added the Cronbach’s alpha value for each construct. The alpha values for these constructs range from

0.739 to 0.905, all above the cut-off value (i.e., 0.70). We also computed average variance extracted (AVE), composite reliability (CR), and then the square root of AVE. The CR values of all the constructs are greater than the threshold value of 0.70. Therefore, we deemed that internal consistency of each construct was adequate (Hair et al., 2009).

The measurement model fit indices (standard-fit indices) were cmin/df = $\chi 2$ (116) = 164.29, Tucker-Lewis Index (TLI) = 0.961, Comparative Fit Index (CFI) = 0.970, Normed Fit Index (NFI) = 0.908, Root Mean Squared Error of Approximation (RMSEA) = 0.037. CFI “values .90 or above are considered indicative of adequate fit” (Ping, 2004). Thus, the CFA model was acceptable (Hu et al., 1999) indicating convergent validity.

Table 8: Result of CFA

Variables	Data Sharing	Product Quality	Supplier Integration	JIT Delivery
DTSH01	0.630			
DTSH02	0.641			
DTSH03	0.780			
DTSH04	0.696			
DTSH05	0.698			
DTSH06	0.677			
DTSH07	0.616			
QUAL01		0.583		
QUAL02		0.719		
QUAL03		0.792		
SINT01			0.787	
SINT02			0.869	
SINT03			0.860	
SINT04			0.835	
JITD01				0.772
JITD02				0.632
JITD03				0.682
Cronbach’s alpha	0.860	0.740	0.905	0.739
AVE	0.534	0.620	0.813	0.615
CR	0.940	0.828	0.945	0.826
SQRT(AVE)	0.731	0.788	0.902	0.784

We compare the square root of AVE with the inter-construct correlations to establish discriminant validity (Table 9). The results in Table 9 demonstrate that the diagonal cells of the matrix (i.e., square root of AVE) are significantly greater than the inter-construct correlations in off-diagonal cells. This shows that the constructs of our research model possess discriminant validity (Fornell & Larcker, 1981; Chin, 1998; Chen & Paulraj, 2004; Flynn et al., 2010).

Table 9: Inter-construct correlations and Square Root of AVE

	Product Quality	JIT Delivery	Supplier Integration	Data Sharing

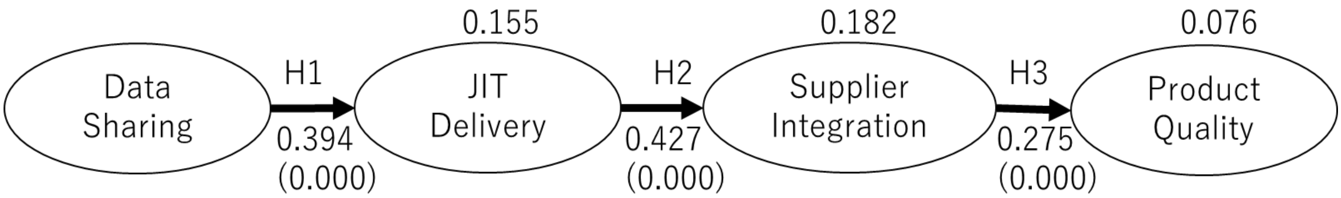
Product Quality	0.787			
JIT Delivery	0.020	0.784		
Supplier Integration	0.276	0.414	0.902	
Data Sharing	0.125	0.388	0.306	0.731

MODEL ANALYSIS

We employed Covariance-Based Structural Equation Modeling (CB-SEM) to estimate our research model using Amos version 25. SEM allows us to test the direct and indirect effects on pre-assumed causal relationships (Fan et al., 2016; Hair et al., 2021). "The CB-SEM allows us to test how well the model fits the data and it aims at minimizing the difference between the model covariance matrix and the sample covariance matrix which is obtained from the observed manifesting variables" (Jannoo et al., 2014). CB-SEM is suitable for testing or confirming a theory (Jannoo et al., 2014; Hair et al., 2021). CB-SEM is precise when the sample size is sufficient, even if distributional assumptions such as normality are not met (Jannoo et al., 2014).

Figure 2 shows the result of our first research model. Values under arrows are the estimate of standardized coefficients and p-values. All standardized coefficients are strongly significant ($P < 0.001$). The model had good fit (Brown, 2006): The fit indices for Figure 2 exceed the critical cutoff levels commonly used in empirical research. CFI = 0.970; NFI = 0.908; cmin ($\chi 2$ /df) = 1.416 (Chi-Square ($\chi 2$) = 164.292, df = 116, $P < 0.002$), with a large sample, Chi-square test "may reject good models" (Dion, 2008); root mean square error of approximation (RMSEA) = 0.037. An RMSEA below 0.05 suggests close fit. The result supported all the three hypotheses.

Figure 2: SEM Result of First Research Model



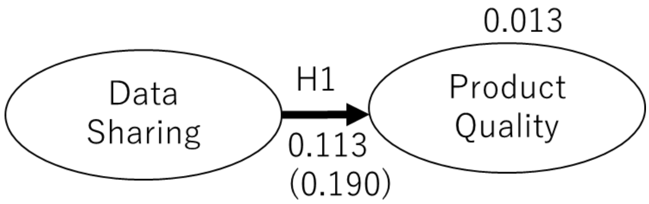
MEDIATION EFFECTS

So far, we set both JIT Delivery and Supplier Integration as full mediators from data sharing to product quality in our first research model. However, we can suppose the addition of some direct effects among factors (VanderWeele, 2015, 2016). We need to test a variety of direct effect models. We study the possibility in this section.

Direct Effect Model

First, we started testing the direct effect model of Data Sharing on Product Quality simply. Figure 3 shows the result. The effect of Data Sharing on Product Quality is not significant (p=0.190) even though the model-fit is good: CMIN=54.09, df=34, p=0.016, CMIN/DF=1.591, CMIN/df=1.591, NFI = 0.927, IFI=0.972, TLI=0.953, CFI=0.971, RMSEA=0.044, AIC=116.09. From the comparison between Figures 2 and 3, we can suppose that JIT Delivery and/or Supplier Integration would have significant mediation effects.

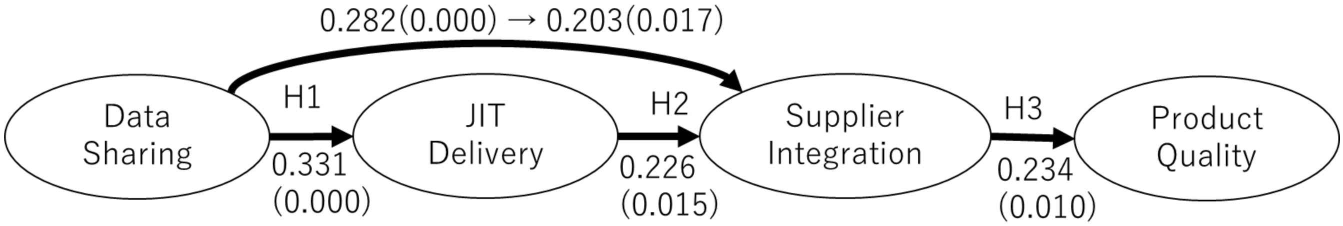
Figure 3: SEM Result of Direct Effect Model



Direct Effect of Data Sharing on Supplier Integration

Second, we added the direct effect of Data Sharing on Supplier Integration to check the mediation effect of JIT Delivery in Figure 2. The values above or below the direct effect arrow denotes a change of coefficient (and p-value) from when we removed the mediation factor to when we added the mediation factor. We employed the bootstrap method (5,000 iterations) to validate the significance of the indirect and mediating effect with Amos version 25 (Roh et al., 2022). As shown in Figure 4, the direct effect of Data Sharing on Supplier Integration is significant at a 5% level even after inserting the mediation factor (JIT Delivery). Both H1 and H2 are still significant. Therefore, it suggests a partial mediation effect of JIT Delivery.

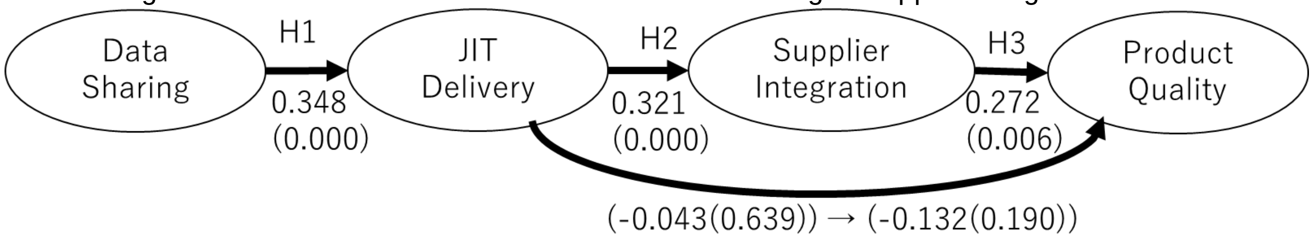
Figure 4: SEM Result of Direct Effect from Data Sharing to Supplier Integration Model



Direct Effect of JIT Delivery on Product Quality

Third, we added the direct effect of JIT Delivery on Product Quality to check the mediation effect of Supplier Integration in Figure 2. We employed the bootstrap method (5,000 iterations). As shown in Figure 5, the direct effect of JIT Delivery on Product Quality is insignificant, while the mediation effects (H2 and H3) are significant at the 1% level. The direct effect of JIT Delivery on Product Quality is still not effective. Therefore, it suggests a full (pure) mediation effect of Supplier Integration.

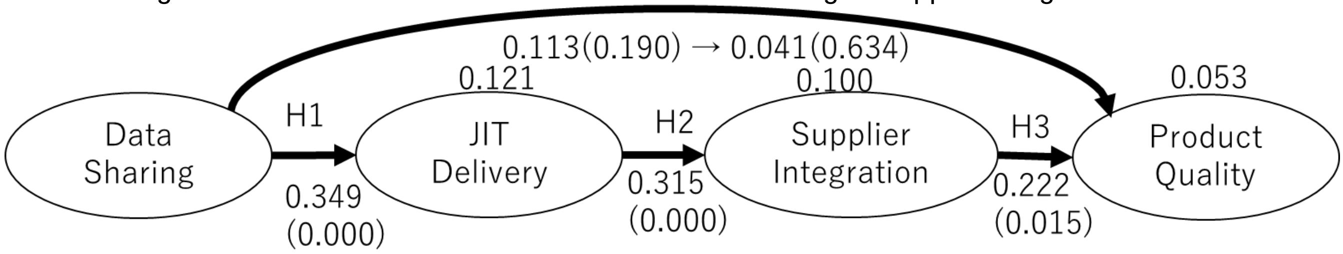
Figure 5: SEM Result of Direct Effect from Data Sharing to Supplier Integration Model



Direct Effect of Data Sharing on Product Quality

Fourth, we added a direct effect of Data Sharing on Product Quality to check both the mediation effect of JIT Delivery and Supplier Integration in Figure 2. We employed the bootstrap method (5000 iterations). As shown in Figure 6, the direct effect of Data Sharing on Product Quality is not significant. While the mediation effects (H1, H2, and H3) are significant. Therefore, it suggests a full (pure) mediation effect of JIT Delivery and Supplier Integration.

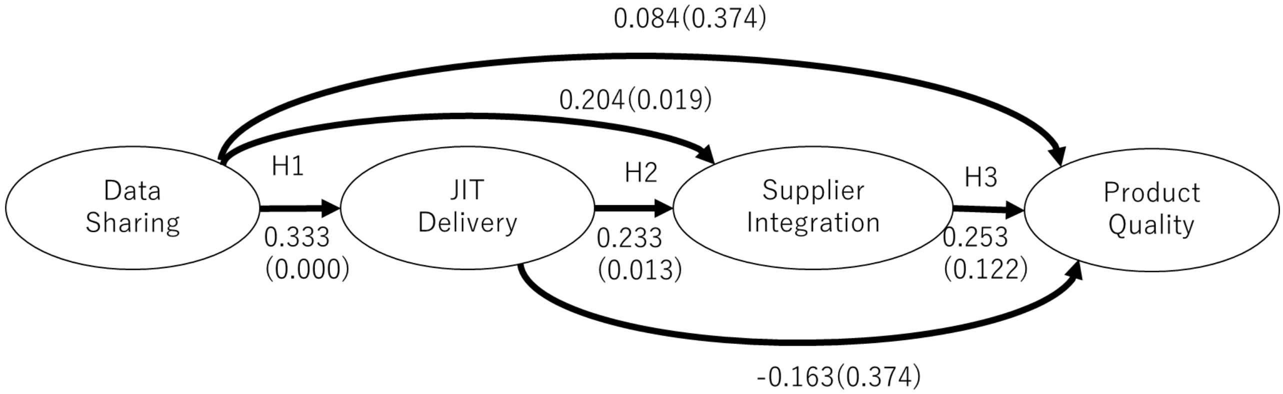
Figure 6: SEM Result of Direct Effect from Data Sharing to Supplier Integration Model



All Direct Effects Model

Finally, we added all direct effects to the model in Figure 2. As shown in Figure 7, both the direct effect of Data Sharing on Product Quality and JIT Delivery on Product Quality are insignificant. Still, the direct effect of Data Sharing on Supplier Integration is significant. All other indirect effects were significant. JIT Delivery is the partial mediator of the effect of Data Sharing on Supplier Integration. Supplier Integration is the full (pure) mediator of the effect of JIT Delivery on Product Quality. Figures 4 and 7 are the final models that our data suggested when we checked all direct effects.

Figure 7: SEM Result of All Direct Effects



Tables 10, 11, and 12 show lower and upper limits of bias-corrected confidence intervals of 95% for standardized coefficients (upper) and results of hypothesis testing including the estimate of standardized coefficient and p-value (lower). They are bootstrap approximations. Colored cells are not significant. Table 10 suggests that JIT Delivery is a significant mediation factor. When we consider both factors simultaneously (Table 12), supplier Integration looks significant. However, because another factor (JIT Delivery) is not significant in the model, the combination is not significant at last.

Table 10: A mediation analysis of JIT delivery			
Direct (unmediated)Effect	Data Sharing	JIT Delivery	Supplier Integration

JIT Delivery	(0.489, 0.165) 0.331 (0.001)		
Supplier Integration		(0.399, 0.043) 0.226 (0.017)	
Product Quality			(0.399, 0.055) 0.234 (0.011)
Indirect (mediated) Effect	Data Sharing	JIT Delivery	Supplier Integration
JIT Delivery			
Supplier Integration	(0.161, 0.017) 0.103 (0.017)		
Product Quality			
Total Effect	Data Sharing	JIT Delivery	Supplier Integration
JIT Delivery	(0.489, 0.165) 0.331 (0.000)		
Supplier Integration	(0.424, 0.124) 0.282 (0.000)	(0.399, 0.043) 0.226 (0.015)	(0.399, 0.055) 0.234 (0.010)
Product Quality			

Table 11: A mediation analysis of Supplier Integration

Direct (unmediated)Effect	Data Sharing	JIT Delivery	Supplier Integration
JIT Delivery	(0.507, 0,177) 0.348 (0.000)		
Supplier Integration		(0.474, 0.144) 0.321 (0.001)	
Product Quality			(0.450, 0.090) 0.272 (0.002)
Indirect (mediated) Effect	Data Sharing	JIT Delivery	Supplier Integration
JIT Delivery			
Supplier Integration			
Product Quality		(0.064, -0.097) -0.043 (0.639)	
Total Effect	Data Sharing	JIT Delivery	Supplier Integration
JIT Delivery			
Supplier Integration		(0.474, 0.144) 0.315 (0.000)	
Product Quality	(0.064, -0.097) -0.041 (-0.634)		(0.450, 0.090) 0.223 (0.015)

Table 12: A mediation analysis of JIT Delivery and Supplier Integration

Direct (unmediated)Effect	Data Sharing	JIT Delivery	Supplier Integration
JIT Delivery	(0.508, 0.179) 0.333 (0.000)		
Supplier Integration	(0.362, 0.029) 0.179 (0.024)	(0.469, 0.134) 0.233 (0.013)	
Product Quality	(0.272, -0.109) 0.072 (0.386)	(0.100, -0.394) 0.089 (0.216)	(0.437, 0.059) 0.235 (0.007)
Indirect (mediated) Effect	**Data Sharing**	**JIT Delivery**	**Supplier Integration**
JIT Delivery			
Supplier Integration	(0.214, 0.036) 0.076 (0.001)		
Product Quality	(0.070, 0.006) 0.024 (0.006)	(0.157, 0.017) 0.059 (0.008)	
Total Effect	**Data Sharing**	**JIT Delivery**	**Supplier Integration**
JIT Delivery	(0.491, 0.165) 0.329 (0.001)		
Supplier Integration	(0.424, 0.123) 0.281 (0.002)	(0.405, 0.052) 0.298 (0.015)	
Product Quality	(0.273, -0.071) 0.113 (0.256)	(0.151, -0.334) -0.055 (0.421)	(0.437, 0.059) 0.235 (0.007)

DISCUSSION AND CONCLUSIONS

Research Results

Companies and plants are under fierce international competition in many markets today. Product quality is the critical standard to survive there. The SCI affects product quality significantly. Therefore, SCQI is a crucial issue for companies and plants. SCQI includes many factors and aspects. Past studies revealed these factors, but the relationships and cause-and-effect sequences have not been known well. This study tried to fill the gap by adding empirical research with international survey data. Within many factors in SCI, we employed data sharing, JIT delivery, supplier integration, and product quality. Product quality was the dependent variable. The relationship of these SCI factors to SCQI was apparent because SCQI is a part of SCI.

Based on the literature review of past research and our inference, we set three hypotheses and a research model (Figure 1). Hypotheses are as follows:
H1: Data sharing with suppliers is a prerequisite to JIT delivery.
H2: JIT delivery from suppliers is a prerequisite to supplier integration.
H3: supplier integration improves product quality.

We conducted a set of quantitative analyses with the data in hand. We employed CB-SEM. Our result supported all of the above hypotheses strongly (Figure 2). The model fit was also good. Moreover, JIT delivery was a partial mediator (Figure 4 and Table 10). However, we also found that the combination of JIT delivery and supplier integration is not significant as a mediator of data sharing and product quality.

The results of our empirical study above supported that our inference and model path are appropriate. Of course, many factors affect product quality, and the path must be complex. The coefficients of determination in Figure 2 and Figure 7 suggest that our hypotheses and research models are just one of many possible paths. However, we believe that we need to accumulate these empirical results.

Academic Implications

> *Even though much attention has been focused on supply chain management (SCM) concepts in recent years, its interlinking with the quality management perspective is often limited and tangential in nature. While the importance of quality management is universally recognized, academic researchers need a more focused approach in evaluating quality management issues within the internal and external supply chain contexts. (Robinson & Malhotra, 2005)*

So far, we have many studies and papers about SCQI today, but SCQI includes many factors (aspects or tools). Besides, we do not have enough knowledge about how to introduce them. This study found a typical sequence to introduce SCQI to improve product quality in major manufacturing industries in advanced countries. Of course, the factors and their sequence that we studied were limited. We believe that this is an experiment. We need to accumulate experiments to create knowledge about the problem. We believe the knowledge will base our next research step on understanding SCI, manufacturing industries, and business organizations. We also found direct and mediating effects of related factors in the path. We believe that finding the direct path and mediating effect of factors pose additional research implications.

Managerial Implications

SCQI has many benefits with some cautions. However, a smooth introduction and beneficial use of SCQI are not easy. There are some points that managers need to care about or check when they introduce it. We suggested a critical path from data sharing to improving product quality. A simple introduction of data sharing does not prove product quality automatically. There are many factors (tools or aspects) that SCQI includes in the path. If we find a frequently used sequence, it must be the better way to introduce SCQI. Of course, there must be many paths. This study tried to see one of them. We believe that if managers follow the sequence recommended in this paper, managers find more chances to succeed. The result must be better and more accessible to better product quality.

Research Limitations

We got the above research results and implications, but we also know some research limitations in our study. First, the size of our dataset is limited. We need to repeat this study to verify with more data. Second, we need to repeat this study with the newer dataset. Because the world economy and industry environment are changing rapidly today, our hypotheses and research model might become less effective or obsolete in forecasting factor relationships. Third, our data were collected only from three specific manufacturing industries. Different industries may have other factors and relationships to product quality. Fourth, our data were collected from a set of questionnaires. Multiple respondents answered different items, which mitigated concerns about common method bias (Podsakoff et al., 2003). However, single-source common method bias may remain and is a concern.

Fifth, many other SCQI factors affect product quality. However, we need to limit factors to make our model controllable. The inclusion of more factors and different sets of factors may provide different results. We need to experiment with these various factors and factor combinations. There are so many factors that should be included. Our selection of factors is relatively intuitive and ad-hoc. We selected rather popular factors to make our result universal. Finally, our model is fairly simple. We can imagine more complex models, but we employed the simple model as the first cause-effect study. We can extend it in our future study.
Although the above research limitations, we still find a certain level of academic and managerial contributions in this study. The above limitations are left for future research.

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DECISION SCIENCES INSTITUTE

Effect of Security Vulnerability Hype on Open Source Sentiment and Adoption: A Social Media Perspective

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ABSTRACT

Social media (SM) is used extensively to communicate and express opinions related to open source software (OSS). This study analyzed SM discourse to explore the effect of discovered security vulnerabilities on individuals' sentiments and emotions towards OSS. The study also examined the impact on individuals' determinants to adopt OSS. The results suggested that the security vulnerabilities contributed to an increasing anger emotion and negative sentiment. Furthermore, the security vulnerability hype was found to contribute to adverse effects and increased discussion on both the *Amotivation* and *Extrinsic* adoption factors. Implications of this study are also discussed in this paper.

KEYWORDS: Open Source, Security, Vulnerability, Adoption

INTRODUCTION

The source code of open source software (OSS) is publicly available to use, modify and distribute (Gaff & Ploussios, 2012). Contemporary technology advancement has enabled software developers across the globe to collaborate in developing and maintaining OSS projects. As of 2020, there were 430,000 OSS projects and 3.7 million registered developers (Ased et al., 2020) while in 2017, the popular version control platform GitHub hosted more than 62 million communities (Link & Jeske, 2017). OSS started from a disbelief state to hype and exposure in the community (Ferris, 2003). OSS was realized to be a strategic resource in the software innovation (Kenett et al., 2014). Adopters cited different reasons to incorporate OSS, including ease of use, access to source code, cost-effectiveness, and vendor and community support (Singh, 2013).

Despite the numerous attractive reasons to leverage OSS, its adoption is confronted with challenges and barriers (Spinellis & Giannikas, 2012). These challenges include the availability of documentation and training, continuous development and maintenance support, backward and standard compatibility, and integration and architecture suitability (Stol & Ali Babar, 2010) (H. Wang & Wang, 2001). Security is a desirable OSS characteristic (Jusoh et al., 2012), and choosing the appropriate, safe, and reliable OSS project is also a challenge. OSS adopters may avoid vulnerable OSS as breaches become recurrent, incur high costs to organizations, and expose personal private data (Arizon-Peretz et al., 2021).

Arguably, OSS perceived security is a controversial topic. OSS is anticipated to have a bigger chance of being more secure than proprietary closed source software (CSS). This stems from the belief that OSS source code is accessible to security experts around the globe to perform extensive inspections (Greiner et al., 2003). On the other side, OSS is perceived as less secure and does not provide periodic security updates as in CSS (Achuthan et al., 2014). Regardless, the risk of undetected security holes and bugs in OSS is still a possibility. For instance, on December 9th, 2021, a significant security vulnerability in the Apache Log4j2 project was announced. Apache Log4j2 is a popular Java-based OSS library that is used around the globe to log messages in applications (Fortinet, 2021). This security vulnerability, named “log4shell”, poses exploitation risks by hackers to remotely execute malicious code.

OSS is incorporated in many mission-critical software applications. These applications are crucial to governments and organizations in various business domains. Any vulnerability in the underlying OSS would lead to undesirable situations and pose risks to these applications. For instance, the above-mentioned log4shell vulnerability has caused about 22 million applications to become vulnerable to attacks (Qualys Research Team, 2022) and impacted about a third of all web servers in the world (CBS News, 2021). The prevalence of OSS along with the challenges in remediating discovered vulnerabilities in a timely manner cause risky threats to remain for a long time. Such prolonged vulnerability is expected to have consequences on people's moods and decisions to incorporate OSS in software projects.

The serious and widespread exploitation caused by the log4shell incident has motivated the authors of this research to uncover potential implications of a security vulnerability on the software community’s feelings towards OSS and its adoption. The study analyzes people’s discussions on several social media (SM) platforms. Social media micro-blogging platforms are considered tactical in gauging public mood. Furthermore, gathering SM data for evaluation has become easier and faster (Bakshi et al., 2016). To the extent of our knowledge, there has been no prior research that leveraged SM to examine the community subjectivity (sentiments and emotions) towards OSS at times of security vulnerability incidents. Furthermore, there is no prior work that inspected SM to uncover the potential impact on factors affecting individuals’ decisions to adopt OSS. This paper fills this gap and contributes with the following:

- *Exploring sentiment and emotions towards OSS at times of security vulnerability incidents,*
- *Examining factors affecting OSS adoption at times of security vulnerability incidents.*

To foster OSS adoption, several prior academic studies have been reviewed from different theoretical, methodological, and practical perspectives. The review guided the categorization of the collected SM posts based on the discussion narrative about aspects related to individuals’ factors to adopt OSS. The categories were used to examine opinions about the impacting factors in periods before and after the log4shell vulnerability incident was uncovered.

Awareness of vulnerability implications on the public’s feelings and adopters’ perception is crucial. OSS maintainers can take appropriate proactive steps and prioritize fixing patches to address adoption concerns. Organizations and governments can establish a standard procedure to govern adopting, inspecting, upgrading, and patching suitable OSS. Furthermore, the analysis outcome highlights the impact on adoption factors at times of vulnerability to academic researchers to further investigate in a specific organization or industry context.

LITERATURE REVIEW

Open Source

History highlighted the first formation of the OSS Free Software Foundation (FSF) advocate group in 1984. The foundation was followed by the Open Source Initiative (OSI) group in 1998 (Miller et al., 2010). Being a viable and free alternative to costly proprietary software, OSS attracted both adopters to endorse and academia to study its phenomenon. The information systems community has been actively conducting OSS studies. Several empirical studies of the

OSS development (Crowston & Annabi, 2007) and adoption (Munga et al., 2009) were conducted in several contexts and industries. Also, OSS attracts the software development community and users because of its appealing governance over the commercial practice (Jin et al., 2007). But, despite the advantages of using OSS, it introduces risks related to the intrinsic fluidity of the development activities (Franch & Susi, 2016). One of these risks is vulnerability exploitation due to an undetected security defect.

Adoption Motivators

Interviews in a longitudinal study revealed that the responders used OSS due to factors such as cost, ease of use, support, and maintenance (Sooryanarayan et al., 2014). Other researchers attributed the high level of OSS usage to unrestricted use, relief from the need to perform in-house development, customizability, flexible legal aspects, and leadership encouragement (Maua & Mwiti, 2013). Researchers also suggested that OSS is the only chance for developing countries to join the IT revolution (Oreku & Mtenzi, 2013). The researchers highlighted the advantages to promote OSS including licensing, localization, and local skill-building. Furthermore, it was realized that OSS encourages open thinking, leads to flexible business models, enables better collaboration, and prevents vendor's lock-in (Munga et al., 2009). Additionally, factors such as good project maturity and support were suggested to promote OSS adoption (Ven et al., 2008).

Adoption Challenges

Researchers pointed out that a lack of an agreed acceptable set of criteria to evaluate and decide amongst varieties of OSS projects hinders the OSS adoption (Jusoh et al., 2012). Researchers also conducted a case study to summarize the technological risks affecting information technology management decisions in adopting OSS (Silic & Back, 2017). These risks include legal compliance, migration, training sustainability, and interoperability. The case study pointed out that the high perceived risk of OSS impacts executives' decision-making. The authors cited the adverse impact of a security vulnerability incident that occurred in 2014 on the open source OpenSSL project. The incident affected all major websites including Google, Facebook, and Yahoo.
Consequently, adopters were noted to become reluctant to adopt OSS. They were unsure whether to trust the security of the OSS libraries (Silic & Back, 2017). Furthermore, it was suggested that the lack of formal notifications when vulnerabilities occur in OSS would expose applications to exploitable risks (Achuthan et al., 2014). Other researchers highlighted several concerns of adopting OSS including security challenges, lack of support from vendors, indirect costs, and usability (Oreku & Mtenzi, 2013). Other challenges were cited to include the struggle of OSS projects to attract contributors, not up to the expected software qualities, and the potential of radical changes that could impact the backward combability (Ayala et al., 2011).

Adoption Factors

Several studies investigated the individuals' decision to adopt a new technology (Dedrick & West, 2004). The Diffusion of Innovation (DOI) theory explains the process by which an innovation is diffused amongst individuals over time. It deals with adopting a new technology upon realizing its importance and useful characteristics (Ghallab et al., 2021). Other researchers suggested an integrated model that is based on the Expectation Confirmation Theory (EXT) to explain individuals' intention for a continuous adoption of the information systems (S. C. Wang et al., 2008). The researchers added more factors to the model to explain the phenomenon, such as individual emotions and cognitive processes. The cognitive process conceptualizes the concepts of “ease of use” and “perceived usefulness” constructs from the Technology Acceptance Model (TAM). Emotions, ease of use, and perceived usefulness were shown to impact satisfaction, which in turn influences the individual’s decision to continue adopting a technology.

Furthermore, the development of the Self-Determination Theory (SDT) guides to explain the level of degree a person could have to endorse a technology (Li et al., 2011). The theory highlights the *Intrinsic* and *Extrinsic* factors to motivate individuals to consider adopting OSS, and the *Amotivation* factor affects those who are already adopting it. *Intrinsic* motivation is when an individual uses OSS for self-satisfaction reasons such as knowing, accomplishing a task or having pleasure and joy. *Extrinsic* motivation is caused by external reasons, such as OSS desired features (availability of source code, security, performance, etc.), corporate policy, gaining rewards, or any obligatory reasons. Lastly, *Amotivation* is any prohibiting factor that causes an individual not to adopt OSS.

The above-mentioned theories explain factors that fulfill individuals’ satisfaction to consider or extend OSS adoption. Holistically, we can summarize these factors as listed in Table 1. The summarized factors are related to an individual’s *Intrinsic* (feeling/emotion), *Extrinsic* (external facilitators), *Amotivation* (prohibition), OSS *innovation characteristics* (quality, ease of use, usefulness, etc.), and the individual’s emotional state. Our aim is to examine people’s opinions on the aspects related to these factors under certain circumstances of a security vulnerability hype. Mainly, we analyzed SM discourse to investigate sentiment, emotion, and thoughts about these factors.

Table 1: Summary of Adoption Factors

Factor	Theory	Reference
Extrinsic	Self-Determination Theory (SDT)	(Li et al., 2011)
Intrinsic	Self-Determination Theory (SDT)	(Li et al., 2011)
Amotivation	Self-Determination Theory (SDT)	(Li et al., 2011)
OSS Innovation Characteristics	Diffusion of Innovation + Expectation Confirmation Theory (EXT)	(Li et al., 2011; S. C. Wang et al., 2008)
Emotion State (sentiment / emotions)	Expectation Confirmation Theory (EXT)	(S. C. Wang et al., 2008)

Social Media Exploration

People around the world use SM to post their daily activities, share pictures, write product reviews, advertise jobs, and disseminate information (Bian et al., 2016). Researchers leveraged the publicly available content from SM to extract information and gain insights into the public’s opinions on various topics. For instance, Twitter was crawled to assess people’s perception of the Internet of Things (IoT) (Bian et al., 2016). The authors have applied the topic modeling technique to learn points and concerns that people were discussing regarding IoT. Another effort examined the perspective of precision agriculture in SM (Ofori & El-Gayar, 2021). The researchers further validated the drivers and challenges that face precision agriculture. Also, prior research used SM to study topics related to the ongoing COVID-19 pandemic. For instance, the Twitter discourse was recently analyzed to gain insight into the pandemic's effect on people's mental health (El-Gayar et al., 2021).

It is known that OSS is owned and driven by a community of developers and users. The level of the community’s activities acts as a signal to indicate OSS takeoff and success (Ased et al., 2020). The interactions and communication in SM by the OSS community could be considered as one of these activity signals. Therefore, and like prior research, we can consider SM as a good source for our study to explore the considered OSS phenomenon.

METHODOLOGY

This study applied a combination of opinion mining (OM) techniques to publicly available posts collected from a selection of social network platforms. The sentiment analysis (SA) technique was used to determine the polarity in the posted texts as either positive or negative expressions. SA technique was used in prior studies and various domains such as sociology, politics, and law (Bakshi et al., 2016). Further, the emotion analysis (EA) method was also used to detect people's feelings as expressed in their posted messages. Examples of emotions used in a prior study include anger, calm, disgust, fear, sadness, surprise, and neutral (Khun et al., 2019). Additionally, this study used the content analysis (CA) technique to examine factors that influence an individual's decision to adopt OSS in the context of the collected SM posts. The four factors listed in Table 2 were extracted from the cited research above along with their defining characteristics. The defined characteristics guided the delineation of the boundaries between different categories of the collected SM posts based on their narrative. Each category was further investigated to interpret the expressed opinions about each factor.

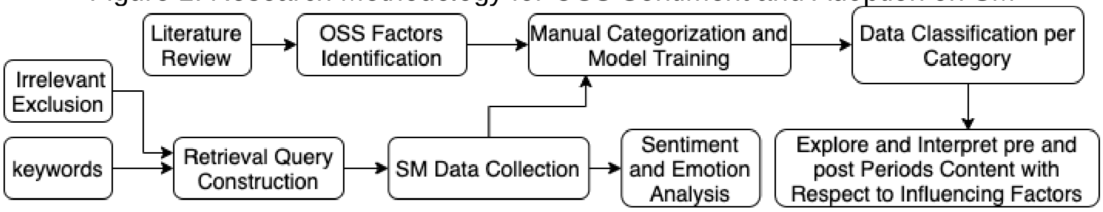
Table 2: Categories of OSS Adoption Factors

Factor Category	Aspects
Intrinsic Motivation	**To know**: pleasure and satisfaction when learning, exploring, understanding **To accomplish**: pleasure and satisfaction when surpassing oneself, accomplishing, creating something **To experience simulation**: sensory pleasure, aesthetic experience, fun and excitement
Extrinsic Motivation	**External regulation**: earning rewards, constraints, avoid punishment **Introjected regulation**: self-imposed pressure, pride, threats from feeling of guilt, shame, obligatory feeling **Identified regulation**: out of choice, judged important, because security OSS, because code is available, because others used it
Amotivation	**Capacity belief**: lack of self-efficacy, cannot commit, no skills, not proper customer support, not friendly user interface, perceived advanced and difficult to use, not competent **Effort belief**: no desire to spend effort, find it difficult to integrate, deal with OSS, and spend time to discover features and work with support **Strategy belief**: belief it would not bring the desired valuable outcome, do not appreciate OSS values / lower cost / available code, claimed performance, prefer proprietary
OSS Innovation Characteristics	secured, level of complexity, combability, reliability, performance, ease to use, useful, scalable, modular, quality, accessibility, learnability, community support, active development, continuous maintenance, stability, operability, documentation quality, functionality, integration, cost, training, licensing.

To determine the influence of security vulnerability, the analysis examined two months' worth of published SM posts. The first month, or the pre-log4shell period, was prior to the log4shell vulnerability announcement and ran from November 9^{th,} 2021, to December 8th, 2021. The following month, or the post-log4shell period, was after the announcement and ran from

December 9th, 2021 to January 9th, 2021. Figure 1 illustrates the high level of encompassing tasks that were performed in the research methodology.

Figure 1: Research Methodology for OSS Sentiment and Adoption on SM



Data Collection

We used Brandwatch online analytics tool to retrieve and analyze publicly generated content from various social media platforms. We considered searching online forums in addition to Twitter, Reddit, and Tumblr platforms. Users post messages, videos, or images on Twitter, in Reddit's community of interest, or on a Tumblr canvas. Technologists use online forums to post blogs about a variety of topics.
To obtain posted texts relevant to open source we used search terms such as “open source”, “open-source”, “open_source”, “opensource”, “OSS”, “FOSS” (Free OSS). After inspecting the result, we tuned the query to eliminate content related to blockchain as it pulled unrelated content. Other unrelated mentions, retweets, and links were also excluded. The query listed in Figure 2 was used to retrieve SM posts during the two months (November 9th, 2021, to January 9th, 2022).

Figure 2: Social Media Search Query

(opensource OR "open source" OR open-source OR open_source OR "FOSS" OR "OSS" OR OSS_INFO) AND -(RT OR http* OR Minecraft OR 100daysofcode OR blockchain OR bitcoin OR #BTC OR bitwarden OR ethereum OR crypto OR cryptocurrency OR POTUS OR senatedems OR elonmusk OR Linux OR Ubuntu OR windows OR operating_system OR "operating system" OR "pig token" OR operating-system OR Fedora OR #OS OR iOS OR Android OR covid OR #ChoiceCoin OR #ChoiceCoinDAO OR #selfwateringplant OR #plant OR #basil OR #tipsylabs OR SONY OR Vaccine OR Drug OR Sex OR War)

Data Analysis

The collected data was analyzed using Brandwatch's sentiment and emotions analysis technique. The “Buzz Monitor” model (Crimson Hexagon, 2022) was used to process text and determine its sentiment. The model provides an additional analysis layer to classify text into one of six emotions. The emotions were defined by the renowned psychologist Paul Ekman (Ekman, 2004) as *Anger*, *Fear*, *Disgust*, *Joy*, *Surprise*, and *Sadness*.
The categorization analysis of the collected SM posts was guided by the extracted aspects of the four factors referenced above. Brandwatch's opinion monitor was used to automatically cluster SM texts using “BrightView” supervised machine learning model. BrightView was able to classify all SM texts after it was trained with a subset of manually labeled texts (Ofori & El-Gayar, 2021). Both authors of this paper exchanged tasks to label and review the classification of at least 70 posts per category. Each post was manually investigated to determine its category based on its respective context. The authors applied an arbitration process to meet for deciding on posts that fell within more than one category. The manually classified texts were then used to

train the model to classify all collected posts. Each category of posts was then explored to discover people's opinions in expressing aspects related to the adoption factors.
The changes in the volume of posts after the vulnerability announcement date were used as one of the indicators to assess the security vulnerability impact. The impact was also assessed based on the reflected sentiments, emotions, and embedded opinions in the posts. Furthermore, the generated discussions after the vulnerability announcement date were also assessed and compared after excluding the SM posts that mentioned the vulnerability incident. We used the difference in the SM posts' volume as a proxy to determine the magnitude of the impact. For ease of search, a lexical search mechanism was used to filter out SM posts that were concerned with the vulnerability incident. The search used possible varying forms for the "log4shell" term.
Furthermore, we adapted the Relative Mention Volume (RMV) indicator method (Bian et al., 2016) to analyze the trends of SM posts over time. The RMV presents how frequently a specific concept is referenced relative to the total number of SM posts over time. The SM posts that mentioned security vulnerability concerns and those that contained relevant information about the adoption factors were normalized and converted to RMV representation in daily intervals.

RESULTS

The query returned about 122,000 SM posts during the two-month period. The SM posts were relevant to OSS in the English language from about 79,928 unique authors. Figure 3 plots the volumes of the SM posts from all the considered social media platforms over time. Twitter was the highest source of content contributing about 55% of the total posts, followed by Reddit (26%), and the various blogging forums (16%). The social media channel to contribute the least was Tumblr (3%).
About half of the content (49.3%) was posted by authors whose locations were identified in their profiles. There were seven countries from where more than 1,000 SM posts were published. The United State of America (USA) accounted for most of the location-identified posts (35,678). The other six countries, as illustrated in Figure 4 were the United Kingdom (UK) with about 4,515; India (2,686 posts); Canada (1,936 posts), Germany (1,891 posts), Australia (1,071 posts), and France (1,031 posts). The USA was also the origin of the highest number of SM posts that mentioned the log4shell security vulnerability (about 423 posts). The other illustrated countries in Figure 5 (UK, Germany, Canada, India, France, Australia, Netherlands, and Finland) were the origin of at least 10 SM posts that were concerned with security vulnerabilities. Most of which were related specifically to log4shell.
As summarized in Table 3, the positive sentiment was dominating most of the published text during the two months. In the post-log4shell period, the positive sentiment increased slightly by 5% compared to the prior month. However, in the same period, the negative sentiment incurred a higher increase of 13% compared to the prior month. Furthermore, the analysis indicated that the anger emotion dominated during the two months. However, the anger emotion accounted for third in rank to increase (11%) during the post-log4shell period compared to the prior month. The sadness emotion increased the most (19%) followed by the fear emotion (18%) during the post-log4shell period compared to the prior month. To clarify, the percentage values listed between the parenthesis in the table were the changes with respect to the earlier month (based on the model's classification and data in the current month).
Furthermore, the analysis assumed a situation where there was no vulnerability incident to assess the impact. The SM posts that were concerned with log4shell were excluded as described above to create the hypothetical scenario. It was found that the positive and negative sentiments would have been affected by the increase of fewer values, 4% (1% less compared to the actual scenario) and 9% respectively (4% less compared to the actual scenario). On the

other hand, the sadness emotion would have increased to 17% (2% less), fear to 14% (4% less), and anger to only 9% (2% less). Figure 6 and Figure 7 highlight the changes in SM post volumes between the two periods. In these two figures, the changes were depicted also in the scenario where vulnerability-related posts were eliminated.
The trained BrightView models in Brandwatch online tool helped to segregate the SM posts into four groups based on context. Each group represents SM posts that were relevant to one of the above-mentioned OSS adoption factors.
As the numbers show in Table 4, the *Extrinsic* factor ended up having the greatest number of related SM posts. The discussion related to the *Extrinsic* factor increased the most (34%) after log4shell was announced. The *Amotivation* factor was second in rank with respect to the number of related SM posts. The discussion related to *Amotivation* factor increased by 19% after the vulnerability was announced. However, before the announcement, the *Extrinsic* factor's discussion had an increase of only 4%. And the discussion that related to the *Amotivation* aspects was at the lowest, with -17% less compared to the prior month.
Furthermore, the *OSS Innovation Characteristics* factor had an increase of 18% before the vulnerability announcement. This factor happened to have the lowest amount of discussion after the announcement. Also in this table, the percentage values between the parenthesis indicate the changes with respect to the earlier month (per the model's classification and data in the current month). The expressed emotions in the discussions are illustrated in Figure 8 for every adoption factor. To also assess the impact of a security vulnerability incident, the analysis built the same scenario of eliminating SM posts that were related to log4shell during the second month period.
Furthermore, the RMV trends of the SM posts that expressed security vulnerability concerns (black curve line) along with those that were relevant to the adoption factors (colored curve lines) are plotted in Figure 9.

Figure 3: Social Media Posts over Time

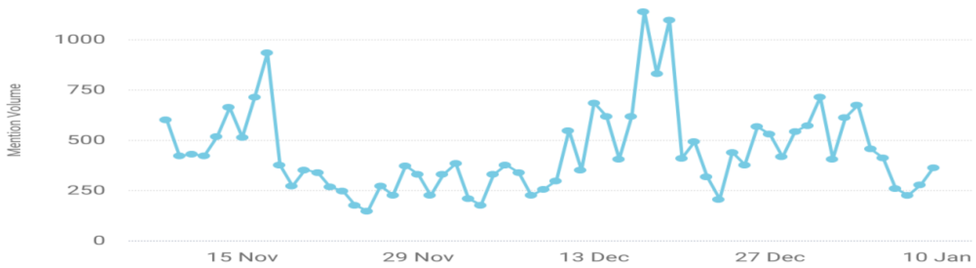


Figure 4: SM Posts Per Country

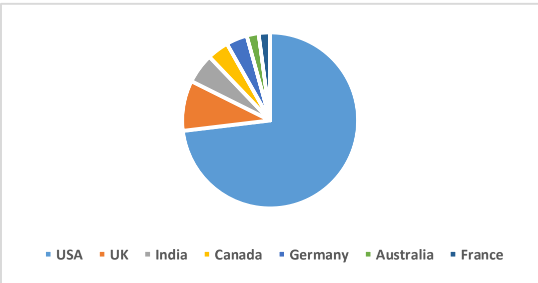


Figure 5: Vulnerability Mentions

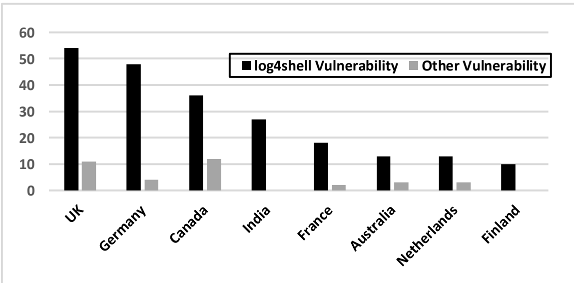


Figure 6: The difference in Sentiment Post Volumes Between Post- and Pre-Period

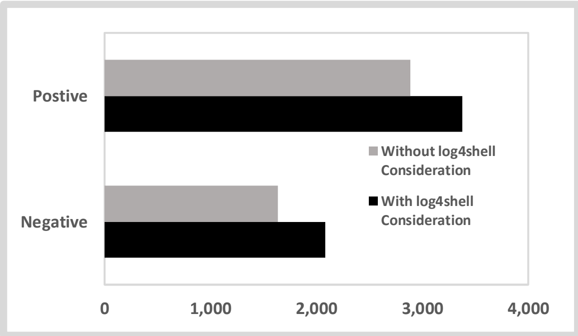


Figure 7: The Difference in Emotion Post Volumes Between Post- and Pre-Period

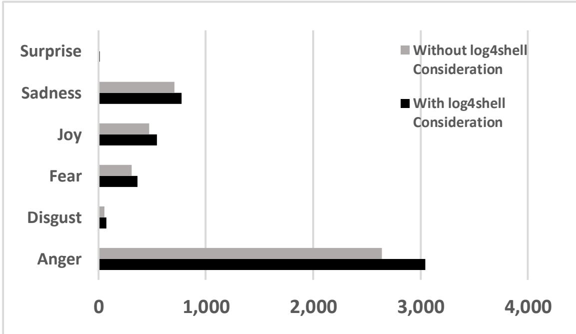


Table 3: log4shell Impact on Sentiments and Emotions

		Pre-Period Posts Volume	Post-Period Posts Volume	Post-Period Posts Volume if no log4shell
Sentiment	Positive	29,908 (+1%)	**33,284 (+5%)**	**32,792 (+4%)**
	Negative	10,272 (-4%)	**12,355 (+13%)**	11,906 (+9%)
Emotion	***Anger***	16,452 (+1%)	19,496 (+11%)	19,093 (+9%)
	Disgust	884 (+3%)	957 (+3%)	939 (+1%)
	Fear	1,524 (-3%)	1,890 (+18%)	1,833 (+14%)
	Joy	10,062 (+2%)	10,608 (0%)	10,532 (-1%)
	Sadness	2,793 (-10%)	3,565 (+19%)	3,502 (+17%)
	Surprise	140 (-6%)	152 (+3%)	145 (-1%)

Table 4: log4shell Impact on OSS Adoption Factors

Adoption Factor	Pre-Period Posts Volume	Post-Period Posts Volume	Post-Period Posts Volume if no log4shell
Extrinsic	**11,862 (+4%)**	**16,078 (+34%)**	**15,457 (+29%)**
Amotivation	11,147 (-17%)	14,971 (+19%)	14,554 (+16%)
Intrinsic	10,397 (+5%)	10,260 (-6%)	10,235 (-6%)
OSS Innovation Characteristics	1,892 (+18%)	725 (-64%)	723 (-64%)

Figure 8: Emotions in Adoption Factors Relevant SM Posts

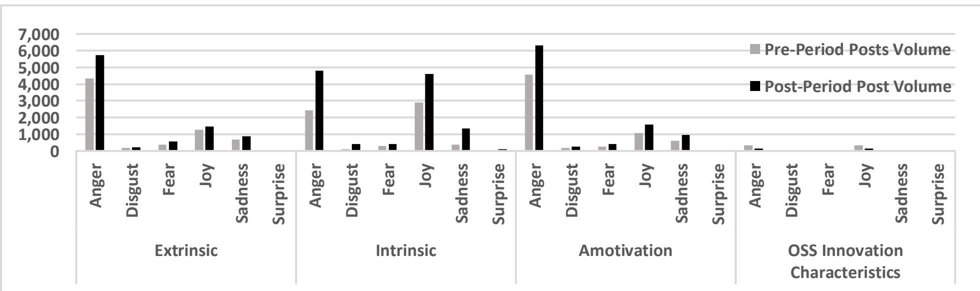
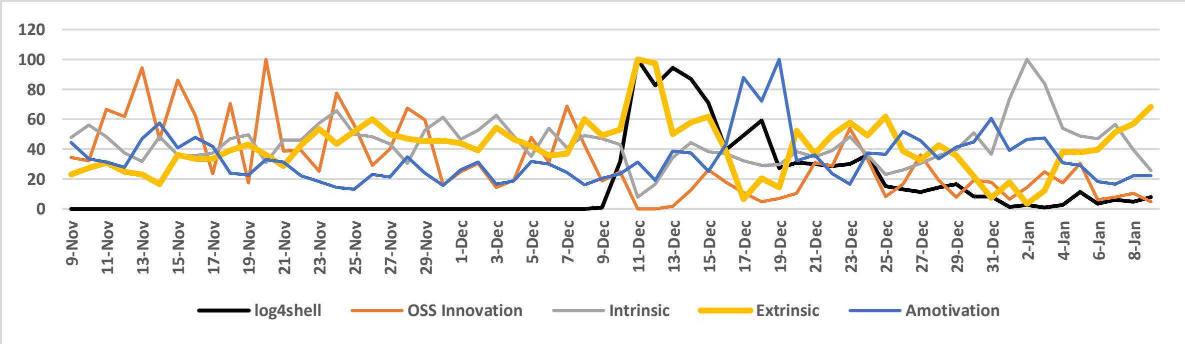


Figure 9: Trends of Adoption Factors Relevant SM Posts



DISCUSSION

The analysis indicated that social media is a worthy source for technologists to stay informed about OSS-related topics. The various platforms allow maintainers and adopters from around the world to keep up with activities and issues in OSS projects. The result showed that most of the posts were in the USA. Reflecting the fact that the USA has the largest number of OSS projects compared to all other countries (Mombach et al., 2018).
The volume of the collected SM posts revealed fluctuating trends in online activities. Apparently, the trend of the SM posts about OSS increased and reached two peak points. The first peak was on November 17th when a discussion sparked about the “Streamlabs” company. This company provides live streaming software and was accused of using the name of the open source project OBS for their product. The second peak in the trend was on December 9th, coinciding with the log4shell security vulnerability announcement. The analysis showed an increase in vulnerability-related posts after the vulnerability was announced.
Despite the occurrence of the mentioned unfortunate events, the overall sentiment towards OSS always remained positive. However, the vulnerability hype caused relatively more negative sentiment in discussions than positive. The magnitude of the increase in the negative sentiment would have been less if the security vulnerability incident did not occur. However, that still would not prevent a relative increase in the negative sentiment during the post-log4shell period. This suggested that other concerns besides the security vulnerability have caused more negative sentiment.
Furthermore, technologists were shown to enjoy OSS projects. However, anger dominated the overall emotion and further increased after the vulnerability was announced. Expressions from unhappy adopters surfaced during this period. The concerns included failure to discover the vulnerability earlier, not using a vulnerability scanner in OSS, and potential risks from transitive dependencies in projects. There were SM posts that expressed dissatisfaction with the level of support to the OSS community and the lack of supporting business models. There were also concerns about the lack of a public common vulnerabilities and exposures (CVE) database for the quality of the readily available libraries. The increase in the number of total SM posts that expressed anger emotion after the vulnerability announcement reached 11%. The anger increase would have been only 9% if the SM posts relevant to vulnerability were excluded. This observation indicated that vulnerability hype increased the anger emotion more.
Despite the dominance of the anger emotion, the analysis showed that the security vulnerability increased the sadness emotion the most (19%). The vulnerability incident was considered a bad experience. Adopters were concerned about not having enough engineers to prevent such incidents. Others wished for funded OSS and community sponsorship to produce more robust projects. Fear was the second emotion to increase after the vulnerability incident (18%). People

around the world were worried about the widespread vulnerability and the impact on affected applications. In case we eliminated the SM posts that were concerned with the vulnerability incident, the increases in these emotions would have been less in value. Apparently, the vulnerability caused inconvenience and contributed to increasing anger, sadness, and fear emotions. A sample of SM posts that were relevant to each of these three highly impacted emotions is listed in Table 5.

OSS Adoption Factors

The SM posts that expressed aspects relevant to the *Extrinsic* factor to adopt OSS were prevalent over the two-month period. The volume of SM posts in this category increased the most after the vulnerability was announced. These posts sensed an elevated level of *anger* emotion. The SM posts suggested extraneous goals as drivers to continue adopting OSS. For instance, discussions indicated that developers were motivated not primarily for the sake of creating OSS projects, but rather to support other passions. Others expressed that building OSS tools and applications would lead developers to reflect positive impact and prestige. Money has also been suggested as a motivating driver. This attested to a realization that about 34% of all contributors to the significant OSS Linux Kernel project were paid for their efforts (Riehle et al., 2014).

Apparently, adopters shifted their attention after the vulnerability incident to more extraneous motivating aspects. After the incident, the discussion suggested having a business model around OSS for companies to pay for support. Such a model was proven to be possible. For example, companies such as “AdaCore” adopted a business model to balance being profitable while alluring the community to contribute to the incorporated OSS (Brosgol, 2019). This suggested that adopters would rather consider perceived robust OSS projects that are sponsored by companies.

Furthermore, the volume of discouraging posts that expressed aspects relevant to the *Amotivation* factor was second in rank. The *anger* emotion was elevated the most in this category. The SM posts expressed concerns that adversely affected people’s intention to adopt OSS. The concerns included a perception of a steep curve to learn new OSS projects, missing features, and limitations in capabilities. Some SM posts indicated a lack of users' experience and skills with the programming languages and techniques to implement OSS projects. The narrative in some posts indicated a belief that free open source does not necessarily equate to having good software. This is attributed to the assumption that OSS authors often lack the resources of commercial software. Some users were discouraged by a belief that the creators of the OSS projects are dictating the terms and direction of the work. Arguably, these discouraging concerns are related either to self-efficacy and capacity belief (Li et al., 2011); OSS perception belief; or perception within the development community.

Furthermore, after the vulnerability was announced people started to worry about the impact of the security vulnerability in their applications. Some discussions started to doubt that other OSS projects might also be vulnerable to exploitation risks. Obviously, security is a desirable feature in OSS projects (Li et al., 2011) that may discourage people away if it is questioned.

Interestingly, the SM posts related to the OSS *Innovation Characteristics* factors decreased in volume the most (-64%) after the vulnerability incident. Before the incident, the discussions were about OSS functionalities, ease of use, programming languages, libraries, and development frameworks. However, after the announcement, the discussions delved into code quality, systems security, unauthorized access, and scrambling of security experts to fix flaws in software impacted by log4sell. It appeared that the vulnerability incident caught people's attention to the security of the OSS projects (Apache log4j2). The discussions started to worry about exploitation risks in applications.

Furthermore, criticisms of OSS projects and quality compared to their closed-source counterparts started to surface. The criticism of OSS quality and comparison to proprietary software is frequent (Raghunathan et al., 2005). People claimed that hackers can access the publicly available source code and be aware of potentially exploitable flaws. However, the security level of OSS projects may not be different from that of proprietary software. A closed code is not proven to be more secure either (Greiner et al., 2003). Bad actors with suitable tools could also reconstruct closed code from compiled executables for adverse reasons. In both cases, systems would be vulnerable once a flaw is discovered.

Patching vulnerabilities in a timely manner is an important characteristic that impacts OSS adoption decisions (Witten et al., 2001). Also, establishing a software practice with a proper testing process, peer reviews, and modular code was claimed to reduce bugs and increase the OSS reputation (Aberdour, 2007). However, it is challenging to assess whether a vulnerability is exploitable to warrant immediate action for providing a fix. Prior research tackled this challenge with a pragmatic approach to assess the impact and assist decision-makers (Plate et al., 2015) to take the appropriate action. Overall, the OSS adoption factor related to OSS *Innovation Characteristics* was negatively impacted in the post-log4shell period.

Finally, aspects of the *Intrinsic* OSS adoption factor were reflected in discussions before the vulnerability was disclosed. The SM posts indicated that adopters were excited, happy, satisfied, and interested in the OSS projects. Technologists appeared to enjoy contributing to innovative OSS projects and involve in related events and episodes. However, the number of SM posts related to the *Intrinsic* factor category dropped in volume during the time the vulnerability was announced. The SM posts related to the *intrinsic* factor scored third in rank after the *Extrinsic* and *Amotivation* factors to express the *anger* emotion. Individuals expressed an unaesthetic experience and thought it was a struggle to improve security. It is apparent that security vulnerability adversely impacts the excitement and satisfaction of OSS adopters.

Additionally, the RMV plot depicts the trend of the discussions about aspects of these factors over the two months. The plot shows an increasing number of SM posts relevant to aspects of the *Extrinsic* factor right after log4shell was announced. The peak of the SM posts related to this factor coincides with the peak point of the SM posts related to the discovered vulnerability. This agrees with our discussion that more attention was given to extraneous motivators. These motivators include adopting OSS with a business model and a supported development community. Furthermore, the trend of the SM posts that were relevant to the *Intrinsic* factor declined after the log4shell announcement. This also supported our discussion that the vulnerability hype reduced one's sense of excitement and pleasure. Also, the trend of the SM posts that were relevant to the *Amotivation* factor remained steady and picked up significantly a few days after the vulnerability was announced. This can suggest that the hype had spread more over time and caused new adopters to raise concerns to adopt OSS projects. Finally, the trend of the SM posts related to the OSS *Innovation Characteristics* factor dipped after the announcement and slightly gained momentum again after a few days. Apparently, the vulnerability caused people to discuss technical features and the qualities of OSS, including security.

In Summary, the vulnerability incident appeared to impact the *Extrinsic* factor the most, followed by the *Amotivation* factor, then the *Intrinsic* factor, and finally the OSS *Innovation Characteristics* factor. Table 5 lists a sample of the SM posts that were relevant to each of the highlighted adoption factors.

Table 5: Sample of Social Media (SM) Posts

Emotion	SM Posts Sample	Factor	SM Posts Sample
Anger	*Kinda ambivalent about what happened to faker/color.js – I agree with the perspective that commercial needs to support open source (better/more), but its hardly a surprise when they didn't, so taking it out on everybody else seems annoyingly I. Becomes a loose/loose for most*	Extrinsic	*There's still extrinsic motivation in the form of prestige in one's field, as measured by citations, impactful papers, awards and tenure. Even people contributing to open source projects know there is social prestige and job prospects that are attached to that activity.*
	They should - 13 -usines the open-source vulnerability scanning tools and keep abreast with Common Vulnerabilities and Exposures (CVE) databases that are publicly disclosed information security issues.		*I am not saying that intrinsic motivation doesn't exist. I am only saying that extrinsic motivation also exists. Many people are programmed to seek status, whether that's wealth or fame or social credit or popularity or power (often these are related). This helped their ancestors find a mate, which is why they're programmed this way.*
	This being open-source, how does one line with such a catastrophic vulnerability not get picked up in 9 years?		*What is your - 13 -usiness model, Mr. Cake? If you are giving away the wallet for free (which is open source) and even providing free 24h support and a Telegram "bot", which answers your questions, where are you getting the money to make all that?*
Sadness	*That kind of stuff happens too, unfortunately. But sunlight is the best disinfectant in the FOSS world, and given enough eyes, all bugs are shallow? We need more new engineers in FOSS to prevent such things, and make it a better place.*	Intrinsic	*Future looks bright for open source! I'm really excited to see where this goes and what the impacts on developer productivity will be. Can't wait to get my hands on it and try it out!*
	In 2022, I wish we get a publicly funded open-source #vulnerability database that is purpose built for applications and not owned by any commercial organization. I believe, this is more important than sorting out sponsorships for individual open-source devs.		*2022 is going to be an amazing year for my career and professional brand. I'm excited for my upcoming shift and journey into the open source web development community.*
	It makes me sad how people belittle the efforts log4j maintainers and say how the bug is stupid. But they are ok with companies exploiting OSS.		*I spent the bulk of my Sunday and most of today scrambling to update our production apps because of this vulnerability. ". This reminded me of the early days of Joomla and Drupal. Open source can be a pain!*
Fear	*Log4j has no doubt made IT professionals and companies nervous and many questions have been raised*	OSS Innovation Characteristics	*Apache is open source so it is easier to hack. Purely proprietary software is a little harder to crack and hack*
	Theoretically, perhaps an unknown vulnerability could be introduced to an open source library that we rely upon. Security theory can get into the weeds a bit, but it's still good to think through the possibilities.		*Oxeye research operations has identified an exploit while trying to create an access path using Jaegar, an open-source software for tracing transactions between distributed services*
	The U.S. Cybersecurity and Infrastructure Security Agency's warning follows the discovery of a technical flaw in popular open-source software, Apache Log4J, used by companies and consumers around the globe		*An official package of an open source app managed by a big company and used by a lot of people will have way more trust amount than on a commercial closed source app*
		Amotivation	*I just started learning FreeCAD some days ago and that was my question too. Starting on FreeCAD has a very steep learning curve because even the documentation is a hit and miss*
			I don't have experience with open source projects, but I work full time as a backend dev and I've touched a little frontend technologies.
			Curious how Log4j vulnerability will impact supply chain management, reduced adoption of OSS and supporting OSS tools companies depend on. I'm afraid it will all be in a negative sense, but

Implications

The increase in the negative sentiment and the anger emotion suggested an adverse impact of a security vulnerability on people's feelings towards OSS. Therefore, it is imperative for OSS maintainers to detect and resolve vulnerability concerns to avoid affecting adopters. Usually, vulnerabilities are detected late compared to non-vulnerability defects. It is advised to develop and promote a practice of performing security tests to identify and address any vulnerability during the development lifecycle. The practice may consider leveraging an improved security-specific software development process such as the suggested Orthogonal Defect Classification (ODC) scheme (Morrison et al., 2018) to distinguish between regular and vulnerability defects for better handling.
Evidently, the adoption of OSS is sensitive to vulnerability risks that affect aspects related to their context and characteristics. A security vulnerability hype could affect attitudes towards trusting, satisfying, and supporting the integration of OSS libraries in solutions. To reduce the potential impacts, the need still exists to establish practices and policies to support OSS developers. The findings also alluded to the need for a business model around OSS to compensate and support the development community. Furthermore, individual adopters expressed concerns relative to limitations in their capacity, self-efficacy, and steep learning curve in learning new OSS technologies. Accordingly, it is recommended for OSS maintainers to provide clear documentation, utilization guides, and intuitive user interfaces to make the learning experience easier and increase adoption.
Apparently, a security vulnerability incident is undesirable to be experienced in OSS projects. The consequences of security exploitation can result in high costs to manage. Obviously, a reputation of a troubling OSS library would cause an adverse impact on the level of users' satisfaction. Satisfaction has been attributed by the referenced theories to drive OSS adoption. As outlined in the explored discussions, the vulnerability hype elevated the levels of the anger, sadness, and fear emotions. This reflects an unpleasant emotional state of the community towards adopting OSS. The potential adverse impacts to the adoption factors can be summarized as listed in Table 6.

Table 6: Potential Implications of Security Vulnerability

Factor / Aspect	Vulnerability implication / Adoption Impact
Extrinsic	Dominating discussion and incurred the highest increase in discussions. 2nd in rank with *Anger* expressed emotion to impact satisfaction. Discussions propose other extraneous motivating aspects such as payable and business-supported models.
Amotivation	Shifted from neglectable to an elevated value level of discussion volume. 1st in rank to express *Anger* emotion to impact satisfaction. Discussions. Concerns include security risks to integrated applications
Intrinsic	Reduced in discussions, low but third level of expressed Anger emotion, to impact satisfaction. Discussions suggested unpleasant and challenging experiences.
OSS Innovation Characteristics	Higher reduction in discussions that concerned with OSS quality (security), to impact satisfaction.
Emotion State (sentiment / emotions)	Increased negative sentiment. Increased fear, anger, and sadness emotions, to impact satisfaction.

Limitations and Future Research

It should be noted that due to data retrieval limitations, the study considered SM posts that were published only during a two-month period (one month before and after the log4shell announcement date). Also, the study focused on one case based on the security vulnerability incident of log4shell. Furthermore, while the social media posts were not geographically limited, most of the posts originated from the USA with limited contributions from China. China ranks second worldwide with respect to the number of OSS projects (Mombach et al., 2018). This suggested that Chinese developers may be using other SM platforms to share their opinions. Accordingly, future research may expand the data collection scope to include longer time frames associated with multiple vulnerabilities and other SM platforms.

Also, to assess the impact, the data analysis used a lexical search method to filter out SM posts that were concerned with a security vulnerability. This method could miss SM posts that implicitly expressed such concern. A machine learning technique could be used instead to eliminate the SM posts that explicitly or implicitly expressed the concern. Future work may also extend this research by triangulating the findings with those obtained using surveys and interviews of the software development community. Researchers can also explore aspects of OSS adoption factors in the context of a specific organization or other major events.

CONCLUSION

OSS can be considered an ambivalent information technology due to its potential for benefit and harm. Users can avoid vendors' lock-in and achieve cost savings while promoting OSS innovations. Adopters can integrate OSS into useful solutions while contributing features and fixing issues. However, recent security breaches have introduced risks with impacts on exploiting applications, compromising personal private data, and damaging reputations. Accordingly, this research used SM discourse to explore the impact of a security vulnerability on the feelings and factors associated with OSS adoption. SM platforms were shown to be powerful sources to understand the relevant phenomenon.

The analysis showed increased SM discussions about OSS concerns when a major related incident occurred. Despite the persistence of the positive sentiment towards OSS, the levels of negative sentiment and sadness emotion increased the most at times of security vulnerability incidents. The triggered conversations were concerned with the widespread exploitation risk, failure to detect vulnerabilities, and community support. Furthermore, and besides other impacts, the uncovering of security vulnerabilities had made adopters to be motivated with having OSS projects that are funded and sponsored with appropriate business models.

From a theoretical perspective, the findings provided insights into factors that are associated with OSS adoption in the context of software security. From a practice perspective, the research could guide the development of processes and measures to reduce the likelihood of security vulnerabilities and mitigate their impact. The findings presented herein can also inform the development and testing of comprehensive theoretical models of OSS adoption.

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Governance Effectiveness and Earnings Management: UK Evidence

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Abstract

This study examines the impact of different governance mechanisms on reducing earnings management practices for UK non-financial listed companies. The results revealed a negative relationship between earnings management and the existence of an active, knowledgeable, and experienced board of directors. In addition, the results of the study highlighted the vital role of an independent Internal Audit Function (IAF) in reducing upward earnings management. Interestingly, the study findings show a significant positive association between the proportion of female members on the board and earnings management.

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Emergent online review linguistic features and review helpfulness: an inductive text analytics approach

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ABSTRACT

Prior research on determinants of online review helpfulness has looked at many factors, including characteristics of platforms, reviewers, readers, products, and more. However, we do not yet know precisely how actual text contents of reviews influence helpfulness. We analyze the texts of online reviews, to enable critical linguistic features to emerge from the data. Our results reveal that reviews of experience goods tagged as Helpful emphasized verbs, while reviews of search goods tagged as Helpful emphasized adjectives. We discuss how our findings can potentially contribute to theoretical understandings and practical benefits of online review helpfulness.

KEYWORDS: online reviews, helpfulness, text analytics, text mining, linguistic features, search goods, experience goods

INTRODUCTION

Electronic word of mouth (eWOM) information, in the form of online reviews posted by consumers about products and services, is ubiquitous in the contemporary consumer digital ecosystem (Filieri et al, 2021). Individuals use eWOM resources when making consumption decisions (Erkan & Evans, 2016). Internet platforms for hosting eWOM allow users to post their own reviews, to browse and read the reviews of others, and to provide an additional layer of feedback by tagging the reviews of others as Helpful or Not Helpful. Since different consumers may rate the same product/service in different ways, the helpfulness metrics supplied on eWOM platforms may help users judge the extent to which they might benefit from the content of a particular review.

It is therefore of considerable interest both to researchers and practitioners, as to what makes a particular online review helpful or not (Mudambi & Schuff, 2010). We understand the helpfulness ratings posted on online review platforms as potential natural experiments, which provide quantitative empirical data from the field, that constitute perceptual measures of user responses to actual online reviews. It is useful, from the standpoint of researchers, that such platforms allow the direct collection of information such as product categories and types, product ratings, reviewer names or nicknames, date and timestamps, location, etc. These measures, some of which constitute digests and/or proxies of the reviewing individual's experience and judgment, have been subjected to statistical analyses to abstract patterns revelatory of important relationships between them. These findings are reported in an extensive literature which has itself been reviewed, for example in Wang et al (2019). To better understand the dynamics of online review, there is a need for departure from measures such as review valence and volume, to focus more on the text content of the reviews (Jabr et al. 2020).

The purpose of our study is to turn to the actual word-by-word contents of the posts themselves, using text analytics. We employ a multi-stage methodology, with a variety of text analysis tools, to drill down further into the individual usages and meanings of the unstructured texts, as they may differentiate helpful from not helpful posts. Based on prior theoretical work which has identified elements with potential for such text unpackings, we look for emergent features of the texts of online review posts which can increase our detailed understandings of specifically why, based on the unstructured text content, some online reviews are more helpful than others. Our research question is thus: "Do linguistic patterns act as determinants of helpfulness in online reviews, and if so, specifically how?". Our work makes three contributions to the generation and evaluation of online reviews. First, we contribute to theoretical understanding of determinants of online review helpfulness by identifying significant linguistic features present in their unstructured texts. More importantly, we present a set of propositions from our inductive theory approach which can be tested in future research in similar or different contexts. Second, we contribute to practice by providing analyses which provide guidance to businesses being reviewed through eWOM, about how to utilize online review texts to spot features of their products or services which are most important to their consumers; our methodology also provides practitioners who host online review platforms with highly effective automated means of immediately predicting the most helpful reviews directly from their unstructured texts, independent of other features. Third, we contribute to research methodology by demonstrating the effectiveness of a multi-stage text analysis process which addresses our research question through the deployment of a variety of text analytics tools.

The remainder of the paper is structured as follows. We present a brief review of relevant literature. Next, we describe a multi-stage methodology of text analyses performed in parallel on two datasets of online review posts, one for experience goods, and one for search goods. We then present a set of propositions that can be tested in other contexts to increase the generalizability of the findings from our study. Finally, we end the paper with discussion of our findings, their implications, limitations, conclusions, and guidance for future research.

LITERATURE REVIEW

Online reviews constitute a form of **electronic Word of Mouth** (eWOM). An early and broadscope definition of eWOM was provided by Stauss (2000): "*customers report/interact about consumption-relevant circumstances on the Internet*". This version leaves open exactly what will be seen to constitute consumption relevance, for example not limited to the scope stated in another definition, "*any positive or negative statement made by potential, actual, or former customers about a product or company, which is made available to a multitude of people and institutions via the Internet*" (Hennig-Thurau et al, 2004). Our research context for this study is specific to online reviews on platforms provided for such purposes, and the feature of helpfulness as recorded on such platforms, while looking for what the linguistic features of the texts themselves reveal as relevant or not.

Mudambi & Schuff (2010) define ‘**online reviews**’ as “*peer-generated product evaluations posted on company or third party web sites*”. This definition points us toward text features which contribute to a notion of evaluation – potentially understood variously as value, usefulness, aesthetics, functionality, pleasure, quality, satisfaction, possible re-purchase, etc. Online reviews were recognized as important factors in Internet-based commerce early on, characterized as ‘electronic word of mouth’ by Camp & Sirbu (1997). Topics of interest for researchers exploring online reviews have included their potential impacts on prices (Li & Hitt, 2010) and on purchases (Forman et al, 2008), reviewer characteristics and behaviors (Hong et al, 2016), features of platforms and posts (Bickart & Schindler, 2001), problems of fake reviews (e.g., Wu et al, 2020), and helpfulness.

Understanding that reviews perceived as helpful by consumers are those most likely to produce their hoped-for benefits, researchers have explored consumer perceptions of helpfulness when reading reviews (Huang et al, 2018), and context and metadata elements which accompany review posts (Kasper et al, 2019; Krishnamoorthy, 2015; Mudambi & Schuff, 2010; Malik & Hussain, 2020). Some researchers have focused on the contents of the posts themselves, including studies of emotions and sentiment (Yin et al, 2014), and measures of post length, readability, extreme terms, vocabulary, and other content features (Kuan et al 2015; Wang et al 2019). The latter have developed a broad and replicated consensus that the amount of information contained in online reviews is positively associated with review helpfulness, variously characterized, and measured as word counts and unique word counts, as indicators of review “depth” (Mudambi & Schuff, 2010; Cheng & Ho, 2015; Lee & Choeh, 2016).

More recent work in online review helpfulness has taken on the somewhat different challenges of analyzing unstructured texts, as opposed to readily available quantitative measures such as word counts. One innovative approach, for example, demonstrates the use of Latent Semantic Analysis techniques to explore meanings in a text corpus, using online review datasets for their instructive examples (Gefen et al, 2017). Krishnamoorthy (2015) tested machine learning models which used “linguistic category features” to characterize the words used in online reviews. There are five such categories, defined in the Linguistic Category Model of Semin & Fiedler (1991); these categories specify purposes for which words are used, such as expression of an emotional state, or describing an action. Krishnamoorthy (2015) used these features to create models predicting helpfulness, with good results. These models distinguished between experience goods and search goods, expecting that users will take differing approaches in interpreting reviews for these two categories. Krishnamoorthy provides an informative review of literature which addresses these linguistic approaches applied to the problems of understanding online review helpfulness; rather than duplicate this work, we refer readers to that paper.

Research into online review helpfulness has progressed with useful findings about features of online review platforms, consumers reading reviews, and reviewers authoring online reviews. While analyses of these elements do increase our understandings of the theoretical relationships and practical uses of online reviews, they do not get into the core artifact itself, the text of the review. For example, findings that increased information amounts contribute to perceptions of helpfulness are significant but leave unanswered questions about the role of shorter reviews. Some short reviews are also helpful. This could even be construed as a more impressive achievement on the part of the reviewer: despite the relatively low amount of information posted, the review crosses the reader’s threshold into helpfulness. Particularly, in light of the ‘tldr’ (too long, didn’t read) tendency in many contexts (Syed et al, 2019), we should continue to push further in the direction of specific meanings.

The most recent work employing machine learning and sophisticated analytics does move us toward uncovering meanings in the corpuses of reviews being subjected to analysis. The broad statement of that research stream would be “What is it about the specific text contents of online reviews that results in their being rated as helpful or not?” In this view, a review author’s choice of one word, one phrase, one sentence, rather than another, is a primary vehicle by which the reviewer’s guidance is transmitted to readers. Our paper is thus intended to contribute to filling that gap, to further unpack the patterns which are embedded and implicit in unstructured texts, under the premise that it is the text contents of online reviews which are the primary drivers of perceptions of helpfulness.

Finally, Topaloglu and Dass (2017), who studied “linguistic style matching” – features of word usage which match or mismatch to varying degrees between reviewers and readers – stated that “online review research benefits from deeper textual analysis that includes review content and linguistic style compared to traditional methods that rely solely on numerical ratings.” We share this opinion, and present in the following sections a process for applying multiple powerful tools of text analytics, for the purposes of discovering salient linguistic features which emerge from the unstructured texts of online review posts.

METHODS

In considering what theory can inform expected linguistic differences in determinants of helpfulness, we follow the examples of Krishnamoorthy (2015), Topaloglu & Dass (2019), Kasper et al (2019), Singh et al (2017), and Akbaradi & Hosseini (2020) and conduct an inductive theory building process.

Data Collection

We extracted 300 online review posts each from two popular online platforms. The reviews are extracted from Yelp.com for experience goods, and from BestBuy.com for search goods. On these platforms, the prospective consumers or the review readers can vote a review as helpful using the “helpful” button, which provides the measure for the review's helpfulness (Mudambi and Schuff 2010). BestBuy is a major electronic goods retailer where consumers can purchase a wide range of electronic products in-store as well as online, and our reviews dataset for search goods addresses a variety of the products they offer. Yelp.com is a third-party online service platform where consumers can post their opinions based on their service experience of a business. For our experience good reviews, we collected reviews of restaurants located in and around a major city in the southwest region of the United States. Our samples were collected from 10 restaurants in the chosen city, to represent a variety of reviews possible among different restaurants.

Analyses

All of the text analytics steps in this section were completed using the Anaconda3 distribution of Python 3.6.5, with custom scripts written for the purposes of this research. A wide variety of packages was needed, including:

- NLTK – word_tokenize, sent_tokenize, stopwords
- pandas, statistics, random, numpy

- sys, os, csv, re
- scipy.stats - ttest_ind, Wilcoxon
- sklearn – model_selection (train_test_split, cross_val_score), linear_model (LogisticRegression), naïve_bayes (MultinomialNB, GaussianNB), svm (LinearSVC), metrics

On a practical note, we have observed that numpy, scipy, and sklearn can be sensitive to updates and new releases among the many dependencies relied upon by these packages. Using the Anaconda3 distribution helps but does not entirely solve this problem. Our scripts were developed and run in the Spyder IDE, whose interactive console is extremely useful for analysis software of this type.

To address our research question, we proceed through a series of steps. Here is an overview of the complete process. All these steps were completed for each corpus separately.

1. Load and pre-process posts.
2. Collect measures from each individual post, create aggregate measures, and develop descriptive statistics.
3. Balance the datasets for equal representation of helpful and not-helpful posts.
4. Tag words in each post for nouns, verbs, adjectives.
5. Perform T-tests for identification of parts of speech with potential discriminating power between helpful and not-helpful categories.
6. Select the most frequent words as candidates for inclusion in a final dictionary with strong classification power between helpful and not helpful posts.
7. Model each frequent word for its potential ability to discriminate between helpful and not helpful posts and select the most powerful words for inclusion in a dictionary to be used for classification.
8. Apply machine learning modeling for binary classification of posts and evaluate classification performance – tune parameters for best results.
9. Select best dictionary, tag all terms with part of speech for nouns, verbs, adjectives, and inspect resulting subsets – helpful nouns for search goods, not-helpful adjectives for experience goods, etc.

<u>Load and pre-process posts</u>

Typical for text analytics preparation, we clean the text of any unrecognized bytes. We also remove all non-alphabetic characters; it is possible that numbers could be important for specific and narrowly scoped topic domains, but for our purposes, we are looking for terms of relatively common usage which might contribute to evaluation of experience goods or search goods in multiple contexts. We omit stopwords from our corpuses, using the NLTK ‘english’ list. All words are reduced to lower case for further analysis.

<u>Collect measures from each individual post</u>

The helpfulness rating for each post is kept, and an additional column, ‘Binary Helpfulness’, is generated. This column places all reviews with a platform score >= 1 in a ‘Helpful’ category. The rest are placed in the ‘Not Helpful’ Category. For each post, the following data constitutes a single row of results for this step:

- file name – each post is stored as a separate .txt file before processing
- word count (non-stopwords only)

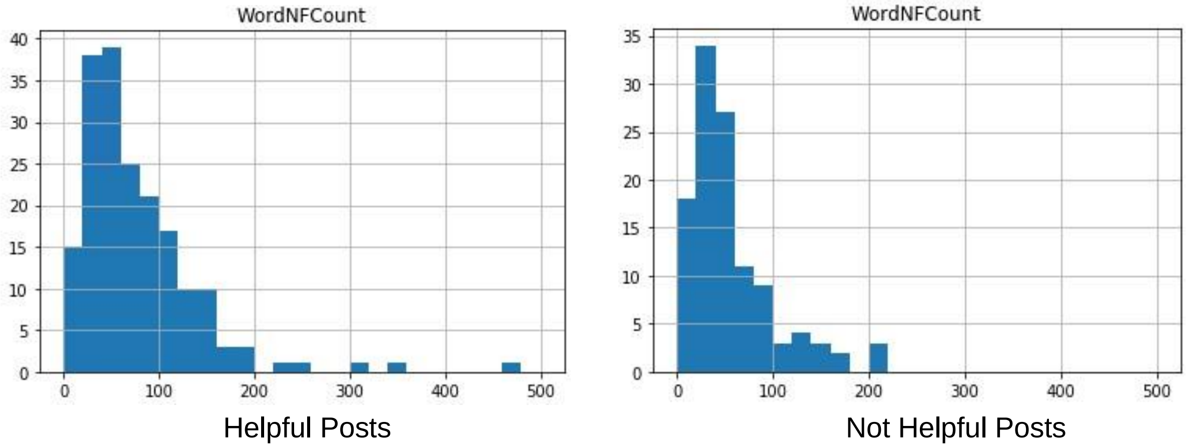
- sentence count
- helpfulness
- binary helpfulness
- noun count
- verb count
- adjective count
- noun percent
- verb percent
- adjective percent
- cleaned text – non-stopwords, stored as a Python list
- full text – all words of the original post, stored as a string

We observed a very strong effect of word count, which replicates and confirms previous studies which identified ‘review depth’, operationalized as word count, as a determinant of helpfulness. However, we also observed that this result dominated the results for noun count, verb count, and adjective count. We reasoned that because 1) longer posts are rarer in both corpuses, and 2) posts which are not long can also be helpful, our interest in linguistic features which determine helpfulness should deploy a metric which can be useful with the shorter posts as well. Therefore, we measured noun, verb and adjective proportions in each post, calculated as count of nouns divided by word count, to derive the noun percent, verb percent, and adjective percent measures. These last three measures were the basis for our T-tests in step 5. The ‘cleaned text’ and ‘full text’ items were for easier and faster retrieval, matched to the other metrics, in other analyses to follow. Table 1 below contains some descriptive statistics of our datasets.

Table 1: Datasets Descriptive Statistics	
EXPERIENCE GOODS (YELP)	SEARCH GOODS (BEST BUY)
# reviews - 300	# reviews - 300
# helpful – 186 # not helpful - 114	# helpful – 29 # not helpful - 271
# sentences: 2685 total # words: 39324 # unique words: 5247 maximum # words: 889 minimum # words: 6	# sentences: 936 total # words: 12814 # unique words: 1911 maximum # words: 476 minimum # words: 7
# non-stopwords: 20276 unique non-stopwords: 5125 maximum # non-stopwords: 479 minimum # non-stopwords: 2	# non-stopwords: 6301 unique non-stopwords: 1801 maximum # non-stopwords: 216 minimum # non-stopwords: 4
average # sentences: 8.95 maximum # sentences: 60	average # sentences: 3.12 maximum # sentences: 18
average # words per post: 131.08 median # words per post: 103.5 average # non-stopwords per post: 67.59 median # non-stopwords per post: 52.5	average # words per post: 42.71 median # words per post: 31.00 average # non-stopwords per post: 21.00 median # non-stopwords per post: 15.0

The distribution of post word counts is of a power-law type for both experience goods and search goods. We see that while the range extends from 2 to 479 words, half of the posts are <= 52 non-stopwords long. The distributions of both helpful and non-helpful posts are very heavily left-skewed (Figure 1).

Figure 1: Distributions of helpful (left) and not helpful (right) posts



Balance the datasets

The Yelp data is not severely imbalanced between helpful and not helpful posts, but the Best Buy data is, so random oversampling was used to create balanced subsets for both. For the Yelp posts, this resulted in 186 posts in both helpful and not helpful categories, for a total of 372 rows. For the Best Buy posts, this resulted in 271 posts in both helpful and not helpful categories, for a total of 542 rows.

Tag words in each post for nouns, verbs, adjectives

The nltk.pos_tag package was used to tag the words of each post for its part of speech. This enabled us to count the number of nouns, verbs, and adjectives per post, and then to compute their proportions, stored as percentages. This makes the linguistic feature being captured independent of the length of the post; a post with 2 verbs out of 10 words will have the same value in this column as a post with 40 verbs out of 200 words.

Perform T-tests

This is the first point at which the sequence of analyses begins to directly address our research question. In looking for significant linguistic features which could potentially distinguish between helpful and not helpful posts, we examine the relative proportions of particular parts of speech. We performed t-tests on the Noun Percent, Verb Percent, and Adjective Percent measures, to test for significant differences of means between helpful and not helpful posts. The tt_ind package from scipy.stats was used. To remove any incidental effects of the random oversampling process used to balance the datasets, we looped each of the t-tests 100 times, repeating the random oversampling rebalancing in each loop before conducting the next t-test. The results were averaged, to produce consistent convergence of numbers thereby obtained.

Select the most frequent words

Our machine learning classification step to follow models only on the words of the posts, with no other features included. Krishnmoorthy (2015) performed a similar test of linguistic features only, compared to and finally combined with other non-linguistic features. For our purposes we hope to obtain a dictionary of terms which are powerful indicators of helpfulness versus nonhelpfulness. To that end, we reason that the most frequent words – words which appear in multiple posts – will be the most useful. We therefore counted the number of posts in which each word appeared, sorted that list in descending order, and chose the most frequent words as potential candidates for the eventual dictionary. In our Yelp reviews, for example, the top 5 words with their associated counts of posts in which they appeared were:

['good', 138], ['food', 123], ['place', 121], ['like', 105], ['great', 104].

Multiple appearances of a word within a single post did not affect these counts.

<u>Model each frequent word</u>

In order for us to detect linguistic differences which could affect determination of helpfulness, we must also know whether or not a particular word is uniformly distributed across both helpful and not helpful posts. It is also useful to cut down the list of frequent words to a more parsimonious dictionary, in hopes of discovering regularities of usage which can contribute to a powerful classification model. We therefore computed each word's 'density' for each post: the number of times that word appears in a post divided by the post word count; this gives us a measure of a word's importance for that particular post, regardless of post length. This measure was used in a simple regression using stats.linregress() to predict binary helpfulness. The resulting model object provides intercept, slope, r-value, and p-value. Our process retained rvalue as the most effective filtering mechanism for finding words which could contribute to the machine learning classification model to follow. This step and the prior step (6 and 7 in the list above) constitute a dual filtering process for arriving at good dictionary candidates. There is a trade-off between these two. Including too few frequent words will reduce the effectiveness of the dictionary. One can compensate for this by including more words with weak r-value, but this will itself also weaken the classification model. We found that there is a broad sweet spot in the balance between these parameters. Dictionaries as small as 106 words, reflecting various combinations of most-frequent thresholds between 500 and 1000, with r-values between .05 and .09, remained robustly in the mid-70s to mid-80s for Accuracy, with many combinations pushing Precision and Specificity into the 90s.

<u>Apply machine learning modeling for binary classification</u>

The dual-filtered dictionary resulting from the two previous steps was used as input for a machine learning classification model. We created a vector for each post of the count of each of the words in the dictionary in that post, to predict the binary helpfulness value for that post. We used the Multinomial Naïve Bayes from sklearn to create the model. The metrics package was used to extract the Accuracy, Precision, Recall, Specificity, and F1 measures, and to create the confusion matrix. To check the robustness of the results, we performed 5-fold cross validation. We further looped 100 times over a StratifiedKFold cross-validation, with shuffle=True to randomize the folds on each pass of the loop. The StratifiedKFold package auto-selects the number of folds, choosing 3 for this data.

<u>Select best dictionary, tag all terms with part of speech, inspect results</u>

With the previous step (8) confirming the power of the dictionary to successfully discriminate between helpful and not helpful posts purely on the basis of the text contents, nltk.pos_tag is used to identify parts of speech. With parsimonious dictionaries with numbers of terms in the range of 100-300, this can also reasonably be done with direct inspection. We separated the dictionary terms into nouns, verbs and adjectives. The resulting subcategory provide indicators of the particular elements of the experience or search good which readers of reviews find most helpful.

RESULTS

The procedures described above were carried out for two different sets of online review posts, one of experience goods, and one of search goods. Our analyses for differences in uses of parts of speech between helpful and not-helpful posts, and our classification modeling techniques, were effective in both cases, but with interesting differences between these two sets.

Experience Goods with Yelp

The t-tests for differences in the proportions of parts of speech in each post detected significant differences for verbs and adjectives. No significant difference was observed for nouns. Table 2 below provides the details. These numbers present the averaged results of 100 t-tests repeatedly performed on datasets which were re-balanced with random oversampling for each run in the loop.

Table 2: T-tests for parts of speech – experience goods (Yelp)

Part of Speech	T-test p-value	Mean Helpful Proportion	Mean Not Helpful Proportion
Nouns	0.350245	48.97%	49.82%
Verbs	**0.001833***	**21.13%**	18.69%
Adjectives	**0.003548***	16.84%	**19.04%**

*Significant at <= .05 level

The directionality of the means points to increased importance of verbs when evaluating experience goods, while the not helpful reviews tended to contain a higher proportion of nouns and adjectives.

We then developed a filtered set of 228 words to use as a dictionary for a Multinomial Naïve Bayes classification model to predict Binary Helpfulness. The numbers below are the average of 100 repeated runs of the model with the datasets being re-balanced with random oversampling for each run. The results were strong. We note that this model out-performs other classification models that we were able to find which deployed only word-based linguistic features (i.e., not word counts, etc). A similar set of 100 looped cross validation tests, to rotate through the available data rows, were run with sklearn's cross_val_score package, using 5-fold cross validation, and with the StratifiedKFold method, which auto-selected 3 folds. These all converged to yield very similar results (Table 3).

Table 3 Machine Learning Models predicting Helpfulness –experience goods (Yelp)

	MultinomialNB 100 re-splits and re-balance	100 StratifiedKFold shuffles	100 5-Fold shuffles
Accuracy	0.8527	0.8428	0.8765
Precision	0.9143	0.9016	0.9624
Recall	0.7833	0.7660	0.7849
Specificity	0.9245		

These results support the notion that robust linguistic features have emerged from the text content of the online reviews of experience goods, which can distinguish helpfulness from non-helpfulness.

Search Goods with Best Buy

The t-tests for differences in the proportions of parts of speech in each post detected significant differences for nouns and adjectives. No significant difference was observed for verbs (Table 4). As before with the Yelp reviews, we averaged results of 100 t-tests repeatedly performed on datasets which were re-balanced with random oversampling for each run in the loop.

Table 4: T-tests for parts of speech –search goods (Best Buy)

Part of Speech	T-test p-value	Mean Helpful Proportion	Mean Not Helpful Proportion
Nouns	**4.5890e-10***	41.62%	**47.94%**
Verbs	0.081432	22.55%	24.14%
Adjectives	**0.000023***	**19.94%**	16.56%

*Significant at <= .05 level

This time, for search goods, the indications from the linguistic features are different from those seen with experience goods. The directionality of the means points to increased importance of adjectives when evaluating search goods, while the not helpful reviews tended to contain a higher proportion of nouns and verbs.

We then developed a filtered set of 180 words to use as a dictionary for a Multinomial Naïve Bayes classification model to predict Binary Helpfulness. The procedures for search goods used here were the same as for the experience goods before, and the models again converged with strong results (Table 5).

Table 5 Machine Learning Models predicting Helpfulness

	MultinomialNB 100 re-splits and re-balance	100 StratifiedKFold shuffles	100 5-Fold shuffles
Accuracy	0.8808	0.8963	0.9043
Precision	0.8439	0.8712	0.8711
Recall	0.9342	0.9270	0.9558
Specificity	0.8311		

These results support the notion that robust linguistic features have emerged from the text content of the online reviews of experience goods, which can distinguish helpfulness from non-helpfulness.

We see that the effects of the linguistic features are not the same for the two different types of goods: verbs are disproportionately emphasized in helpful reviews of experience goods, while adjectives are disproportionately emphasized in helpful reviews of search goods. We also see that nouns do not distinguish between helpful and not helpful reviews for the experience goods posts but have significantly higher emphasis in online reviews of search goods which are not helpful.

DISCUSSION

Towards inductive theory development – allowing the theoretical elements and relationships to emerge from the data – we see that there are more detailed findings about the significance of linguistic features that can be uncovered. Specifically, we observe that while linguistic features are significant as determinants of helpfulness in online reviews, they are not all equal in the impacts, nor in the specific contexts in which their impacts are present.

We see that the effects of the linguistic features are not the same for the two different types of goods: verbs are disproportionately emphasized in helpful reviews of experience goods, while adjectives are disproportionately emphasized in helpful reviews of search goods. We also see that nouns do not distinguish between helpful and not helpful reviews for the experience goods posts but have significantly higher emphasis in online reviews of search goods which are not helpful.

Following the preceding results regarding nouns, adjectives and verbs as potential linguistic distinguishing characteristics between helpful and not helpful reviews, we advance the following propositions, which can be empirically evaluated in future research:

> *Proposition 1: The linguistic features of online reviews of experience goods, as reflected in specific proportions of nouns, adjectives and verbs, are significantly related to the helpfulness of the review.*
>
> *Proposition 2: The linguistic features of online reviews of search goods, as reflected in specific proportions of nouns, adjectives and verbs, are significantly related to the helpfulness of the review.*
>
> *Proposition 3: Reviews of search goods will differ from reviews of experience goods in their specific patterns of linguistics features observed between helpful and not helpful reviews.*

Proposition 3 is thus a follow-on to propositions 1 and 2. Whatever patterns of linguistic features are observed in propositions 1 and 2 respectively, when each type of good is separately analyzed, we expect that those patterns will be different when we compare the first two findings to each other. This prediction is included because of the theoretical work cited above which indicates that information about experience goods and search goods is processed differently by readers of online reviews. With respect to any further details, we remain agnostic prior to analysis, with the intent of observing systematic differences as they appear, emergent from the review texts, and drawing more specific conclusions from those results as they are developed.

The processes of text analytics used here can have direct practical benefits for businesses which are the subject of online review posts. For example, the strong results in accuracy of the prediction models could enable a business which is providing examples of helpful reviews on its website to immediately identify examples of the reviews most likely to be helpful, as soon as they are posted, instead of having to wait for counts of helpfulness to develop over time. Furthermore, the dictionary of specific terms which power the classification models provides specific guidance on what consumers of the experience or search goods are thinking about as they inspect reviews. One restaurant which observed that its helpful reviews tended to include words such as ‘décor’ or ‘ambience’ would thereby learn that these are value-contributing elements for their customers worthy of further attention. Another food establishment might find that those words are not among the most significant indicators, but that ‘price’ and ‘discount’ are, showing that the anticipated experience of its customers has a different focus. These signals from the results of analytics can help businesses to exploit their strengths as well as find ways to improve.

IMPLICATIONS AND FUTURE RESEARCH DIRECTIONS

The results of the study highlight that the specific linguistic features explored here play a critical role in eWOM. The findings show how the evaluative nature of parts of speech of a sentence, here observed as adjectives, can have differential effect from non-evaluative parts of speech, for example in nouns which simply name parts or features. The results are related and have potential implications for persuasion communication literature as well as eWOM studies. Prior persuasion communication research suggests that while good evidence has persuasive effect on attitudinal change, the source credibility or medium of transition does not have direct effect (McCroskey, 1969). In online review context, or eWOM, the text of a review provides the lens to evaluate the persuasive power of a communication agent. It is possible that the reason for the noninfluence of credibility or transmission medium is that instead, linguistic features of the communication transmit their persuasive power. We depart from prior research that has mainly identified individuals’ motivation (Shore et al. 2018; Luo et al. 2017; Hu et al. 2017), to what is relevant in writing online reviews. So ‘relevant’ will be construed as contributing to the function of the review as an evaluation. Mudambi & Schuff define **helpfulness** by describing a helpful review as “*a peer-generated product evaluation that facilitates the consumer's purchase decision process”.* This definition is in service of their development of a theoretical model which hypothesizes ‘review extremity’ and ‘review depth’, as determinants of helpfulness, either of which may be moderated by the type of good, categorized as experience goods or search goods. In our study we see indications that can point to deeper and more complex theoretical understandings of the elements of evaluation that might emerge from online review texts.

Linguistic approaches to text analytics of online reviews have focused on elements which provide clues about how to proceed. For our purposes in this study, depth operationalized simply as word count, and extremity (operationalized as the number of stars in the rating) are outside the immediate scope of our research interest. However, it makes sense that the linguistic elements which contribute to the evaluation of an experience good could be systematically different from those which contribute to the evaluation of a search good. For example, while a relatively generic adjective such as ‘nice’ might reasonably appear either in a review of a restaurant, or in a review of a digital tablet, and contribute to evaluative judgments in both cases, adjectives such as ‘lightweight’ or ‘disposable’ would typically be more relevant to a search good, than to an experience good. Our analyses thus enable us to provide data-driven opportunities for discovering such linguistic differences.

Krishnamoorthy (2015) examined search goods and experience goods with linguistic features determined by the Linguistic Category Model and found that such features are significant determinants of helpfulness for experience goods. In that study, metadata features had better performance than linguistic features when considering search goods, but linguistic features did contribute to a hybrid model incorporating other kinds of features. Wang et al (2019) theorized that helpfulness determinants could differ between experience goods and search goods, reasoning that search goods quality is more objective, with the consequence that experience goods evaluation would require more information from the review, in order to be helpful. Since that consequence element goes to information amount rather than linguistics, we take the broader guidance here that there are good theoretical reasons for considering experience goods separately from search goods. Lee & Choeh (2016) also included product type in their model, hypothesizing this as a moderator for each of their other constructs. Our study followed this prior theorizing by analyzing two datasets separately, one for experience goods, and one for search goods.

In addition to the insights generated by this study, there are opportunities for refining the outcomes. First, helpfulness as a measure of the consequence of the lexical structure is not the end objective for most online businesses. Thus, future studies could aim to understand how more elements involved in the the lexical structure or semantic nature of a review influences repurchase behaviors. Businesses could also inspect the results of detailed text analytics processes such as those we demonstrate here, in order to focus on the precise aspects of a product or service which emerges as most important to their readers of online reviews. Second, the information contained in a review classified as “Not Helpful” is complex. Going further, research could study whether these judgments are attributable to interpretability of the review or its relevance to users’ decision making. Third, the linguistic features we examine here are just a few among many potential factors available in the unstructured texts to be explored in online reviews. Thus, future research could examine how more comprehensive and complex text relationships may be determinants of review helpfulness, as well as how these may perform quite differently in different contexts, as we saw here. Finally, we present a set of a propositions that can be tested with data from similar or different contexts for the purpose of increasing the generalizability of the findings from our study.

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Empirical Study on the Essential Soft Skills for Construction Professionals

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ABSTRACT

The ramifications of proper skillset knowledge for construction workers have been a longstanding and contentious debate within academia. This study investigates the fitness and importance of soft skills as they relate to the construction industry. Through various empirical methods, it was discovered that the most important soft skills for construction professionals include communication, work ethics, dependability, and time management. Eventually, soft skillset findings; herein are in slight congruence with previous qualitative research findings. Findings provide a solid means by which managers and practitioners can properly evaluate and hire appropriate personnel as well as effectively allocate resources to improve worker toolsets.

KEYWORDS: Soft skills, Construction Management, Skillset Knowledge, and Workforce Training

INTRODUCTION

The construction industry has played a pivotal role in driving the US economy over the decades. Texas is one of the states in the US where the sector has thrived and attained enormous growth momentum (Downie 2016). According to the US Bureau of Labor Statistics (2017), there are 711,000 workforces employed by the industry, constituting 6% of the total non-farm workforce of Texas. Following the 2008-09 recession, Texas has been one of the most economically resilient states, experiencing solid year-on-year growth. Throughout the economic recovery phase, the strongest growth industries were linked to energy, construction, and technology. Texas' long-standing economic links to the energy sector helped drive employment and income expansion

(McFarlane, 2017). One of the major beneficiaries of this expansion has been the construction and development industry. While the construction of buildings has been the primary growth engine for this development, commercial construction is also progressing rapidly. Construction as a sector has been fueled by employment growth, improving the housing market and creating a stronger business environment for investment (Choi et al., 2018). In order to keep pace with the expansion of the construction sector, the industry needs to create a sustainable pool of manpower with the right blend of technical and soft skills. Soft skills are as important as technical skills in performing effectively in the construction sector. The objective of this study is to identify key soft skills necessary for construction professionals and to prioritize those skills in order of relative importance. The study has been conducted in the industrial areas of Texas, including Houston and the South-East region.

Real estate construction, which is an integral part of the construction industry, plays a major role in the US economy. Residential real estate caters to the housing needs of families. Commercial real estate, which includes apartment buildings and industrial sites, contribute to job creation and developments for retail, offices, and manufacturing establishments. Real estate as a sector provides a wellspring of income to many people and businesses. In 2016 alone, real estate construction accounted for approximately $1.2 trillion to the US economic output and amounted to 6% of the nation’s gross domestic product (Amadeo 2017). It eventually surpassed its 2006 peak of $1.195 trillion (Amadeo 2017). Real estate construction is highly labor intensive. Consequently, a decline in housing construction was a key contributing factor to the high unemployment rate during the recession. While the US economy has experienced recovery from the slump over the last ten years, construction remained a dominant force in the overall re-stabilization process. The approximate value of the commercial real estate in the United States is $6 trillion (Amadeo 2017).

These numbers substantiate the enormous value and scale of the construction sector in the US. Such a high scale operation of commercial construction demands the right level of skills for the people working in the construction sector. Technical skills or hard skills provide individuals with functional knowledge to do the work (Sing et al., 2018). Soft skills or generic skills work as a catalyst to do the work in a better way. Soft skills are important to acquire or develop in order to do well in the construction industry. Construction organizations need to incorporate soft skills development programs in their training calendar as an ongoing effort and not as a one-off deliverable. It is important for firms to identify soft skills gaps among the employees and find the necessary ways to bridge those gaps. Key soft skills required in the construction industry include communication, time management, work ethics, dependability, teamwork, promptness, trust, problem-solving and listening skills. The absence of these skills can lead to underperformance and failure for professionals in the ever-changing construction industry.

The subsequent section of the paper highlights the dynamics of the construction industry in light of relevant soft skills needed by the people working in this industry. It will essentially explain the growing importance of soft skills in the construction industry and soft skills versus hard skills in construction project management. In addition, it explains different concepts of managing people in the construction industry, relevant workplace skills, and the benefits associated with soft skill development training for the construction workforce. Based on a comprehensive field survey of construction professionals the essential soft skills have been ranked and discussed. This provides a guideline as to how construction firms can focus and prioritize key soft skills development of their workforce.

LITERATURE REVIEW

The construction industry dynamic is changing rapidly. Business cycles, technological advancements, shifts in customer demands and preferences, and challenges related to workforces management and development are some of the key catalysts to this change (Botke et al., 2018). Construction firms endeavoring to subsist on tight budgets and margins are contemplating ways to do more with fewer resources. In order to attain this goal, the firms are continuously working on driving efficiency and productivity involving people, processes and operations management (Azhar et al., 2014). With these challenges, the industry workers and professionals need to adapt to the changes in the construction environment (Toor and Ofori, 2008). They need to be mentally ready to do things differently, undertake more work, gather new technological knowledge, and improve and enhance communication and other relevant soft skills (Toor and Ofori, 2008). This section gives a synopsis of the relevant soft skills and their relative importance in the construction industry.

Success in the construction industry largely depends on an amalgamation of technical skills and soft skills. According to the Oxford Dictionary, soft skills are personal characteristics that enable people to interact effectively and cordially with other people. While technical skills are often prerequisites for many specialist positions, interpersonal skills (i.e. being able to communicate and get along well with peers and external people) remain essential (Kaye, 1999). Soft skills can be described as a combination of interpersonal skills, communication skills, behavioral attributes, attitudes, and emotional intelligence quotient (EQ) that enable people to effectively suit their work environment, get along well with others, perform and achieve their goals with accompanying right set of hard skills (Lippman et al., 2015).

Construction is a substantially technical, contractual, and interpersonal business by nature (Kagerer, 2010). It is governed by deadlines, failure to meet deadlines has severe financial implications. It demands immaculate project management skills. Conflict is unavoidable in this industry as project owners, design teams, contractors and subcontractors all have divergent goals, ideas, and standards. Conflicts in the work environment can arise from seemingly congenial atmospheres. As a result, construction workers and professionals need to enhance their soft skills to meet such challenges in the workplace effectively. Such skills include negotiation and conflict resolution skills. In addition, as in other professions, many construction professionals can experience high levels of stress. Workplace stress can lead to psychological, physiological, and social strain effects (Bowen et al., 2014). Stress can have an adverse impact on personal discipline and may lead to increased absenteeism. Construction operations depend on workers' continuity and productivity. Absenteeism on a job site can hamper project performance in many ways. Construction managers have predictably viewed absenteeism as an individual's issue. As a result, individually focused punitive measures have been used to reduce absenteeism in construction projects (Ahn et al., 2013), but this approach often produces inadequate reinforcement of attendance motivation. Behavioral control of workers is another very important aspect of managing absenteeism in the workplace. Such behavioral control mechanisms include workers' perception about formal and social rules for absence, attitudes toward these rules, and ways to control their absence behavior appropriately. In the subsequent section, the authors have reviewed different soft skills needed for construction project management.

One of the key attributes of a construction project manager is flexibility (Kerzner 2013; Safa et al., 2013). A project manager having an understanding of the project management techniques and tools can adapt to any type of construction projects and manage them (Zhang, 2012; Safa et al., 2015). While technical skills can be a great advantage for a project management role, its absence does not necessarily mean the project will fail. Technical skills or hard skills can be developed through training. In order to obtain the right construction project manager for a project, it is essential to find someone who has the optimum blend of both hard and soft skills. The nature of the construction project determines the degree of hard and soft skills required by that project (Dainty et al., 2003). Technical or hard skills can be learned and acquired. Broadly speaking, hard or technical skills desired in a project manager include the ability to use project management software, project planning, scheduling, controlling, proper documentation such as technical writing, and sketching. In project management, hard skills are generally adequately defined and reasonably straightforward. It is important to understand the core soft skills required for effective construction project management jobs (Needs, 2007).

A project manager spends about 90% of his time in a project on communication (Payne 1995). Effective utilization of this time on communication is key to a project's overall success. To be successful in construction project management roles, managers predominantly need to have soft skills such as planning, organizing, leading and correcting people, problem-solving, negotiation, and conflict resolving (Robles 2012). While soft skills are difficult to instill and quantify, they can be learned and developed. Nonetheless, the development of soft skills requires conscious efforts and diligence. This is primarily due to the fact that humans find it difficult to unlearn ways of doing things or change a habit which was inherent. Some key soft skills for effective project managers (Gillard, 2009) can be discussed in further detail. Problem-solving is the ability to look beyond an immediate problem, get to the root level of the problem, and offer long-term solutions. As a project manager one needs to remember that he or she is not just solving the problem, but also making sure that people involved in solving the problems are satisfied with the overall solutions (Segal, 2014). A project manager needs to take a broader consideration of the team while solving problems in a project environment (Thamhain, 2004).

Furthermore, project managers need to be trained in the critical area of conflict resolution, as they are primarily responsible for handling conflict within the team during a project (Meredith and Mantel, 2011). When resolving conflict, a project manager should ensure the problem is confronted impartially. It is important for managers to understand the emotional state of the parties involved, assess how sensitive they are to the issue and communicate the proposed solution in a well thought out manner. In many cases technical skills or knowledge are required in resolving conflict; however, the softer part of the skills is equally very important to achieve an optimal solution (Deutsch et al., 2011). Another important skill for project managers is a negotiation, which is an integral part of a project or program management. Negotiation skills are useful in many areas of project management such as conflict management, contract management, and stakeholder management (Englund, 2010). While technical skills help managers to manage the job, negotiation skills (Edum-Fotwe and McCaffer, 2000) are important to win the project.

Likewise, motivation is a key soft skill which project managers need to practice ensuring that their team members maintain high morale. Good project managers should know various motivation factors (Walker, 2015) and tools; understanding when and how to apply them is even more important. Since working and succeeding in most of the projects requires a team effort, motivation techniques that foster teamwork should be project managers' absolute priority (Ammeter and Dukerich, 2002). Good performances within the team should be duly recognized and rewarded to build a high performing team (Katzenbach and Smith, 2015). Leadership skills and capabilities are important for construction project managers. Project leadership, an emerging popular field of study, is growing in relevance and significance (Walters and Sirotiak, 2011). Projects are being delivered in a more complex and demanding environment, which requires greater leadership skills from the project manager or lead (Krahn, and Hartment, 2006). A project manager should possess a good blend of people skills and strategic leadership skills and be able to demonstrate both leadership and management at work in a balanced way (Skipper and Bell 2006).

The construction project management role requires the application of both technical and soft skills at a balanced level (Heckman and Kautz, 2012). The nature of the project and the organization's structure will determine the type and degree of skills combination required for the project (Kwak and Anbari, 2009). Soft skills can be related to leadership style (Sunindijo et al., 2007). Construction project managers naturally differ in their leadership styles. Some leadership traits are inherent (Amabile and Khaire, 2007); however, there are always ways to fine-tune them as learning is a continuous thing in a dynamic project environment. While managing construction projects requires these key soft skills, it is also important to understand how soft skills can help in managing people in the ever-dynamic construction industry.

One of the unique characteristics of the construction sector is the high emphasis on flexibility and adaptability of the workforce (Right and Snell, 1998). Atkinson's model of labor flexibility categorizes workers into two types – core workers and 'peripheral' workers (Atkinsons, 1984). Core workers are usually the permanent type of employees with good pay and career prospects. They are expected to be functionally flexible, and adaptable across a range of tasks, and their skills will be applied to key business activities of the firm. Examples of such roles include structural and civil engineers, architects, commercial, and building construction management roles. Such roles require both technical and soft skills. A flexible workforce can possess various merits and demerits for employers and personnel (Valverde et al., 2000). For employers, the ability to cater to cyclical and irregular demands by supplying required skills when needed is viewed as a great advantage. Flexible working terms also require greater adaptability, which is a valuable soft skill for this sector. Furthermore, different workers and professionals encounter varied terms, conditions, and length of work for which they are employed. This requires effective project coordination and employee motivation skills for the project leads and supervisors for different levels of contingent staffs (Procter et al., 1994; Safa et al., 2017). Challenges with contingent workers include work-related quality issues, cost increases, and project completion delays. Other concerns pertaining to the contingent workers involve inadequate training, development and career opportunities, less job security, environmental, health and safety risks, and limited or absent employee welfare or Social Security (Wilkinson, et al., 2012). On many occasions, organizations are reluctant to invest in contingent staff's development.

People are at the core of any business and are the most valuable asset for all industries including the construction business. In the construction industry, workers who receive regular occupational training contribute more effectively to the company's goals achievement. Employee training and development is essential as it helps to uplift the overall performance of the construction industry. Construction companies should continue to invest in workforce training through a well-conceived human resources development strategy that encourages continuous occupational training, including soft skills development training (Bassioni et al., 2004). For construction businesses, soft skills training needs to be an ongoing process rather than a one-off activity. Such training and development need to focus on improving on-the-job performance and satisfaction of the construction workers to bridge the current and anticipated future skills gap by applying both formal and informal training and development interventions (Kululanga and McCaffer, 2001).

Construction technologies and work procedures are experiencing a rapid advancement within the construction industry; therefore, workers' skill levels must be constantly refreshed in order to maintain effectiveness and produce quality results (Aziz and Hafez, 2013). According to Barker and Ingram, employee skills directly influence organizational performance providing a company an edge over other competitors (Barker and Ingram, 2011). With the aim to perform effectively in their roles, workers need specific skills to respond to the numerous and frequently changing job requirements. Having a workforce with diverse skills allows a company to be more flexible, agile, and better equipped to respond to changes (Pollitt, 2010). Hence, it is important for companies to have training programs that address the needs of both soft skills and technical skills of the workforce. Companies with multi-skilled workforce naturally have a better ROI of its workforce, permitting continuity of their performances in the highly unpredictable condition of construction projects (Gomar et al., 2002, Simpson, et al., 2019, Safa et al., 2020). Different studies have confirmed that a strong positive correlation exists between employees' disposition towards the intended benefits of training and their organizational commitment (Redford 2007). Ongoing training and development can help a company retain good employees by reinforcing strong organizational commitment and motivation among the employees (Newman et al., 2011). Construction companies have become increasingly cognizant of workforce training and development. Soft skills training can play an important role in increasing workforce productivity, improving staff retention, driving employee engagement, and building a strong organizational culture (Jackson, 2009).

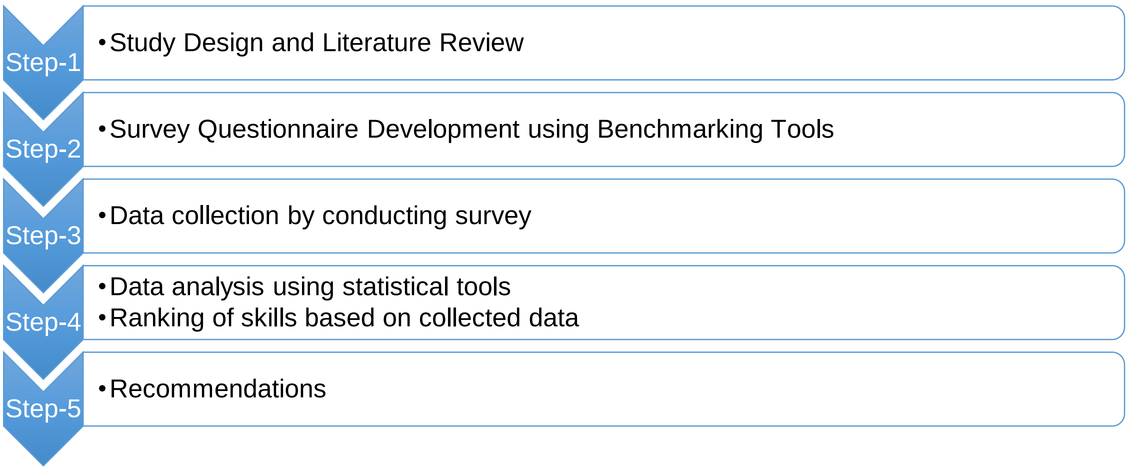
One distinctive facet of the construction industry is most of the employees in managerial roles rise in the ranks and therefore have strong function-specific skill sets, including technical expertise about processes. These employees often lack soft or generic skills and people skills required to excel in managerial roles (Riley et al., 2008). A soft skill-related study conducted in the construction industry reveals that mid-level managers within the industry often believe that there is no training available for them and that the industry is not supportive of capacity development related to soft skills (Hager et al., 2000). In many advanced countries like Australia, it has been noticed that training plans are strongly driven by an obligation to remain compliant with current government regulation (Bahn and Barratt-Pugh, 2012) and not by the actual interest or training needs of the employees. As a result, technical skills development training, such as Workplace Health & Safety training, are predominantly chosen by employers over soft skill development training. A study of 20 UK-based construction companies revealed that soft skill development training programs that stimulate teamwork capabilities provide employees with greater flexibility and also help employees working in a team understand how their action can affect others (Briscoe et al., 2001).

Two main forms of learning that take place in a workplace - formal and Informal. Taylor & Evans defined formal job-related training (Taylor and Evans, 2009) as courses or programs related to an employee's current or future job. These courses can take place in the form of seminars, workshops, boot camps or conferences. There are also programs such as apprenticeships or vocational programs under formal training. Such training is usually conducted by a facilitator or an instructor, following a set structure, and providing the employee with some form of formal recognition upon completion. On the other hand, informal training is described as self-directed knowledge creation or learning from experience. Individual employees may undertake such training for the purpose of self-development to remain competitive. Informal training does not follow a formal set of specific guidelines and does not lead to a recognized qualification (Noe et al., 2013). Construction workers should also engage in onsite informal learning and practice environment to develop some immediate-task related soft skills. In the view of the literature, the subsequent sections of the study will describe the research methods and present and summarize the key findings from an empirical study on the most important soft skills for the construction professionals.

THEORETICAL DEVELOPMENT/MODEL

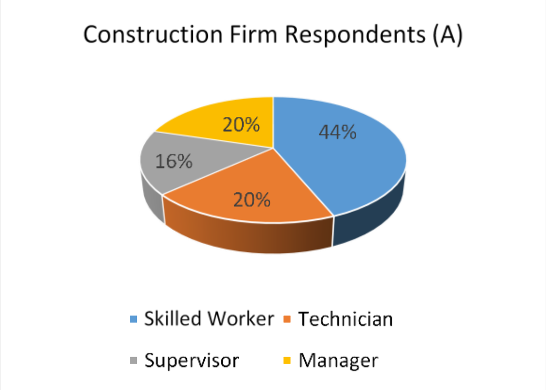
The study was designed to explore the most important soft skills for construction professionals. Based on the scholarly work on soft skills and their importance in the construction industry, a literature review was conducted. A questionnaire was developed with insights from the Soft Skills study conducted by the Research and Statistics Office for the Workforce Development Division, Department of Labor and Industrial Relations, State of Hawaii (June 2015). The questionnaire has been modified with the help of expert opinions from Construction and Management specialists. The overall steps of the study are shown in Figure 1 below.

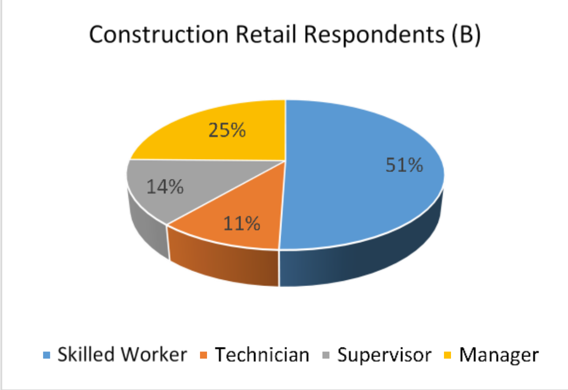
Figure 1: Steps of Research Conducted



A questionnaire-based survey was conducted at different construction sites and offices in Southeast Texas and in Houston. The participants were chosen randomly from construction and construction retail organizations. These participants have only asked to provide their general professional/managerial rank in their organizations. A total of 204 participants comprised of Skilled Workers, Technicians, Supervisors, and Managers participated in the survey. Of the 204 participants, 78 of respondents were from Construction Retail and 126 were from Construction firms. Figure 2 presents the profile of the respondents working in construction firms.

Figure 1: Respondents Profile – Construction Firm; (B) Respondents Profile – Construction Retail





With the help of the questionnaire, respondents were asked to rate each of the 30 soft skills on a scale of 1 to 5, in which 5 stands for 'high' and 1 denotes 'low' in importance with reference to the construction industry (Appendix A). In other words, a 5-point Likert scale is used to run the statistical results which can be labeled as 1: strongly agree; 2: Agree; 3: Neutral; 4: disagree; 5: Strongly Disagree. Finally, an overall ranking of soft skills has been done based on the inputs from 204 respondents' rating scores. The questionnaire is enclosed as a reference in the Appendices. While performing the analysis, statistical techniques such as ordinal regression analysis, goodness-of-fit tests, and factor analysis has been applied and results have been validated. Minitab 18 has been used as a major statistical tool for data analysis. Ordinal logistic regression techniques are usually applied to analyze and determine if there are meaningful relationships between the variables (Aydin et al., 2008). Logistic regression is used to determine the probability linked with each of the response variables by establishing a linear relationship between predictor variables and a link function of these probabilities. Link functions vary in producing different levels of goodness of fit for the data. The goal of the logistic regression model is to correctly predict the category of outcome for individual cases using the most efficient model. Subsequently, a model is created that includes all predictor variables that are useful in predicting the response variable (Aydin et al., 2008). The multiple logistic regression model of this study can be written as:

$$\ln(\text{odds ratio}) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \varepsilon_i \qquad (1)$$

In equation (1) k denotes the number of independent variables in the study, ε_i represents the random error in an observation i. A logistic regression is usually based on the odds ratio, which demonstrates the probability of success compared with the probability of failure. Also, the maximum likelihood method is used to find the estimates of the parameters in the logistic regression equation (1). The deviance test is used as an indicator to measure the model's goodness of fit. The model is usually considered acceptable or reliable if the deviance is not significantly large.

RESULTS AND ANALYSIS

From the data of this study, some key statistics were derived upon and summarized in Table 1, which lists the top seven soft skills with a high mean value among the surveyed 30 soft skills. Here, the mean value is derived from the rating score given by 204 participants who had individually rated those 30 soft skills on a scale of 1 to 5, 5 being 'very high' in importance. Subsequently, based on the mean rating score, the most important soft skills for the construction industry include Communication, Work ethics, Dependability, Time management, Listening, Trust, and Integrity.

Table 1: Key Soft Skills with High Mean Value

Variable	Mean	SE Mean	Std Dev	t-score	p-value
Communication	4.667	0.048	0.685	97.229	0.0
Work ethics	4.607	0.053	0.751	86.924	0.0
Dependability	4.593	0.047	0.670	97.723	0.0
Time Management	4.593	0.049	0.713	93.734	0.0
Listening	4.529	0.052	0.745	87.096	0.0
Trust	4.525	0.049	0.705	92.346	0.0
Integrity	4.515	0.053	0.753	85.188	0.0

The standard error of the mean in Table 1 can provide a rough estimate of the interval in which the population means is likely to fall. In fact, the level of probability selected for the study (typically $P < 0.05$) is an estimate of the probability of the mean falling within that interval. This interval is a crude estimate of the confidence interval within which the population means is likely to fall. A more precise confidence interval should be calculated by means of percentiles derived from the t-distribution. Using Minitab, the t-score and p-value have been derived. The p-value for each of the top seven variables (skills) equaled to zero (or less than 0.05) indicating that all these variables are significant.

In this study, the response variables used are from 1 to 5; which is ordinal. Hence, ordinal logistics regression has been applied to analyze and predict a significant relationship between the categorical outcome and the independent variables. Table 2 presents the Logistic Regression data holding Dependability variable as constant and with reference to the other 29 variables (skills) of the study.

Table 2: Logistics Regression with Dependability Variable as Constant

						95% CI	
Predictor	**Coef**	**SE Coef**	**Z**	**P**	**Odds Ratio**	**Lower**	**Upper**
Const 1	14.5104	2.84590	5.10	0.000			
Const 2	23.6728	3.42330	6.92	0.000			
Const 3	27.9714	3.782530	7.39	0.000			
Communication	-1.77166	0.499199	-3.55	0.000	0.17	0.06	0.45
Flexibility	-0.873896	0.392624	-2.23	0.026	0.42	0.19	0.90
Adaptability	0.111466	0.460098	0.24	0.809	1.12	0.45	2.75
Listening	-1.12852	0.494100	-2.28	0.022	0.32	0.12	0.85
Coaching	-0.0642232	0.410457	-0.16	0.876	0.94	0.42	2.10
Problem solving	-1.90862	0.485028	-3.94	0.000	0.15	0.06	0.38
Work ethics	-0.386548	0.468961	-0.82	0.410	0.68	0.27	1.70
Team work	-0.257228	0.483452	-0.53	0.595	0.77	0.30	1.99

Stress Management	0.583602	0.426795	1.37	0.171	1.79	0.78	4.14
Safety-conscious	-0.763677	0.427440	-1.79	0.074	0.47	0.20	1.08
Positivity	-0.242092	0.473163	-0.51	0.609	0.78	0.31	1.98
Respectful	0.460969	0.419047	1.10	0.271	1.59	0.70	3.60
Creativity	0.393556	0.489639	0.80	0.422	1.48	0.57	3.87
Trust	-0.948487	0.493011	-1.92	0.054	0.39	0.15	1.02
Social Competency	0.148475	0.401511	0.37	0.712	1.16	0.53	2.55
Assertiveness	0.147040	0.572418	0.26	0.797	1.16	0.38	3.56
Self-Assessment	-0.605374	0.457767	-1.32	0.186	0.55	0.22	1.34
Self-Discipline	-0.0752807	0.483565	-0.16	0.876	0.93	0.36	2.39
Confidence	-0.470649	0.386470	-1.22	0.223	0.62	0.29	1.33
Learning Diagnosis	1.56811	0.507209	3.09	0.002	4.80	1.78	12.96
Active Learning	0.151990	0.496722	0.31	0.760	1.16	0.44	3.08
Vision	1.24022	0.440315	2.82	0.005	3.46	1.46	8.19
Time Management	-0.271988	0.385362	-0.71	0.480	0.76	0.36	1.62
Integrity	-0.326765	0.427503	-0.76	0.445	0.72	0.31	1.67
Interpersonal Skills	-0.0190997	0.397577	-0.05	0.962	0.98	0.45	2.14
Leadership	-0.904198	0.498919	-1.81	0.070	0.40	0.15	1.08
Courtesy	0.0316028	0.427304	0.07	0.941	1.03	0.45	2.38
Empathy	0.257259	0.452099	0.57	0.569	1.29	0.53	3.14
Promptness	-0.484165	0.393131	-1.23	0.218	0.62	0.29	1.33

Here the Link Function is Logit, which means the inverse of the standard cumulative logistic distribution function. The above logistic Regression Table (Table 2) shows the results for estimated coefficients, standard error of the coefficients, z-values, and p-values of all the 29 predictors (skills) holding dependability variable (skill) as constant. The coefficient of the 29 variables (skills) indicates the estimated change in the logic of the variable for the change in the predictor (dependability). For instance, Learning Diagnosis has a positive high coefficient (1.568). This indicates if Dependability variable changes positively by 1 unit, the estimated log-odds ratio of Learning Diagnosis increases by 1.568 unit. Hence, a construction professional with a high dependability score is more likely to be strong in Learning Diagnosis. Standard Error of Coefficients indicates the precision of the estimated coefficient. Variables with the lowest standard errors such as Time Management (0.3853), Confidence (0.3864), Flexibility (0.3926), Promptness (0.3931) and Interpersonal Skills (0.3975) provide a more precise estimate of the coefficients. Furthermore, the p-value is used in hypothesis tests to help decide whether to reject or fail to reject a null hypothesis. The p-value is the probability of obtaining a test statistic that is at least as extreme as the actual calculated value if the null hypothesis is true. Z is used to determine whether the predictor is significantly related to the response. Larger absolute values of Z indicate a significant relationship. Variables with p-value lower than 0.05 and with high corresponding z-value in this study are: Communication (p=0.00; z=3.55), Problem Solving (p=0.00; z=3.94), Learning Diagnosis (p=0.002; 3.09), Vision (p=0.005; z=2.82), Listening (p=0.022; z=2.28), and Flexibility (p=0.026, z=2.23).

The authors also looked at the estimated Odds Ratio, which utilizes cumulative probabilities and their complements. Here variables with higher odds ratio such as Learning Diagnosis (4.8) and Vision (3.46) indicate construction professionals with good learning diagnosis competency and vision are more likely to be dependable. Then the authors looked at the Log-Likelihood along with the statistic G. This statistic tests the null hypothesis that all the coefficients (β) associated with predictors equal zero versus at least one coefficient is not zero. Here, Log-Likelihood = -68.436 and G = 199.568, DF = 29, P-Value = 0.000 indicates there is sufficient evidence to conclude that at least one of the estimated coefficients is different from zero (assumptions: simple random sample, independent variables and normal distribution of the data). It can be concluded that the variables used in this study of soft skills are important and statistically significant. Goodness-of-Fit Tests suggest the correlation between the variables (skills) is statistically significant. Using the Pearson method, it was found that P-value is 0.00 and less than the significance level (α = 0.05). Also from the deviance test, P-value = 1.00 indicates there is sufficient evidence to claim that the model fits the dataset appropriately. Table 3 presents the results of Goodness-of-Fit Tests.

Table 3: Goodness-of-Fit Tests

Method	**Chi-Square**	**DF**	**P**
Pearson	1901.83	448	0.0
Deviance	136.87	448	1.0

Table 4 summarizes the Measures of Association between the response variable and predicted probabilities. According to this test, two of the three summaries of the table of concordant and discordant pairs such as Somers’ D and Goodman-Kruskal Gamma indicated a high measure of probability (0.90) which strongly suggests a good predictive ability of the model used in this study.

Table 4: Measures of Association

Pairs	**Number**	**Percent**	**Summary Measures**	**Score**
Concordant	9176	94.9	Somers’ D	0.9
Discordant	484	5	Goodman-Kruskal Gamma	0.9
Ties	14	0.1	Kendall’s Tau-a	0.42
Total	9674	100		

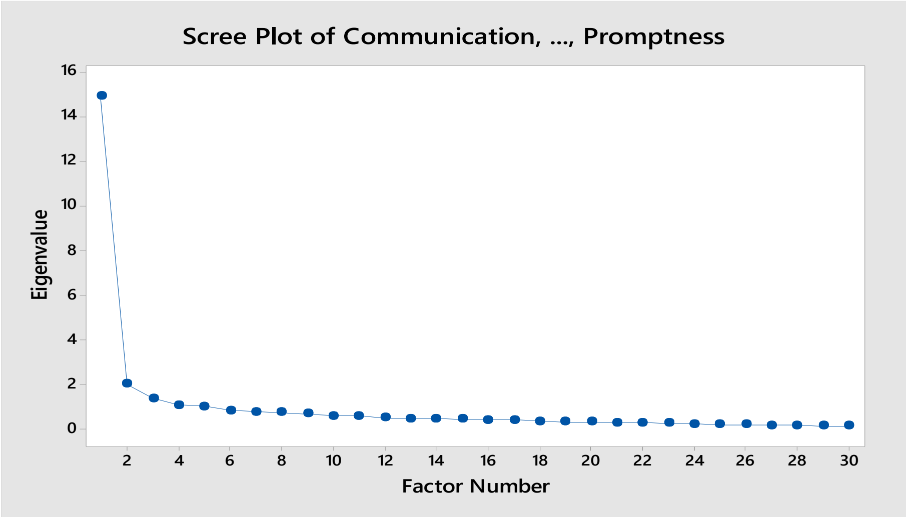
As a final step, the authors applied factor analysis in order to reduce the number of variables and to identify structure in the relationships between the variables. While doing so Varimax was used as the rotation technique. Table 5 summarizes the results of the Rotated Factor Loadings and Communalities, which helped to cluster the variables across factors. Varimax rotation is the most common method used in factor analysis. It involves scaling the loadings by dividing them by the corresponding commonality. Varimax rotation transforms the initial factors into new ones that are easier to interpret.

Table 5: Rotated Factor Loadings and Communalities

Variable	**Factor1**	**Factor2**	**Factor3**	**Factor4**	**Communality**
Communication	0.784	0.136	0.112	-0.149	0.668
Dependability	0.772	0.133	0.223	-0.281	0.742
Flexibility	0.458	0.127	0.203	-0.581	0.604
Adaptability	0.457	0.634	0.111	-0.203	0.664
Listening	0.693	0.261	0.271	-0.156	0.647
Coaching	0.321	0.384	0.040	-0.653	0.679
Problem Solving	0.446	0.614	0.201	-0.242	0.675
Work Ethics	0.772	0.175	0.365	0.044	0.761
Team work	0.438	0.057	0.685	-0.080	0.670
Stress Management	0.523	0.332	0.389	-0.248	0.596
Safety-conscious	0.315	0.096	0.651	-0.241	0.591
Positivity	0.441	0.567	0.154	-0.393	0.694
Respectful	0.455	0.284	0.496	-0.169	0.562
Creativity	0.304	0.57	-0.020	-0.506	0.674
Trust	0.444	0.362	0.461	-0.204	0.583
Social Competency	0.064	0.296	0.315	-0.666	0.635
Assertiveness	0.131	0.645	0.419	-0.316	0.709
Self-Assessment	0.285	0.504	0.507	-0.251	0.656
Self-Discipline	0.360	0.394	0.420	-0.398	0.619
Confidence	0.355	0.393	0.477	-0.316	0.608
Learning Diagnosis	0.067	0.538	0.630	-0.222	0.740
Active Learning	0.219	0.620	0.455	-0.195	0.677
Vision	0.050	0.807	0.191	-0.288	0.773
Time Management	0.382	0.404	0.372	-0.126	0.463
Integrity	0.414	0.328	0.369	-0.176	0.446
Interpersonal Skills	0.263	0.362	0.276	-0.485	0.512
Leadership	0.020	0.271	0.319	-0.777	0.78
Courtesy	0.210	0.112	0.571	-0.515	0.648
Empathy	0.089	0.233	0.580	-0.566	0.719
Promptness	0.254	0.278	0.592	-0.247	0.553
Variance	5.1774	5.0712	4.934	4.1664	19.349
% Var	0.173	0.169	0.164	0.139	0.645

From the Scree Plot chart below shown in Figure 3, it is quite evident that a maximum of 3 factors is sufficient to classify the variables in terms of the structure of their relationship.

Figure 3: Scree Plot Chart



Factor loadings represent how much a factor explains a variable in factor analysis. It is visible that the first factor strongly loads on variables like Communication, Dependability, Listening, Work ethics. The second factor strongly loads on Vision, Adaptability, Assertiveness, Problem-solving, and Creativity. The third factor moderately loads on Learning Diagnosis, Empathy, Teamwork. The rotated factors also explain 64.5% of the data variability and the communality values indicate that all variables except Time management and integrity (commonality is less than 0.5), are moderately well represented by these three factors.

SUMMARY OF FINDINGS

Statistical analysis of the survey data helped to establish a logical ranking of the most important soft skills for construction professionals. With the help of logistic regression technique, the most reasonable and best fitting model has been developed to describe the relationship between the variables (skills). The goodness of fit test also indicates the model is reasonable as the deviance is not significantly large. Moreover, it suggested the correlation between the variables (skills) is statistically significant. Measures of the association test including Somer's D and Goodman-Kruskal Gamma suggested a good predictive ability of the model used in the study. Finally, factor analysis has been conducted to reduce a large number of variables into fewer numbers of factors. Skills such as communication, dependability, work ethics, and listening, have been found to have high loading to one factor. Authors have also performed a test of the internal consistency and reliability of the survey using the Cronbach's Alpha. Cronbach's Alpha=0.9682 > 0.70 which indicates the internal consistency and the excellent reliability of the analysis.

From the overall study, Communication Skills have been rated as the most essential soft skills for the construction industry. Communication Skill is the ability to convey information clearly and effectively, use appropriate body language, present one's self in meetings, in email, and on the phone. Without sound communication skills, a construction professional will not be able to progress in this ever-changing construction industry. The next most important skills are Work ethics, Dependability and Time Management. Employees possessing a strong work ethic are motivated, dedicated, and willing to work hard. Construction projects have many tasks and key milestones. The work is very demanding. It is important for construction employees to be strong on work ethics in order to excel in this competitive industry. Dependability or reliability is the capability of being able to be counted on or relied upon - following through with what was promised. Having this skill is essential to delivering consistent performance and results in a demanding environment like the construction industry. Dependability is a virtue that involves consistent efforts and firm commitments. Time management is the ability to plan and complete tasks on time. Construction projects are extremely time sensitive; in the absence of proper time management skills of the workforce and professionals, no project will be delivered on time by the companies.

CONCLUSION AND RECOMMENDATIONS

Businesses need to prioritize which soft skills on which to focus on for employee training and development. Soft skills can be developed through formal training programs as well as informal self-directed development initiatives. It is important for individuals and their managers to identify key skill gaps in order to perform the job better. Soft skills are often called employability skills that offer a great deal of flexibility to the organization along with greater adaptability and ability to respond to changes. It is also evident that employees having a positive outlook towards the benefit of the training programs are expected to have greater organizational commitments. Therefore, it is essential to have the right mix of technical and soft skills for the employees to enhance their professional development and growth. Soft skills act as leverage to bring the best outcome of a professional's technical skills on the job.

The finding of the study indicates that the most important soft skills for construction professionals are communication, work ethics, dependability and time management. Other soft skills are important too, but these four skills emerged as the most important ones from the study. Construction managers or practitioners should emphasize more on these skills while hiring and training construction professionals along with the required technical skills to perform the job. For instance, construction firms including retail organizations can schedule periodic training and development programs for employees in certain soft skill areas as communication and listening skills, dependability, time management, and work ethics. After the training, it is important to measure the effectiveness of the training by observing the on-job performance of the trainees. Coaching and follow-ups from managers can help construction professionals to improve on those skills. Construction professionals should also engage in an onsite informal learning and practice environment to develop some immediate task-related soft skills and remain competitive in the industry. It should be noted that the priorities of different stakeholders in this study were very similar.

One of the limitations of the study is the fact that it was focused on the construction industry of Southeast Texas and the Houston area. Going forward, the authors intend to extend the scope of the research to other regions of the United States and international markets to gather deeper insights into soft skills for construction professionals. In addition, the inclusion of Human Resources specialists for the next phase of the research can add significant value. Soft skills development for construction employees needs to be carried out in a sustainable manner with periodic reinforcement and continued to follow up. Businesses with the right emphasis on soft skills development are expected to have a more motivated, agile and efficient workforce.

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DECISION SCIENCES INSTITUTE

Encroachment of Retailer's Own-Brand Business: Does Data Sharing Act Play as a Remedy in e-Marketplace?

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ABSTRACT

Regulators show great concern about how the giant retailer allegedly is quashing its smaller rivals and unveil plans to oblige it to share data with the rivals. In this paper, we investigate the data-sharing legislation from a policy maker's standpoint. Surprisingly, we show that a ban on sharing, rather than sharing, should be enforced if the retailer's information is not of high quality and the seller thinks too highly of its value. Furthermore, we confirm that the intervention for sharing is not valid in many circumstances. Our results provide the requisites for successful intervention of the regulators for the data-sharing.

KEYWORDS: Antitrust Regulation; Information Sharing; Information Asymmetry; Online Marketplace; Own-Brand Business

DECISION SCIENCES INSTITUTE

Enhancing Safety and Environmental Compliance: Evidence from the Aviation Industry

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ABSTRACT

To guarantee consistent levels of aviation service under a variety of pressures, the airline industry is often subject to regulatory frameworks. Regarding civil aviation operations, the importance of preventive measures against safety issues cannot be overemphasized. Furthermore, as the industry has gotten bigger, there have been numerous calls to comprehensively consider its environmental impact. In this study, we investigate how airlines react when a new regulation comes into force. In addition, we examine if airlines that extensively engage in sustainability reporting have different operational performance under the regulation. Lastly, whether potential economic gains via compliance behavior take place is also presented.

KEYWORDS: Safety, Sustainability, Regulation, Public Policy Analysis, Disclosure

INTRODUCTION

Regulation is known to play a pivotal role in an individual firm's internalization of compliance norms and the terms of regulatory action (Parker, 2006). Regulation, by extension, often goes beyond legal mechanisms by incorporating surrounding economic, social, and political pressures, so it may not be as simple as just the imposition of obligations on private entities (Gunningham & Sinclair, 2017). Scholarly evidence indicates that those pressures on firms to comply with regulations regarding environment and safety have drawn much more public attention over the last few decades (Gunningham et al., 2003; Parker, 2006). In practice, government-level regulations intervene in many capital-intensive industries (Ouellette et al., 2010) with an aim to achieve a high degree of uniformity as well as intended consequences through regulatory enforcement. In this regard, as a well-known example, global aviation industry has adopted a variety of aviation regulations for the regional level harmonization and operational safety. However, since the introduction of the Airline Deregulation Act in 1978, in spite of the importance of regulatory action particularly regarding aviation safety and environment management, the impact of regulatory enforcement on compliance commitment has remained insufficiently explored.

Aviation safety has long been one of the top priorities in commercial aviation operations. Since the Airline Deregulation Act, commercial airline market has grown explosively in conjunction with an influx of new airline carriers and the restructuring of airline networks. However, despite the fact that fatal accidents that mainly come from airline operations are rare as compared to other modes of transportation, an unprecedented expansion in market size has resulted in greater exposure to potential risk (Chang & Yeh, 2004). One of the major causes of operational risk in the aviation industry relates to safety issues due to the lack of proper maintenance of airplanes (Braithwaite et al., 1998; Maurino, 1999; Mcdonald et al., 2000). As an example, on 8th June 1995, as soon as ValuJet DC-9 started to take off, the right engine exploded with a loud noise. Fortunately, there were no fatalities, but the accident came close to producing many victims. Based on the investigation, the National Transportation Safety Board concluded that the unexpected engine explosion was attributable to maintenance failure. In practice, it is estimated that 30 to 90 percent of accidents are rooted in human error and related maintenance failure (Shanmugam & Robert, 2015). Incidentally, the number of aviation maintenance technicians currently employed in the aviation industry is insufficient when compared with passenger miles flown (Latorella & Prabhu, 2000). In view of that, ensuring that the inspection and maintenance operations are well-staffed can mitigate operational risk stemming from human error and mechanical failure.

Regulations can provide impetus for incorporating appropriate safety measures. Several safety regulations have been established in the aviation industry. However, substantial variation in terms of demand, political environment, and aviation economics in different regions of the world makes it difficult to implement internationally integrated safety regulations. Nevertheless, there have been perceived needs for external congruence to ensure that common policy instruments are applied across nations (Pierre & Peters, 2009). Organizations such as the International Civil Aviation Organization (ICAO) and the European Union Aviation Safety Agency (EASA) have been set up to streamline safety relevant regulatory activities among member countries as well as to consistently manage multilateral aspects of aviation operations. Establishment of these global regulatory organizations responds to the call for globally integrated management of aviation safety by government bodies and cross-national organizations, but there is a lack of understanding regarding the effectiveness of regulations created by these organizations on the safety of civil aviation operations (McFadden & Hosmane, 2001). Furthermore, regulatory enforcement may not always go as planned because of penalties for noncompliance that are either sometimes so strong as to jeopardize the stability of firms or too feeble to deter their misbehavior, and this situation is often called deterrence trap (Coffee, 1981; Braithwaite, 2002). These variations in regulation could lead to contrasting results of compliance commitment in a different context (Adjerid et al., 2016; Ball et al., 2018), which further exacerbates appropriate interpretation of the impact of regulation.

Another important facet of the continuing effort by government, industry, and individual firms is to maintain the environment sustainable. One of major concerns in aviation is its impact stemming from harmful emissions and wastes on environment. However, due to the nature of corporate-level profit seeking activities, curbing environmental degradation may not be readily achieved (Gunningham et al., 1999). In particular, environmental regulation can cause the potential costs of complying with requirements that it imposes (Fiorino, 1996), and many of benefits through regulation is offset by unnecessarily high economic and social costs (Gunningham et al., 1999). Nonetheless, with more strict and well-specified environmental regulation, firms are incentivized to devise less polluting methods of operation and production (Zhuge et al., 2020). Given the rising volume of harmful emissions during flights and growing public awareness, it is inevitable for airlines to come up with a new plan to avoid a detrimental impact on the environment.

The Bilateral Aviation Safety Agreement between the United States of America and the European Union (hereafter referred to as “EU-USA BASA”) is one such regulation that was put in action in May 2011. The primary focus of the EU-USA BASA is on airline safety with a secondary focus on reducing environmental impact. Not only is the adoption of a regulation framework important, tracing compliance behavior after its adoption is crucial because it is relatively less visible to external monitoring (Chandler, 2014). From a perspective of both a regulatory authority and organizations that are subject to the regulatory requirements, whether such a bilateral regulation is helping in both complying with the requirements and achieving the desired outcomes is worth examining. This study considers the following research question to address this issue: *Does bilateral regulation such as EU-USA BASA positively impact the primary (safety) and secondary (reduced emissions) outcomes of interest?*

In addition to regulations, an organization's stance on corporate social responsibility (CSR) also influences its compliance behavior. Through disclosures, firms provide information about an organization's activities and future plans with regards to CSR (Meek et al., 1995; Rezaee & Tuo, 2017). Even so, while some firms are willing to report their sustainable operations and sometimes go beyond requirements, others hesitate to share internal proprietary information (Lang & Lundholm, 1993). Depending on the extent of a firm's willingness to report, it has been known that sustainability reporting is intrinsically intertwined with its performance (Ullmann, 1985; Pava & Krausz, 1996). Although sustainability disclosure may not always be in line with the objectives of its performance (Ullmann, 1985; Klassen & Mclaughlin, 1996), as another form of regulatory pressure, it helps business operations in several different ways by building public trust (Sodhi & Tang, 2019). In this study, we consider if an airline's action and intent on sustainability reporting to the public further strengthen their compliance behavior over and above that due to regulations. Specifically, we seek answer to the following research question: *Do organizations that provide corporate sustainability disclosures attain higher outcomes by complying with regulatory requirements?*

Based on the long-standing cooperation and the continued airworthiness facilitated by regulation, economic benefits through managing strategic factors in aviation operations are often acquired (Schefczyk, 1993). In this study, direct gains stemming from corporate compliance behavior can boil down to two points: safety compliance to aim for a higher safety level and the reduction in environmental impacts. According to the EU-USA BASA, its primary focus is to raise the level of airworthiness by means of environmental testing and monitoring of maintenance status. In other words, financial gains are not the one that the Agreement directly aims for. However, it has also been seen that regulation may have an impact on the corporate bottom line particularly in the context of the airline operations (Li et al., 2016; Ouellette et al., 2010; Sickles et al., 1986). Taken together, this study extends the research questions by incorporating the following inquiry: *Do organizations gain additional indirect benefits via corporate compliance behavior for the requirements of regulation?*

We draw upon institutional theory and voluntary disclosure theory (VDT) to guide our research. The institutional perspective primarily highlights that institutional environment serves a major role in constituting the organizational predispositions, such as structures, practices, and behaviors (Dimaggio & Powell, 1983; Delmas & Toffel, 2004; Shou et al., 2016; Wang et al., 2018). Regulations create an institutional environment that influences managerial decisions such that similar practices and structures are shared and established across organizations. As opposed to normative and cognitive pressure, regulatory pressure derived from regulation is, in particular, distinguished from the former, while related regulatory agencies tend to be more influential than other stakeholders in that they often carry a legal sanction (Kennedy & Fiss, 2009; Miller et al., 2020). We lean on the VDT to demonstrate the differential role played by organizational CSR disclosure. According to VDT, firms disclose information in an effort to showcase their performance and, thereby, not only reduce transaction and legal costs but also manage adverse selection (Lang & Lundholm, 1993; Lys et al., 2015; Rezaee & Tuo, 2017). Studies have also shown positive association between performance and discretionary disclosure (Clarkson et al., 2008), whereas legitimacy theory reverses the arguments of VDT to some extent by indicating that companies with poor performance would give more positive disclosure in their reports (Cho & Patten, 2007). We draw on VDT to examine the role played by corporate sustainability disclosures over and above the outcomes attained by regulatory compliance.

To answer our research questions, we collect data from multiple sources and collate an unbalanced panel data set for 32 airlines spanning 2007 to 2016. The results of difference-in-differences (DiD) analyses show that airlines do well on increasing the relative number of maintenance, repair and overhaul (MRO) workers and reducing environmental impact quantities after the enactment of EU-USA BASA. The results of difference-in-difference-in-differences (DDD) models also indicate that airlines disclosing corporate sustainability actions and outcomes still adhere to the terms of the Agreement by maintaining not only a higher level of the volume of maintenance workers but also reduced emissions level. To be more specific, our empirical findings reveal that airlines that come under the purview of the EU-USA BASA tend to proactively comply with the regulatory requirements by employing relatively more workers in the maintenance, overhaul and repair sector as well as by reducing total external cost on the direct environmental impacts, as opposed to other airlines that did not join the Agreement. To further investigate the impact of corporate environmental disclosure under regulation, reporting on their efforts into sustainability is additionally incorporated, suggesting that airlines that not only joined the Agreement but also disclosed their nonfinancial performance to the pubic outperform their competitors who did not engage in the reporting activity, in terms of MRO employment and the reduction in the environmental impacts. Last but not least, according to additional mediation analysis, our findings uncover the fact that regulatory compliance would bring unexpected benefits via corporate safety and environmental compliance. Even though a direct windfall gain of the implementation of regulation could not be found through mediation analysis, our empirical results suggest that complying with the terms as well as implementing the direction of the EU-USA BASA results in the reduction of operating expenditure during the period of investigation.

The rest of the manuscript is structured as follows. In the next section we present the contextual background, review related literature and develop our hypotheses. Section 3 presents our research design, including details on the empirical context, data, operationalization of variables, and estimation models. We present the results in section 4. In section 5, we discuss the implications of our findings and provide directions for future research.

BACKGROUND & HYPOTHESES DEVELOPMENT

Regulatory Context

The EU-USA BASA entered into force on May 1, 2011 (EASA, 2011b). The purposes of this agreement are:

> *(1) to enable the reciprocal acceptance of findings of compliance and approvals issued by the Technical Agents and Aviation Authorities*[1]*, (2) to promote a high degree of safety in air transport, and (3) to ensure the continuation of the high level of regulatory cooperation and harmonization between the United States and the European Community (EASA, 2011a).*

The EU-USA BASA requires the executive management to ensure the effective execution and evaluation of the Agreement on a regular basis under the supervision of a Bilateral Oversight Board. The Agreement is exclusively limited to the EU member states and the US (EASA, 2011b). In order to achieve the objectives specified in the Agreement and its annexes, the Federal Aviation Administration (FAA) and European Union Aviation Safety Agency (EASA) prepared technical implementation procedures (TIP) for airworthiness and environmental certification, and the maintenance annex guidance (MAG) for maintenance (EASA, 2011b). As part of the Joint Maintenance

[1]"Aviation Authority" means a responsible government agency or entity of a European Union Member State that exercises legal oversight on behalf of the European Community over regulated entities and determines their compliance with applicable standards, regulations, and other requirements within the jurisdiction of the European Community (EASA, 2011a)

Coordination Board (JMCB) meetings, EU community and the US are obligated not only to review the progress on compliance requirements, such as certification of airworthiness, contracted maintenance, human factors training, quality monitoring system, but also to suggest changes to the MAG.

In addition, according to the territorial applicability in Article 12 of the EU-USA BASA, the Agreement shall apply:

> *"[...] to the United States civil aviation regulatory system as applied in the territory of the United States of America, and on the other hand, to the European Community civil aviation regulatory system as applied in the territories in which the Treaty establishing the European Community is applied [...] (EASA, 2011a)"*

Hence, governments and airline companies in two different geographical regions (i.e, EU and USA) turn their attention to collective efforts for making their standards consistent with regulatory initiatives specified in the EU-USA BASA. By doing so, they can expect to enhance the degree of airline operational safety and to reduce the duplication of assessment. For the purpose of our study, the intervention created by the EU-USA BASA divides the considered time frame into two parts. As shown in Figure 1, the first time frame represents the pre-regulation period (years between 2007 and 2010), whereas the second time frame represents the post-regulation period (years between 2011 and 2016) in which the enforcement of the EU-USA BASA is taken into consideration.

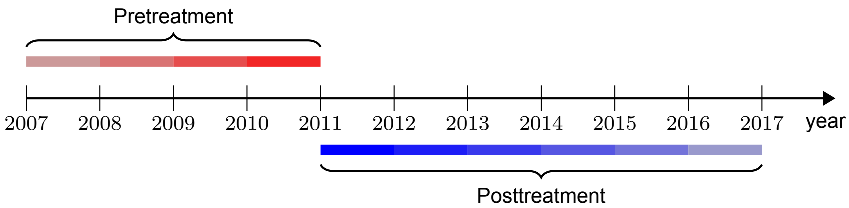

Figure 1: Timeline of Before and After the EU-USA BASA

Operational Coordination and Compliance Behavior

One of the widely-known regulatory frameworks to improve a firm's compliance commitment is responsive regulation. As opposed to simple deterrence that levies on penalties for noncompliance, responsive regulation guides a firm's moral commitment to compliance with regulation based on both cooperative and punitive manners (Ayres & Braithwaite, 1992; Parker, 2006). In practice, implementing a mixed regulatory strategy improves corporate compliance commitment to regulation (Parker, 2006), and scholarly evidence also shows that the responsive regulatory approach works well in a variety of contexts by encompassing different levels of players and regulatory mechanisms (Gunningham & Sinclair, 2017).

However, regulatory enforcement may not always go as planned and often fail to end up with beneficial outcomes. With regard to this, there has been extensive literature that shows a tension between complying to regulation and the ability of firms to maintain performance levels in a different research context, such as retail sector (Quak & De Koster, 2007), labor economics (Haltiwanger et al., 2014) and healthcare (Adjerid et al., 2016). Nonetheless, the impact of regulatory enforcement on a firm's compliance behavior that leads to intended consequences can be also found in the airline industry (Bernardo & Fageda, 2017). As far as the complex nature of corporate compliance with regulation, its mechanisms and even expected impacts are concerned, the EU-USA

BASA that takes both supportive and rigorous measures seems a good exemplar to examine a firm's compliance behavior by coordinating safety and environmental purpose all at once. In practice, firms collectively comply with shared instruments and common goals imposed by regulatory enforcement, which often results in intended and even desirable consequences (Lo et al., 2014; Scott et al., 2021). Corporations develop compliance mechanisms under different regulatory environments so as to continue their operations and remain competitive in the market (Reger et al., 1992). In this section, we aim to examine the impact of regulatory actions on corporate compliance behavior and how regulatory authorities coordinate business operations specified in the terms of the Agreement for the purpose of achieving common objectives.

Safety

Aviation safety has been part of several research investigations. In this stream of research, authors often gauge the levels of aviation safety and the way companies deal with issues caused by the failure of aviation safety (i.e., service failure) based on measures like aircraft accident rate, fatal crash (Barnett et al., 1979; Barnett & Higgins, 1989), and on-time performance (Siegmund, 1990; Mellat-Parast et al., 2015). However, since safety measures tend to be context-dependent and take ex post operational consequences into account, there is no universal consensus regarding safety indicators in the civil aircraft industry (Chang & Yeh, 2004). In an effort to categorize and identify causes of safety failure and safety-relevant factors, past research has explored measures that could be used for analysis and evaluation. For example, accident-related measures have been widely used in the passenger aviation industry, and given that airplane accidents are often caused by human errors, such as maintenance and inspection failures, there have been several studies that focus on human factors (Gramopadhye & Drury, 2000; Chang & Wang, 2010; Shanmugam & Robert, 2015). In general, safety-related accidents are expected to be reduced when a firm cares about maintenance activities. From a business viewpoint, one way that organizations strengthen their maintenance operations is by ensuring a strong maintenance, repair and overhaul team that plays a pivotal role in inspection, quality control, production planning and control, and hangar and line maintenance (IATA, 2017). Given that prior studies have considered maintenance-related factors, including maintenance personnel, as part of investigations on aviation safety (Chang & Yeh, 2004; Liou et al., 2007; Cui & Li, 2015; Barak & Dahooei, 2018), it is meaningful to see a firm's substantive response to civil aviation safety regulation. In this regard, aviation safety depends on how airlines manage their maintenance operations. The EU-USA BASA also gives prominence to maintenance and defines it as:

> *'Maintenance' means the performance of any one or more of the following actions: inspection, overhaul, repair, preservation, or the replacement of parts, materials, appliances, or components of a civil aeronautical product*[2] *to assure the continued airworthiness of such a product; or the installation of previously approved alterations or modifications carried out in accordance with requirements established by the appropriate Technical Agent*[3] (EASA, 2011a).

Within the aviation sector, the number of MRO technicians managing an airline's fleet could help mitigate airline safety issues. Even though the quality of MRO work is vital in determining the

[2] 'Civil aeronautical product' means any civil aircraft, aircraft engine, or propeller, or appliance, part, or component to be installed thereon.

[3] 'Technical Agent' means, for the United States, the Federal Aviation Administration (FAA); and for the European Community, the European Aviation Safety Agency (EASA)

potential safety risk and service quality, airlines often outsource a portion of maintenance manpower to outside MRO service providers either within a national border or sometimes overseas markets (United States General Accounting Office, 1998). Nonetheless, contracting out a key element of business operations is risky in that it is hard to monitor and control them (Rieple & Helm, 2008; United States General Accounting Office, 1998). Hence, we posit that airlines that have their own maintenance work force would be in a better position to enhance aviation safety owing to the visibility of work and inspection. According to the EU-USA BASA, the two parties involved in the Agreement are also required to assess each other's standards and systems relating to the approval of repair stations and maintenance organizations that perform maintenance on civil aeronautical products (EASA, 2011a). Given the importance of skilled MRO technicians as well as a need for more proactive involvement in safety regulatory actions, we expect that civil aviation service providers under the influence of the EU-USA BASA will undergo a transformation particularly in the MRO sector by owning a higher level of the MRO staff. Specifically, in an effort to abide by the provisions of a new safety regulation, the administrative change facilitated by the EU-USA BASA will lead to a relative increase in the number of MRO staff in airlines that come under the purview of this regulation as compared to those that are not part of it. Thus, we hypothesize:

> *Hypothesis 1 (H1) Airlines that come under the purview of the EU-USA BASA will expand their direct employment of MRO technicians, as opposed to airlines that are not affected by the EU-USA BASA.*

Environmental Stewardship

Environmental issues have drawn corporate attention to the need for considering sustainability in organizational actions. Although managers occasionally take account of environmental management as a means of compliance with relevant regulations (Klassen & Mclaughlin, 1996), due to growing government pressure and changes in customer demand and environmental regulation surrounding firms, organizations have developed their own environmental policies that are consistent with a newly introduced regulation (Rondinelli & Vastag, 1996; Sroufe, 2003). In addition, waste has become recognized as something that should be minimized or removed (Sroufe, 2003), while firms have also become focused on CSR performance (Wood, 1991; Pava & Krausz, 1996; Sroufe, 2003).

This increasing trend in environmental regulation and its regulatory compliance by firms can be also observed in the aviation industry. Since the airline industry is highly competitive and firms unevenly adopt environmental standards, airlines are even willing to take more stringent environment standards as long as they do not have negative impacts on safety, environmental benefits along with economic feasibility (Lynes & Dredge, 2006). With this rising trend of regulation and public awareness of environmental problems, airlines try out various approaches to adequately address environmental issues (Lynes & Dredge, 2006; Hagmann et al., 2015). With a view to being more environmentally friendly, the airline industry has been stimulated not only by internal motivations (e.g., economic benefits and an improvement in the public image) but also by external pressures (e.g., new policies and regulations) (Lynes & Dredge, 2006; Hagmann et al., 2015).

According to the announcement of International Air Transport Association (IATA), in 2019, civil aviation accounts for a little more than 2% of man-made annual carbon emission. In response to overall negative effect of aviation operations on the environment, companies in the industry attempt to lessen the industry-wide air pollution. To meet the industry needs, the scope of cooperation under the EU-USA BASA also incorporates environmental testing as well as environmental certification. In particular, the terms of the EU-USA BASA define environmental approval and testing in detail as below:

> *'Environmental approval' means a finding that the design or change to a design of a civil aeronautical product meets applicable standards concerning noise, fuel venting or exhaust emissions (EASA, 2011a).*
> *'Environmental testing' means a process by which the design or change to a design of a civil aeronautical product is evaluated for compliance with applicable standards and procedures concerning noise, fuel venting or exhaust emissions (EASA, 2011a).*

Social and cultural pressure for safety and environmental issues accommodates additional interests in environmental regulation to control negative externalities (Kleindorfer et al., 2005). The Agreement aims to improve transatlantic cooperation not only in civil aviation safety but also in environmental testing and approvals (EASA, 2011a), while the EU and USA are responsible for ensuring the effective functioning of the EU-USA BASA via continuous communication and mutual trust. In this regard, we propose the following hypothesis:

> *Hypothesis 2 (H2) Airlines that come under the purview of the EU-USA BASA will reduce the external cost of direct pollutants released to air, as opposed to airlines that are not affected by the EU-USA BASA.*

Sustainability Reporting

With an increasing demand for the consistent evaluation and comparability of corporate performance, multinational corporations nowadays have become more engaged in public awareness through reporting activity. Nonetheless, it is still limited not only to the corporate bottom line but also to a certain business context. In this section, through the review of voluminous literature, we aim to develop hypotheses about the impact of corporate sustainability disclosure under regulation.

A positive relationship between more extensive disclosure of environmental information and environmental performance has been presented in previous literature (Al-Tuwaijri et al., 2004; Clarkson et al., 2008). In line with the good news explanation of discretionary disclosure theory, Al-Tuwaijri et al. (2004) highlighted that high performers are more likely to disclose pollution-related environmental information, compared with poor performers. This finding implies that firms utilize the environmental disclosure as a way of communicating with market participants by providing forthright environment-related information and by setting a rational lower bound for future reference (Al-Tuwaijri et al., 2004). As opposed to socio-political theories that insist on a negative association between them, such as political economy, legitimacy theory, and stakeholder theory (Patten, 2002), VDT (Dye, 1985; Verrecchia, 1983) predicts that higher performers appear to be more involved in discretionary disclosure channels (Clarkson et al., 2008). It was also shown that firms that aim to proactively disclose environmental and social performance tend to achieve higher market value (Qiu et al., 2016). Consistent with Verrecchia (1983), Qiu et al. (2016) also showed that firms that extensively commit to employees and other stakeholders (i.e., social disclosure) are able to yield a positive growth rate of their future cash flows due to investors' favorable expectations. Thus, in compliance with the logic of VDT along with signaling theory in some degree, the positive association between voluntary non-financial disclosure and corporate sustainability performance has been highlighted to show the underlying reasoning behind the stronger efforts of superior performers in their voluntary disclosure (Clarkson et al., 2008; Hummel & Schlick, 2016; Rezaee & Tuo, 2017).

From a business standpoint, an association between the motivation for corporate disclosure with the intention of reducing transaction costs and adverse selection and diverse firm characteristics, such as performance, information asymmetry, and disclosure costs, has been studied

(Lang & Lundholm, 1993). As a means for communicating with stakeholders and contributing to the higher business competitiveness, the essence of CSR reporting consists in the management of social responsibility and the description of corporate CSR performance (Moravcikova et al., 2015). When it comes to the relationship between CSR disclosure and corporate economic performance, companies in a poor performance group often have stronger incentives to disclose their positive outcomes so as to safeguard their legitimacy (Cho & Patten, 2007; Patten, 2002), while voluntary environmental disclosure is, in general, expected to be higher for firms within environmentally sensitive industries (Cho & Patten, 2007).

Since this study aims to see how airlines under the purview of the EU-USA BASA comply with it by adjusting their operational compliance behavior, it is worthwhile to investigate sustainability disclosures under the context of regulation. As a form of self-regulation, CSR is often perceived in connection with a compliance issue (Perry et al., 2015). In this sense, Gond et al. (2011) examined the relationship between CSR as a form of privatized governance by incorporating government as another independent actor in CSR. The study demonstrated that partnering with government on CSR helps in combining resources and objectives of corporations and governments. On the other hand, if CSR is viewed as a form of governance mechanism, companies might contribute to social benefits and have control over their own business activities in lieu of government (Gond et al., 2011). Moreover, firms that extensively report environmental performance as part of their disclosure tend to experience less negative market reaction, which could lower overall regulatory costs for proposed or enacted government regulations (Blacconiere & Patten, 1994). Nonetheless, there have also been studies that showed the contrasting results by highlighting the relationship between the level of disclosure under a either regulated or unregulated environment and environmental performance (Delgado-Márquez & Pedauga, 2017; Delgado-Márquez et al., 2017). Based on an investigation of related study literature in conjunction with the logic of VDT, in order to examine the effect of sustainability reporting on corporate compliance behavior under a certain regulatory framework, we further develop hypotheses that airlines that disclosed their corporate sustainability performance while operating under related regulation are expected to continuously maintain higher safety and environmental performance as below:

Hypothesis 3A (H3A) Airlines that not only are under the purview of the EU-USA BASA but also extensively report their corporate sustainability performance have higher direct employment of MRO technicians than their counterparts.

Hypothesis 3B (H3B) Airlines that not only are under the purview of the EU-USA BASA but also extensively report their corporate sustainability performance have lower the external cost of direct pollutants released to air than their counterparts.

The Mediating Effect of Safety and Environmental Stewardship

One of the major objectives of the EU-USA BASA is to ensure the continued airworthiness, building upon the long-standing cooperative relationship between the two involved parties. Above and beyond that, all parties involved are simultaneously expected to minimize overall economic burden on operators by sorting out redundant regulatory oversight and promoting a uniform high level of safety (EASA, 2011a). By complying to service conditions within the scope of the EU-USA BASA, the Agreement will also help set limitations on the regulatory duplication of assessments, inspections, tests, and controls to regulatory differences (EASA, 2011b).

Previous literature has shown economic benefits via the adjustment of business activities concerning airline operations. Schefczyk (1993) evaluated operational performance of global major airlines to provide an insight on the relative operational efficiency of those airlines. This study clearly showed how strategic factors targeted by well utilized passenger-focused airlines, such as high operational efficiency and passenger load factors, lead to higher profitability. Consistent with this study, the economic impact of various Bilateral Aviation Safety Agreements (BASAs) was evaluated, notably on aviation repair stations recognized by aviation authorities situated outside the repair station's country. BASAs, in general, eliminate regulatory barriers by allowing domestic aviation authorities to conduct audits and report results on behalf of foreign authorities (AeroStrategy, 2011). To be specific, the economic benefits of implementing BASAs appear to be visible because aviation repair shops in the United States pay a lot less for certification from countries under the purview of BASAs with the United States, but all inclusive expenditures for getting certification by regions/countries without a BASA are relatively high, as opposed to the revenues that it generates (AeroStrategy, 2011). Apart from these studies, there has been prior research on how regulatory action within the context of airline operations exercises influence on a firm's financial performance (Li et al., 2016; Ouellette et al., 2010; Sickles et al., 1986).

To further support the mediating effect of the EU-USA BASA on corporate economic benefits via adjusting firm-level safety, the role of maintenance, repair, and overhaul task on financial performance should be also examined. The first point to make is that there is at least a substantive relationship between an airline's financial stability and operational safety (or regulatory compliance) or between several measures for economic performance in airline operations and the level of maintenance (Chang & Yeh, 2004; Rose, 1990; United States General Accounting Office, 1998). That is to say, it is evidently said that profitability is intertwined with various operational performance measures, including airline safety (Raghavan & Rhoades, 2005; Rose, 1990; Suzuki, 1998). Raghavan & Rhoades (2005) suggested that there is an inverse relationship between the level of airline safety (i.e., accident rates) and operating profitability. In addition, Rose (1990) found that higher operating profit margin is associated with the reduction in airline incident rates. Even so, in both studies, while the profitability-safety link seems strongest especially for smaller regional air carriers due to the degree of discretion in safety investment, it does not necessarily mean that legacy carriers are free from considering the profitability-safety link. Similarly, a link between profitability and maintenance policy (or maintenance performance) has also been examined in different research contexts (Alsyouf, 2007; Komonen, 2002). All things taken together, we posit that:

> *Hypothesis 4A (H4A): The relationship between the implementation of the EU-USA BASA and economic performance is mediated by corporate safety compliance.*

Although previous studies acknowledged the costs of compliance and its detrimental effects (Hart & Ahuja, 1996; Kroes et al., 2012; Porter & Linde, 1995), they also showed that firms could derive secondary tangible and intangible benefits from environmental betterment in various ways (Hart & Ahuja, 1996; Klassen & Mclaughlin, 1996; Porter & Linde, 1995; Russo & Fouts, 1997). In particular, Klassen & Mclaughlin (1996) demonstrated that environmental performance has a beneficial influence on a firm's financial performance via either market revenue gains or cost savings. In line with Klassen & Mclaughlin (1996), a phrase that 'it pays to be green' was often reaffirmed through an emphasis on the positive relationship between corporate environmental initiatives to reduce an adverse effect on the environment and profitability (Hart & Ahuja, 1996; Russo & Fouts, 1997). Even so, the EU-USA BASA is meant to be focused on airworthiness only via environmental friendly operations in lieu of directly seeking profit maximization. At the same time, given the literature review, pollution prevention has a favorable effect on corporate financial performance, especially on the expense side of the ledger. Thus, consistent with the previous work and the focus of the regulatory requirements of the EU-USA BASA, we hypothesize:

Hypothesis 4B (H4B): The relationship between the implementation of the EU-USA BASA and economic performance is mediated by corporate environmental compliance.

Figure 2 presents the conceptual framework that illustrates the proposed relationships between the EU-USA BASA and safety (i.e., a_1 which represents H1) and environmental compliance (i.e., a_2 which represents H2) and dual mediation (i.e., a_1, b_1, a_2, and b_2 which respectively represent H4A and H4B). Moreover, the additional impact of corporate sustainability reporting on the main analyses (i.e., d_1 and d_2 which respectively represent H3A and H3B) is provided.

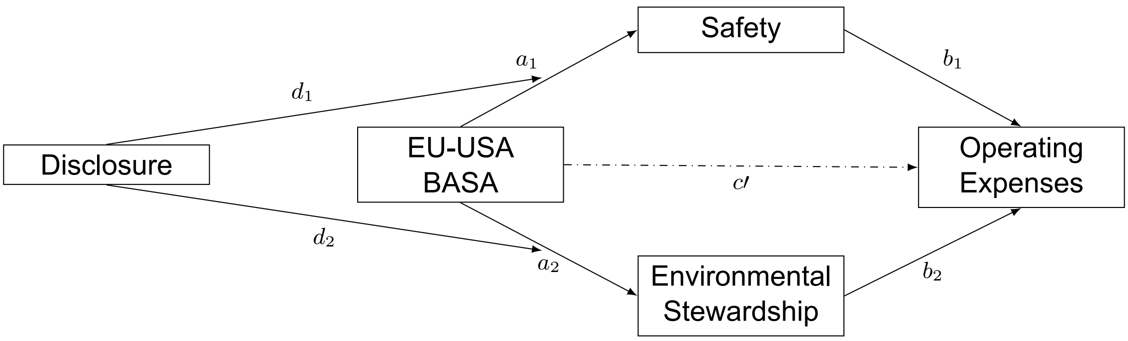

Figure 2: Conceptual Framework

RESEARCH DESIGN

Data

Data Collection

In this study, we examine the impact of regulatory enforcement along with sustainability reporting based on secondary data. Data used for our analysis mainly come from two major data streams along with some backup sources, including each airline's websites and additional information on aircraft specifications via reports published by aircraft manufacturers for the purpose of investor relations. The first data set includes World Air Transport Statistics (WATS) produced by IATA, which has gathered and offered statistics on passenger and freight traffic, fleet, employee numbers and high-level financials that are aggregated at both the industry level and the airline level on a yearly basis. Furthermore, environmental data we tap into are mainly obtained from a Trucost database which includes, but not limited to, its original sources of data from company annual reports, scientific literature, and direct disclosures.

Since our empirical analysis is conducted at the firm level as well as we select the global airline industry as our main focus, the unit of analysis is international air traffic service providers (i.e., airlines). Fortunately, the two main data sets are composed of firm level statistics with the industry-wide summaries. In accordance with International Securities Identification Number (ISIN) and IATA codes, we combine the two data sets with supplementary data on detailed information on aircraft and create a data set of 32 global airlines. Depending on the territorial applicability in Article 12 of the EU-USA BASA, 32 airline samples are collectively divided into 2 separate groups. Airlines whose headquarters reside in the areas given in the conditions of the territorial applicability are deemed as a treatment group, whereas other remaining airlines that deviate from the territorial applicability condition are treated as a control group, assuming that airlines in a control group are unaffected by the Agreement at all. When it comes to geographical regions, our data comprehensively contain North America, Central America, South America, Europe, Middle East, Africa, Asia, and Southwest Pacific regions.

As stated previously, on May 1 2011, the EU-USA BASA came into force. However, since we use annual firm level data, we measure its initial impact of the EU-USA BASA from 2011. With this year as a starting point of the intervention, we confine the period of interest to some degree. In other words, the period covers 4 years prior to the treatment and 6 years after the implementation of the EU-USA BASA, so, as a result, our panel data span from 2007 to 2016. In this regard, since we have yearly data across 32 global airlines from 2007 to 2016, theoretically, our final sample should contain 320 observations. However, due to the lack of available disclosed data which are not in both data sets all at once, the final sample data set is not perfectly balanced over the years and firms. Therefore, our final sample is an unbalanced panel of 202 annual observations.

Dependent Variables

To investigate the impact of the EU-USA BASA on aviation safety, we use information on the aircraft engineering, maintenance, overhaul and repair personnel (hereinafter called "MRO_{it}") (Cui & Li, 2015), including corresponding administration, accounting, time-keeping, stores, planning, training and inspection staff, as our dependent variable (IATA, 2017). To be more specific, employees in this category are in charge of the following activities—including, but not limited to, technical management, inspection and quality control, technical engineering, production planning and control, and hangar and line maintenance (IATA, 2017). All personnel data used in this section and the subsequent sections, including MRO technicians and employees allocated to other categories (i.e., pilots, cockpit, cabin attendants, etc.), are collected at December 31 of the relevant year.

To examine environmental performance, we utilize the direct amount of pollutants released to air by the consumption of fossil fuels and production processes which are owned or controlled by the company (Source: Trucost). Since the EU-USA BASA requires airlines to engage in environmental approval and testing of their civil aeronautical products with an aim to reduce fuel venting or exhaust emissions, using the direct air pollutant quantities (hereinafter called "APD_{it}") appears to be valid. In addition, according to data description, monetary values are applied to the direct amount of air pollutants to measure their global average damage. Regarding the use of the given environmental data, according to the European Aviation Environmental Report published by EASA, particulate matter, nitrogen oxides and ground-level ozone not only play a significant role in air pollution but also have impacted the health of the European urban population. By extension, EASA highlighted that similar emissions to other sources of fossil fuel combustion, including but not limited to nitrogen oxides, particulate matter, sulphur dioxide and carbon monoxide, all of which are included in the air pollutants criteria, are produced by aircraft engines.

Last but not least, to test the mediation effects of the EU-USA BASA via aviation safety and corporate environmental stewardship, we use one of annual corporate financial outcomes provided by IATA. According to the annual air transport statistics provided by IATA, total yearly operating expenses (hereinafter called "OE_{it}") are operationalized by direct and indirect expenses incurred in operating scheduled and charter flights and providing services to third parties (IATA, 2017), and the operating expenditure is used in a dual mediation analysis.

Explanatory Variables

Our focus of this study is to examine how airlines within a treatment group behave differently when external intervention comes into play. To measure the impact, a primary indicator variable that represents a treated group under the influence of external intervention together with another dummy variable that denotes whether observations correspond with the post-treatment period should be respectively incorporated in our empirical models. Then, as our variable of interest to measure the effects of difference-in-differences, an interaction between the two indicator variables should be taken into consideration. In total, there should be two respective binary variables with one interaction term constructed by their combination as main explanatory variables. In brief, the indicator variables can be shown as follows:

$$BASA_i = \begin{cases} 1, & \text{if i = an air carrier within the territorial applicability of the EU-USA BASA} \\ 0, & \text{otherwise} \end{cases}$$

$$POST_t = \begin{cases} 1, & \text{if } t > 2010 \\ 0, & \text{otherwise} \end{cases}$$

To estimate the impact between before and after the introduction of the EU-USA BASA, the interaction term between $BASA_i$ and $POST_t$, $BASA_i * POST_t$, should be included in our empirical model. $BASA_i * POST_t$ indicates a binary variable that has only two values 1 (a treatment group after the enforcement of the EU-USA BASA) and 0 (otherwise) in our research setting, and its estimated coefficient is of our primary interest in difference-in-differences estimation.

With the difference-in-differences model specification, we also aim to expand this simple causal estimation by incorporating an additional indicator variable. Based on a study conducted by the Governance & Accountability Institute as to the top 10 Global Reporting Initiative (GRI) aspects in the aviation sector, we particularly focus on disclosures of the environmental aspect that reflects on emissions, effluents and waste. Given limited data availability, if an airline company simultaneously discloses carbon dioxide emissions and waste disposal data in any specific fiscal year, the company is determined to be the one that reports sustainability performance to the public. Consistent with $BASA_i * POST_t$, EVD_{it} (i.e., a variable that presents the level of a firm's environmental disclosure) has two values depending on corporate environmental disclosure. Its triple interaction term along with each indicator variable for the treatment and a binary variable for the identification of the time period will be also added into triple difference estimation models.

Control Variables

For the purpose of alleviating potential confounding effects and reducing unobserved impacts on dependent variables, a set of variables that reflect a few characteristics of air traffic service providers, including aircraft specifications and airlines' operational activity and the size of a firm, should be controlled for in the model. Accordingly, these time-variant control variables may explain some factors that vary across airlines.

Given that control variables are to help models to lessen unnecessary effects, variables regarding the specifications of aircraft usage control for the undesirable effects that come from the different composition of aircraft models across airlines. First, PH_{it} refers to the proportion of heavy flights, which is computed as:

$$PH_{it}(\%) = \frac{\text{Total number of heavy flight models}}{\text{Total number of different aircraft models}} \times 100$$

The computed values of PH_{it} must lie between 0% and 100%. In this study, whether a specific model is classified as a heavy flight is determined in reference to aircraft radii. This variable is particularly appropriate in that information on airlines' route and flight distance is known to be relevant to fuel usage and maintenance costs (Daft & Albers, 2012; Wensveen & Leick, 2009). Consistent with this study, aircraft size is often used as a controlled factor to assess CO_2 emissions intensity in an empirical analysis (Yamaguchi, 2010). This classification of commercial flight models could also provide an insight into the flight length of aircraft models in which there are three categories: long-, medium- or short-haul. However, because both imply similar information, we only keep PH_{it} to evade a potential multicollinearity issue. Also, PP_{it} denotes the proportion of passenger flight models in service, which is adopted as another control variable (Cui & Li, 2015). In general, aircraft in service is used for two distinct purposes, freight and passenger service, both of which are the main source of the basic revenues of airlines (Daft & Albers, 2012). Hence, this passenger aircraft model control is also informative in that airline operations may vary depending on how differently airlines use their aircraft in service. This second control variable is calculated by relying on the equation below:

$$PP_{it}(\%) = \frac{\text{Total number of passenger aircraft models}}{\text{Total number of different aircraft models}} \times 100$$

As a third control variable expressed in percentage terms, $PKFI_{it}$ is also applied to control for the effects that derive from the gap between domestic market-focused and international market-based air service. The international air travel is known to be associated with the level of aviation safety (Barnett & Higgins, 1989) and, by extension, safety and energy efficiency along with airline network structure as an influencing factor have a decisive effect on overall airline efficiency (Li et al., 2016). This control variable is also restricted below 100% and computed as follows:

$$PKFI_{it}(\%) = \frac{\text{Total kilometers flown (International)}}{\text{Total kilometers flown (International + Domestic)}} \times 100$$

When it comes to control variables for airlines' operational performance, average flight utilization is another control variable in our model estimation. In fact, due to tight scheduling requirements, how intensively aircraft is being used in aviation operations relates to maintenance functions (Cui & Li, 2015; United States General Accounting Office, 1998). According to the WATS report, utilization is defined as the average block time flown with respect to hours and minutes per aircraft per day (IATA, 2017). With this in mind, we come up with a control variable that represents average flight utilization, and this variable can be calculated as below:

$$AvgUT_{it}(hours:mins) = \frac{\text{Total amount of daily aircraft utilization across all models in service}}{\text{Total number of aircraft}}$$

To be specific, based on the given statistics in WATS, we calculate this variable according to the above equation. In the initial data set, average daily aircraft utilization (HH:MM) by aircraft model, its status (owned or leased), and the number of its corresponding aircraft models were given in conjunction with the name of a specific model. By inclusively utilizing the degree to which aircraft is being used, this control variable takes into account how much airlines are willing to operate their tangible assets in an efficient manner. Instead of directly using the given data (i.e., average daily aircraft utilization of a specific aircraft model with the number of respective aircraft models) which are subject to a specific aircraft model, we formulate a new variable across all used aircraft models in service by airlines to give more weight to a certain model that is more frequently used over the other models. Along with the variable that represents airlines' operational efficiency, traffic performance data, including the number of passengers carried (SPAXTS) (Cui & Li, 2015) and passenger load factor (SPLFTS) (Ouellette et al., 2005; Yamaguchi, 2010), are collected in a given year. These two control variables can be easily drawn from the initial data set, and the latter variable expressed in percentage terms can be also computed based on the following equation:

		Treatment Group		Control Group	
Variable	Window	Mean	Std. dev.	Mean	Std. dev.
ln(MRO)	Before-Treatment	8.407	1.644	7.382	1.155
ln(APD)		4.346	0.776	1.564	1.724
ln(OE)		16.768	0.755	15.352	0.768
PH (%)		37.149	16.525	58.795	28.244
PP (%)		96.224	4.483	90.668	8.487
PKFI (%)		72.242	21.601	68.513	33.384
SPLFTS (%)		78.489	3.525	75.827	4.851
ln(AvgUT)		2.148	0.175	2.363	0.160
ln(SPAXTS)		17.669	0.472	16.835	0.685
ln(TE)		10.674	0.940	9.555	0.493
ln(MRO)	After-Treatment	8.615	1.163	7.090	1.365
ln(APD)		3.696	1.837	2.518	1.661
ln(OE)		16.689	0.881	15.543	0.661
PH (%)		37.101	19.591	56.402	27.353
PP (%)		97.001	4.895	90.199	9.652
PKFI (%)		55.575	28.431	66.500	31.478
SPLFTS (%)		81.668	3.944	78.098	4.537
ln(AvgUT)		2.190	0.222	2.313	0.215
ln(SPAXTS)		17.904	0.608	17.034	0.651
ln(TE)		10.776	0.883	9.663	0.627

Table 1: Summary Statistics by Time Period and Treatment

$$SPLFTS_{it}(\%) = \frac{\text{Passenger-Kilometres Flown (thousands)}}{\text{Available Seat-Kilometres (thousands)}} \times 100$$

Both firm-level control variables also mirror airlines' operational activities and their annual business performance, which are all evidently related to our response variables in the sense that it is meaningful to consider operational sides when we examine operational performance of airlines and the degree of compliance. In addition, it is crucial to control for the relative firm size effects. We use the total number of employees in any given year. Regarding the firm size control, the level of external pressure is relevant to the size of firms because smaller firms tend to be more sensitive to external pressure (Adhikary et al., 2020). A firm size control may be also useful when employees' willingness to invest in firm-specific human capital is under consideration. Depending on the market in which firms are engaged and the size of firms, their willingness would vary. Judging from this, instead of relying on financial measures like total revenue as a firm-size control, using the number of employees fits better in this study (Wang et al., 2009). To sum up, depending on whether a firm is treated across two predetermined periods, summary statistics of all of the key variables are reported in Table 1. In addition, Table 2 also reports correlations between the key variables used in our estimation.

Model and Estimation

Parallel Trends Assumption and Difference-in-Differences (DiD) Estimation

	1	2	3	4	5	6	7	8	9	10
1. ln(MRO)	1.0000									
2. ln(APD)	0.3840*	1.0000								
3. ln(OE)	0.5998*	0.6581*	1.0000							
4. PH	−0.0861	0.1406*	0.2507*	1.0000						
5. PP	0.2511*	0.0423	−0.0927	−0.5462*	1.0000					
6. PKFI	−0.3045*	0.0504	0.0427	0.5140*	−0.4513*	1.0000				
7. SPLFTS	0.1393	0.2361*	0.2736*	0.0134	0.0018	−0.1248	1.0000			
8. ln(AvgUT)	−0.0918	−0.1605*	−0.2908*	0.2374*	−0.3333*	0.3181*	0.1783*	1.0000		
9. ln(SPAXTS)	0.6175*	0.4449*	0.8146*	−0.1629*	0.1729*	−0.5337*	0.1752*	−0.2870*	1.0000	
10. ln(TE)	0.7894*	0.5661*	0.9082*	0.0470	0.0994	−0.1431*	0.3237*	−0.1251	0.7831*	1.0000

Note: *p<0.05

Table 2: Correlation Matrix

In this study, we adopt a DiD method to estimate how treated airlines behave and perform differently as opposed to untreated airlines during the post-treatment period. To test causal effects of a treatment, a DiD as a causal inference technique is widely used. In a DiD setup, as an underlying identification assumption, parallel trends assumption should be examined to see whether the difference between the treated and untreated groups would have stayed stable without the presence of the treatment effect (Angrist & Pischke, 2009; Alonso & Andrews, 2019; Scott et al., 2021). Its canonical format has only two time periods and two different groups, one of which is treated in the post-treatment period (Callaway & Sant'Anna, 2021; Goodman-Bacon, 2021). Accordingly, a DiD method can serve useful purpose for treating one group only and identifying different trends in outcomes across two time periods. With this basic setup, the parallel trends assumption is referred to as an assumption regarding the change in no-treatment counterfactual (unobservable) outcome across the two time periods, and the parallel trends assumption deems that the change is the same between the treated and untreated. However, for the treated, since identifying the counterfactual is literally unable, the parallel trends assumption cannot be easily verified. At the same time, we have multiple time periods which are by far more than those of the canonical format. As a statistical assessment for the parallel trends assumption, we implemented a test method proposed by Callaway & Sant'Anna (2021). According to the computed test statistics, the parallel trends assumption holds for all before treatment across different causal inference models intended for hypothesis testing. To be specific, under the null hypothesis of the parallel trends assumption that holds in multiple pre-treatment time periods, pre-treatment estimates can be used to pre-test the parallel trends assumption by showing that these should equal to 0 (Callaway & Sant'Anna, 2021). Across our DiD estimation models for testing safety and environmental stewardship, we fail to reject the null hypotheses of the parallel trends assumption with p-values 0.18 and 0.25, respectively, indicating that the parallel trends assumption using pre-treatment estimates is satisfied.

Our study aims to estimate the impact of regulatory action on two different dependent variables and compare outcomes of the ones subject to the regulation with those of remaining airlines. In this regard, Akturk et al. (2018) suggested that a simple approach may not be suitable for examining the impact of a policy intervention on different outcomes between before and after the intervention due to endogeneity and impacts from other unobserved factors. In fact, DiD estimation is useful in that it may circumvent a great deal of potential endogeneity that might happen due to the comparison between heterogeneous individuals (Bertrand et al., 2004). To further alleviate these concerns, a DiD method can be used in this study. Nonetheless, addressing endogeneity in empirical studies is the current touchstone to substantiate statistical inference and get proper estimates (Ketokivi & McIntosh, 2017; Miller et al., 2021; Busenbark et al., 2022). Regarding endogeneity in this research setting, Bun & Harrison (2019) specifically discussed the interaction between two variables in which one variable is exogenous and the other one is endogenous, which may also end up being an endogenous regressor. To correct for the potential endogeneity due to the endogenous variables, including both interaction term and its endogenous component, researchers seek to conduct instrumental variables estimation (Bun & Harrison, 2019; Miller et al., 2021). In this interaction model setup, Bun & Harrison (2019) demonstrated that endogeneity concerns due to omitted variable bias can be considerably reduced so that credible inference can be made without having instruments due to the reliance on standard exclusion restriction. Moreover, Busenbark et al. (2022) mainly talked about endogeneity caused by omitted variable bias in empirical estimation, and they revealed that the bias is often overstated in causal inference. Through a series of studies using the impact threshold of a confounding variable, two major findings were highlighted, suggesting that omitted variables may not be a primary source of making most of the causal inference biased as well as a two-stage least square estimator can be worse than a biased OLS estimator for the causal inference except when unrealistically strong instrumental variables are under consideration to attenuate the bias or the bias due to omitted variables is extreme. By relying on the given explanation regarding the omitted variable bias which is known to be the most common problem in causal inference and the use of instruments through previous studies, we omit the further discussion about endogeneity in this study. As a matter of fact, in comparison to a situation in which variables of interest are endogenous to managerial decision making (Ketokivi & McIntosh, 2017), given that the EU-USA BASA is exogenously enforced from a corporate perspective, related independent variables can be assumed to be exogenous in this DiD setup. Moreover, another indicator variable of interest that denotes the point of time when the Agreement came into effect is absorbed by two-way fixed effects over the course of our analysis. Based on the logic regarding the endogeneity issue, we presume that using instruments to correct for the potential bias in the interaction model is no longer essential at this research level.

Model Specification

In order to estimate the variation in outcome variables for treatment and control groups between before and after the introduction of regulatory intervention in this study, a set of hypotheses are tested based on the dependent variables of interest with different sets of explanatory and control variables. Since we postulate that treated airlines tend to proactively comply with the EU-USA BASA by showing the relative expansion of the MRO workforce as well as the reduction in environmental impact, we can set up the estimation equation as follows:

$$ln(Y_{it}) = \beta_0 + \beta_1 * BASA_i * POST_t + \beta_{d2} * \mu_{dit} + \alpha_i + \gamma_t + \epsilon_{it} \tag{1}$$

In equation (1), Y_{it} is estimated for the two dependent variables—the relative volume of MRO personnel and direct air pollutant quantities. In addition, we have a single indicator variable, the interaction term ($BASA_i * POST_t$), as a main independent variable of interest, and the coefficient of the interaction term (β_1) is the estimate of interest to test H1 and H2 in the DiD estimation model. When it comes to holding only a single interaction variable made up of $BASA_i$ and $POST_t$ in the multiple time-period model, due to the fact that the variations associated with both covariates are explained by our fixed-effects model, we decide to drop $BASA_i$ and $POST_t$ in our model specification. This two-way fixed effects parameterization would accommodate more variation in the details of the DiD design (Wing et al., 2018). In this empirical model (1), the dependent variables indicate that the number of employees apportioned to MRO work and the amount of direct pollutants released to air in firm *i* during the specific year *t*. To show a set of control variables, our seven control variables are combined into one term μ_{dit} with a vector of coefficients (i.e., β_{d2}) for the set of control variables in the model. Here, subscript *d* denotes the dimension of a set of control variables, and *i* and *t* are the same as the dependent variable case. Firm fixed effects and year fixed effects, α_i and γ_t, are also applied across all empirical models. Indeed, this linear model with the multiple time periods and cross-sectional unit observations is commonly called a fixed-effects model, and its corresponding estimator is referred to as the two-way fixed effects estimator accordingly (Wooldridge, 2021).

Difference-in-Difference-in-Differences (DDD) Estimation

As a more robust approach, we expand DiD models by incorporating an additional indicator variable (EVD_{it}) that represents how extensively airlines disclose their sustainability performance to the public with its interaction terms with other predetermined explanatory variables. This extended model with three levels of differencing is called a difference-in-difference-in-differences (DDD) or triple difference (TD) model (Olden & Møen, 2020). As a matter of fact, the application of this empirical approach has been observed in finance and economic literature (Low, 2009; Seru, 2014; Mo et al., 2021), but it is relatively uncommon in operations management studies. The logic of DiD and DDD models in this study is practically the same, but they are different in terms of how we define our treatment group. Angrist & Pischke (2009) briefly discussed the value of a DDD research design with improved control groups in causal inferences in that it modifies a traditional DD design that only taps into the differences given by treatment and time to enable higher-order contrasts and provide a more convincing set of results. In this sense, adopting a DDD design could be powerful in this study because corporate compliance with safety and environmental requirements may be tied to firms' reporting of sustainability performance. In line with this thinking, we are interested in how transparency in sustainability is intertwined with regulatory action, and, by extension, how they have influence on safety and environmental compliance behavior all at once. To execute DDD models in equation (2), we add one more indicator variable (EVD_{it}) that refers to whether a firm discloses its environmental performance. Further, this variable is allowed to interact with other indicator variables (i.e., $BASA_i$ and $POST_t$) in the models. Since a new dummy variable for the sustainability disclosure and its interaction terms are included in DDD models, there will be theoretically seven indicator variables in estimation models along with controls. However, consistent with the previous DiD models, a fixed effects model with both unit fixed effects and time fixed effects allows for only part of independent variables of interest to be included in the model (2). Our estimated coefficient of interest is β_5. We test H3A and H3B using the following model:

$$\begin{aligned} ln(Y_{it}) = \beta_0 + \beta_1 * BASA_i * POST_t + \beta_2 * EVD_{it} + \beta_3 * BASA_i * EVD_{it} + \beta_4 * POST_t * EVD_{it} \\ + \beta_5 * BASA_i * POST_t * EVD_{it} + \beta_{d6} * \mu_{dit} + \alpha_i + \gamma_t + \epsilon_{it} \end{aligned} \tag{2}$$

Estimating the Mediation Effect

To test H4A and H4B, we adopt mediation analysis to examine whether the effect of the EU-USA BASA on operating expenditure is mediated by corporate compliance behavior. The objective of mediation analysis is to extend the direct causal effect of a predictor on a response variable through the indirect effect of the predictor by further investigating how the causal effect can be also explained by a third variable (i.e., mediator (M)) (Demming et al., 2017). In this study, we assume that both airlines' safety and environmental compliance play a mediating role, which could be interpreted as multiple mediators relating one predictor (i.e., EU-USA BASA) to one response variable (i.e., operating expenditure) with multiple steps (Rungtusanatham et al., 2014). Related to the multiple mediation model, Figure 2 shows how the relationships between variables are conceptualized.

As for the model specification, a dual mediation model is assumed. In the model, the total indirect effect via two mediators can be disintegrated into two parts: one for the indirect effect of an independent variable (X) on a dependent variable (Y) through the first mediator (M_1) and the other one for the indirect effect of an independent variable (X) on a dependent variable (Y) through the second mediator (M_2). As shown in Figure 2, in this study, the total indirect of the EU-USA BASA on operating expenses would be the sum of a_1b_1 and a_2b_2. Mediation is known to happen under three different conditions: 1. X significantly affects M when regressing M on X, 2. X also significantly affects Y when regressing Y on X without M, 3. M significantly affects Y when regressing Y on both X and M (Baron & Kenny, 1986). Among various methods to test for mediation effects, a method proposed by Preacher & Hayes (2008) can be reasonably used due to the fact that this approach is particularly useful when multiple simultaneous mediators are taken into consideration. Moreover, unless there are large samples, using the distribution of the product approach or bootstrapping is superior to the Sobel test or causal steps approach in that higher power as well as appropriate control over the Type I error can be maintained (Preacher & Hayes, 2008). According to our pre-test results, since our empirical models all pass the above three necessary conditions, we can proceed with mediation analysis with multiple simultaneous mediators for regression models along with the further significance test for the indirect effect with a bootstrapping method.

RESULTS

In Table 3, we present our estimation results for our empirical models, all of which are the baseline models provided in equation (1) and (2). A time-invariant covariate in the regression models ($BASA_i$) will not appear in the output table because they are absorbed by unit fixed effects. Likewise, time fixed effects remove the variable that has the same effect on all units ($POST_t$) (Wooldridge, 2021).

To better sort out those models according to the respective dependent variables, we group the six fixed-effects models into two different panels, both of which, as a result, have three regression models. The first column of each panel (Models 1 and 4) represents a regression model with only a set of control variables applied commonly across all fixed effects regression models. In the second column in each panel (Models 2 and 5), each model further includes the interaction term of two indicator variables (i.e., $BASA_i \times POST_t$) that reflects the treatment effect of the EU-USA BASA on each dependent variable. Lastly, in each panel, the respective models in the third column (Models 3 and 6) incorporate an additional dummy variable that indicates whether a firm reports its sustainability performance. We also include the interaction of this dummy with $BASA_i$ and $POST_t$, respectively.

Impact of the EU-USA BASA

To test H1 and H3A, we use the log transformed volume of MRO employees (i.e., $ln(MRO_{it})$) as our dependent variable in panel A in Table 3. As we expected, we do observe empirical support that there is a significant and relative increase in the volume of MRO staff in model 2 if airlines are under the purview of the EU-USA BASA, as opposed to other remaining airlines. In other words, we identify that the intervention is positively associated with a significant increase in the volume of staff apportioned to MRO service. Its magnitude is large enough (β_1 = 0.401, p < 0.01) to indicate that airlines engaged in the safety agreement tend to employ relatively more MRO employees in an effort to comply with the requirements of the EU-USA BASA. Judging from this, H1 is supported. To extend our analysis further by considering CSR dimension operationalized by corporate environmental disclosure, we add an additional indicator variable, EVD_{it} that reflects how extensively airlines participate in sustainability reporting activities in a specific year, together with its combinations of other two indicator variables. In model 3, our main variable of interest to estimate a DDD model is now $BASA \times POST \times EVD$ (β_5). Its estimated coefficient is still clearly positive with a significantly small p-value (p < 0.05), indicating that there is a noticeable difference in the volume of MRO staff between airlines that joined the Agreement and also disclosed their environmental performance and their counterparts. In other words, depending on how much effort they put into sustainability reporting, a conspicuous gap in the volume of MRO staff can be observed between companies under the same regulatory framework, accordingly. Therefore, empirical results from Model 2 and 3 collectively provide support for H1 and H3A.

	Label	Panel A: MRO Employee			Panel B: Direct Air Pollutant Impacts		
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Main effects							
BASA×POST	β_1		0.401***	-0.012		-1.890***	0.639
			(0.139)	(0.110)		(0.675)	(0.753)
EVD	β_2			0.124			1.100
				(0.105)			(0.726)
BASA×EVD	β_3			-0.595*			-3.452**
				(0.322)			(1.646)
POST×EVD	β_4			-0.229**			-0.019
				(0.105)			(0.753)
BASA×POST×EVD	β_5			0.840**			-2.124**
				(0.328)			(0.876)
Control Variables	μ_{dit}						
PH	β_{d2} & β_{d6}	-0.457	-0.692	-0.986*	0.514	1.667	2.498
		(0.467)	(0.441)	(0.494)	(1.446)	(1.602)	(1.738)
PP	β_{d2} & β_{d6}	0.614	0.501	0.242	1.260	2.772	1.884
		(0.621)	(0.521)	(0.526)	(3.419)	(3.110)	(2.305)
PKFI	β_{d2} & β_{d6}	-3.155**	-3.101**	-3.193**	-0.751	-1.311	-0.842
		(1.496)	(1.471)	(1.464)	(4.541)	(5.077)	(4.437)
SPLFTS	β_{d2} & β_{d6}	0.813	1.064	1.375	4.567	3.258	0.711
		(1.244)	(1.318)	(1.228)	(7.737)	(6.447)	(6.372)
ln(AvgUT)	β_{d2} & β_{d6}	0.042	-0.057	-0.046	-0.616	-0.271	-0.430
		(0.193)	(0.171)	(0.183)	(0.717)	(0.706)	(0.739)
ln(SPAXTS)	β_{d2} & β_{d6}	-1.016	-1.012	-0.969	-0.146	-0.231	-0.098
		(0.733)	(0.724)	(0.712)	(0.742)	(0.627)	(0.525)
ln(TE)	β_{d2} & β_{d6}	1.442***	1.376***	1.332***	0.244	0.107	-0.132
		(0.514)	(0.479)	(0.424)	(0.332)	(0.385)	(0.332)
Intercept	β_0	11.619	12.422	12.355	-0.865	0.532	3.306
		(9.366)	(9.465)	(9.604)	(14.249)	(11.580)	(11.900)
Model Specification							
Firm Effects	α_i	Yes	Yes	Yes	Yes	Yes	Yes
Year Effects	γ_t	Yes	Yes	Yes	Yes	Yes	Yes
Observations		183	183	183	199	199	199
R^2		0.278	0.312	0.346	0.105	0.222	0.457

Note: *p<.1, **p<.05, ***p<.01 indicate statistical significance at the 10 percent, 5 percent, and 1 percent levels. Cluster-robust standard errors are reported in parentheses below parameter estimates.

Table 3: DiD & DDD Estimations: Main Variables of Interest (EU-USA BASA)

To examine H2 and H3B, both of which evaluate the impact of the EU-USA BASA on corporate environmental compliance, we draw upon the log transformed total direct environmental impacts (i.e., direct air pollutant quantities). As shown in model 5 in Table 3, the result indicates that the introduction of the EU-USA BASA is associated with a large difference in the estimate of the environmental impacts (β_1 = -1.890) between airlines engaged in the EU-USA BASA and their counterparts, and the estimated value is statistically significant (p < 0.01). Hence, given the statistical result from model 5, we can find support for H2. Similarly, the estimate of $BASA \times POST \times EVD$ (β_5) in model 6 is computed as -2.124 (p < 0.05), suggesting that substantial reduction in the relative environmental impact quantities can be observed among airlines that joined the EU-USA BASA and also disclosed their environmental performance to the public. Concretely, depending on how much effort they put into sustainability reporting, we can also notice a clear distinction between regulated firms in respect of the change in environmental impact quantities and their counterparts. As far as CSR and the regulatory requirements are concerned, this gap is quite understandable because airlines make an extra effort to safeguard their legitimacy and create a favorable image by proactively reducing harmful impacts on the environment over time, our empirical results certainly mirror their efforts on the environmental goal. Hence, empirical results from Model 5 and 6 also provide support for H2 and H3B.

Mediation Effect

We test for H4A and H4B using a method suggested by Preacher & Hayes (2008). As shown in Table 4, based on the multivariate delta method for the product-of-coefficients strategy, we can find a significant total indirect effect of the EU-USA BASA on operating expenses with -0.189 (p < 0.01). Further, in the mediation models, the specific indirect effects can be gained with -0.065 (safety compliance, p < 0.05) and -0.123 (environmental compliance, p < 0.05), respectively, which can help us conclude that environmental compliance of the EU-USA BASA tends to be the most critical mediator. With these significant point estimates of mediating effects, both H4A and H4B are supported. According to our empirical analysis, the total direct effect, which was originally significant, turns out to be insignificant after controlling for two mediators. Regarding this change in the significance of the direct effect of the EU-USA BASA on operating expenses, previous studies have termed it in different ways, such as perfect mediation (Baron & Kenny, 1986), complete mediation (James et al., 2006), and full mediation (Fritz & MacKinnon, 2007). As a result, we can conclude that the two variables of corporate compliance behavior perfectly, completely, and fully mediate the effect between the EU-USA BASA and operating expenditure (Rucker et al., 2011).

When it comes to the bootstrapped indirect effects of the EU-USA BASA on operating expenses in Table 4, consistent with estimates of the product-of-coefficients strategy, both the specific indirect effects and the total indirect effect are all significant at the 5% significance level. These results further indicate that there are strong mediating effects through corporate compliance behavior.

Robustness Check

Robustness to Sample Size

In the main analysis, we use yearly data of global air transport service providers that span from 2007 to 2016. Due to the data availability of airline operations and performance, we end up gathering only about 202 annual observations, which do not appear to sufficiently guarantee whether our estimates in the main analysis truly contain a genuine empirical effect. Thus, to add more validity to our empirical results, we do power analysis and also show the consistency of the empirical

	Product of Coefficients			Bootstrapping 95% Confidence Interval					
				Percentile		BC		BCa	
	Estimate	SE	Z	Lower	Upper	Lower	Upper	Lower	Upper
ln(MRO)	-0.065**	0.028	-2.33	-0.139	-0.014	-0.147	-0.016	-0.147	-0.016
ln(APD)	-0.123**	0.049	-2.50	-0.219	-0.035	-0.238	-0.049	-0.236	-0.048
Total	-0.189***	0.057	-3.27	-0.311	-0.078	-0.321	-0.086	-0.319	-0.085

Note: Cluster-robust standard errors are reported. BC stands for bias corrected; BCa stands for bias corrected and accelerated; 5,000 bootstrap samples.

Table 4: Mediation Effects of the EU-USA BASA on Operating Expenses via Corporate Compliance Behavior

results based on a bootstrapping method.

In determining statistical power, a few surrounding factors, such as sample size, the size of the empirical effect, and the level of statistical significance, play a pivotal role (Ioannidis et al., 2017). As for the relationship between sample size and statistical power, it has been known that the larger sample size is, the more likely the empirical effect can be detected due to the greater statistical power (Ioannidis et al., 2017). Related to this, Favaron et al. (2022) specifically conducted power calculations to achieve a convincing identification strategy in DiD estimation. In the study, they adopted the STATA package called ‘PCPANEL’ (Burlig et al., 2017), which allows for the computations of statistical power for difference-in-differences designs, based on the minimum detectable effect (MDE). MDE is particularly useful when ex post power is calculated in the sense that MDE is not contingent on the point estimate of the treatment effect, but rather it relies on the estimated standard error (Favaron et al., 2022). Given my choice of power (0.8) according to previous studies (Cohen, 1992; Ioannidis et al., 2017), we do power calculations for our causal inference models. According to the computed ex post power for our models, sample size in the main analysis across DiD and DDD estimation turns out to be sufficiently large enough to show the validity of our empirical results. Along with power analysis, we also compute the coefficient estimates with the bootstrap standard errors to construct 95% bias-corrected confidence intervals by employing 1000 bootstrap replications. The results suggest that the use of bootstrapped standard errors with 95% bias-corrected confidence intervals does not significantly change our empirical results of main analysis.

DISCUSSION

By focusing on the civil air transport industry, this study seeks to demonstrate compliance behavior of firms when a new intervention enters into force. Previous studies in the aviation industry have mostly considered ex-post performance assessment based on operational measures, such as accident records (Barnett et al., 1979; Barnett & Higgins, 1989) or on-time performance (Mellat-Parast et al., 2015; Siegmund, 1990). Although safety is essential to guarantee consistent airline operations, the effectiveness of various safety frameworks (e.g., a safety agreement, program, and system) has not been sufficiently investigated (McFadden & Hosmane, 2001). At the same time, a lack of conclusive data that are consistent across multiple airlines’ operational behaviors may prevent both researchers and practitioners from examining the efficacy of external interventions. In this regard, we consider corporate compliance behavior under regulation and draw attention to the role of corporate environmental disclosure. Our study also investigates the mediating effect of the implementation of regulatory requirements on economic performance via corporate compliance behavior.

Theoretical Implication

According to the EU-USA BASA, airlines under the purview of territorial applicability agree to co-operate in the following regulatory requirements: 1. airworthiness approvals and monitoring of civil aeronautical products, 2. environmental testing and approvals of the products, 3. approvals and monitoring of maintenance facilities (EASA, 2011a). Upon accepting the regulation of civil aviation safety, the level of requirements (e.g., TIP for airworthiness and environmental certification and the MAG for maintenance) imposed on concerned parties increases. Thus, not only is the adoption of a new regulation important, but tracing how airlines actually implement the relevant regulatory requirements is also crucial in that their compliance behavior can be a manifestation of organizational commitment (Chandler, 2014). Our main focus of this study lies in the latter by looking at firms' actual implementation of the requirements imposed by regulation along with the potential impact of regulatory mandates.

With this in mind, we aim to examine how differently commercial airlines behave depending on whether they are under the influence of an external intervention particularly with respect to two operational measures: MRO technicians and total direct environmental impact quantities. We find significant differences in the volume of employees apportioned to maintenance, overhaul and repair sector as well as total external costs on the direct environmental impacts between airlines that joined the EU-USA BASA and other airlines that did not join the Agreement. Along with the compliance behavior, we further incorporate a firm-level sustainability disclosure to assess whether airlines that not only joined the Agreement but also extensively disclosed their sustainability performance to the public outperform their competitors who did not so during the same investigation period. Our findings show that regulated firms that extensively provide environmental disclosure still tend to maintain the sufficient volume of employees in their maintenance operations and have lower environmental footprint. Lastly, on the basis of the findings from mediation analysis, the results suggest that the impact of regulatory requirements on operating expenses are completely mediated by corporate compliance with regulation.

Since the regulatory action is meant to cover firms in different geographical regions (i.e., EU and USA), it underpins a cross-border regulation. So, after the EU-USA BASA entered into force as of 2011 and airlines fulfilled and internalized the regulatory requirements, we investigate if there are commonly observed compliance behaviors among firms under the same regulation in spite of them being located in different regions as well as whether firms capture similar benefits from implementing the regulation. On the basis of institutional theory, which suggests that the organizational arrangements are affected by legally, socially, politically, and culturally formed systems (Shou et al., 2016), the findings of this study show that institutional environment nudges organizations to collectively comply with the safety and environmental requirements of regulation. We are able to clearly observe this by examining how firms respond to them not only by showing a significant gap in the volume of workers for maintenance-related tasks but also by showing the relative reduction in their environmental footprint. This can be interpreted as airlines being willing to pay attention to the multiple objectives that the regulation pursues for enhancing the safety of commercial air fleet operations and coordinated efforts on environmental inspections and sanctions. Throughout this study, we generally refer to this as corporate compliance behavior because the regulation of interest is not voluntarily chosen by airlines but are imposed on them.

We also contribute to extend the literature on sustainability disclosure under the context of regulation. Corporate disclosure helps narrow the information gap between firms and stakeholders outside of the firms. Thus, depending on the levels of corporate disclosure under regulation, how corporate compliance behavior and the subsequent benefits change is also investigated. It is observed that there is a clear gap facilitated by putting an additional effort on corporate sustainability disclosure. To be specific, even if airlines are obligated to comply with the same regulatory requirements, corporate compliance behavior as well as its subsequent benefits is also to some degree contingent on whether firms put extra effort into corporate environmental transparency and accountability. Regarding this, VDT suggests that a firm's level of disclosure relates to its own performance and how sensitive a firm can be with regards to outside perceptions (Lang & Lundholm, 1992). In a broad sense, even if there might be noticeable costs regarding information disclosure, a certain portion of firms with good news are willing to pay the costs of disclosure (Lang & Lundholm, 1992, Verrecchia, 1983, Verrecchia, 1990). In addition, although CSR and its implementation vary across firms, they are often considered to be firm-specific governance in the absence of a strict rules imposed by the government (Perry et al., 2015). To fulfill several business functions, firms with economic, social, and environmental objectives should be also committed to CSR instead of merely pursuing immediate rewards and complying with other regulations (Davis, 1973; Perry et al., 2015). Based upon a string of empirical results, our findings would give an insight into how differently firms manage their resources and environmental performance depending on how much effort they put into sustainability reporting under the influence of external regulation. Our results show that firms under regulation still keep the continuing commitment to the requirements of the regulation, while disclosing their proprietary information to the public well.

Managerial and Policy Implications

The findings of this study also offer implications for both managers and policy makers within the context of the airline industry. When an external policy is put into effect, firms adjust their resources and corporate operations, accordingly, to adapt to the newly imposed requirements of the intervention. Nevertheless, our findings indicate that this does not necessarily imply that only obligations are imposed on firms, but rather they could derive the prospective benefits from adopting and implementing the details of regulation. Under safety regulation in the airline industry, it is conceivable that firms may hesitate to expand the volume of employees in managing the maintenance, repair and overhaul activities owing to the fact that they do not know how differently other competitors under the same regulation react to the intervention. In this study, by providing evidence that implementing a new policy would not harm corporate business in the long run, managers' concern about potential operational risk under regulation is addressed in a visible way. In a similar vein, operating in a safe manner is sometimes at odds with achieving better performance, suggesting that safety precautions are taken at the expense of continuing operational efforts, which could pose a managerial challenge (Zohar, 2002). In contrast, it has also been argued that safety is complementary to operational performance (Das et al., 2008). Likewise, institutional pressures for environmental issues sometimes place an additional burden on a firm's business operations, whereas environmental management helps accrue premium profits through the so-called amelioration of environmental process in relation to surrounding stakeholders, such as environmental groups and regulators (Delmas, 2001). Judging by our empirical findings, a policy that is bilateral with multiple objectives in scope can result in the desired effects, which are again followed by visible benefits. Thus, while managers should acknowledge that there might be a trade-off between compliance behavior and operational performance, the continuing compliance with the appropriate standards would facilitate firms to pursue what regulation is really intended for by adjusting their business functions, which could ultimately lead to windfall gains. Managers should also be mindful that the implementation of regulation and its following management supervision will somehow lead to corporate commitment to the regulatory compliance, which determines managerial decisions.

Our findings have implications for policy makers. In the context of the EU-USA BASA, to ensure the continuation of the high level of regulatory cooperation between involved parties across different geographical boundaries, the Agreement enables the reciprocal acceptance of certain approvals and certification in the field of civil aviation safety and environmental compatibility (EASA, 2011b). In addition, to keep the mutually cooperative relationship between involved parties, developing a comprehensive system of regulatory cooperation is particularly essential (EASA, 2011a). To do so, policy makers should provide practical support for their continuous communication and mutual confidence through diverse enforcement activities (e.g., data and information exchange, and notification of applicable requirements, procedures and guidance material (EASA, 2011a)) so as to promote the continued understanding of general provisions of the regulatory framework and its effective functioning. Moreover, the Agreement is bilateral in nature. In other words, since it is binding on both parties, the consistent application of the agreed upon standards, rules, and procedures for both of them should be ensured. As an execution plan, policy makers could also consider taking appropriate enforcement action on the basis of legal and regulatory structure. In particular, the EU-USA BASA takes advantage of joint coordination bodies, such as a joint maintenance coordination board and a joint technical coordination body together with joint certification. The Agreement also acknowledges the potential amendment on additional areas of cooperation by mutual consent. All of the action plans require mutual trust based upon the continued corporate compliance with agreed upon standards. Even though our empirical findings clearly indicate that firms are committed to obeying the regulatory requirements, which could turn out to be beneficial after a certain time period, policy makers should offer a regulatory arrangement that firms can consistently pursue with no harm to their businesses. Along this line, it seems worthwhile to provide regular evaluation systems as to the continuation of the regulatory cooperation.

According to our findings, disclosures also provide a good mechanism not only to showcase sustainability related activities to stakeholders but also to be able to be used as a means for internally assessing various activities that firms have been undertaking. Being upfront can ensure that firms express their interest in corporate transparency and accountability. Such an assessment provides an opportunity for decision makers to constantly reflect on how these activities are fulfilling the regulatory requirement (even though they may not be explicitly noted in the report) and to enable them to evolve their own CSR road map. CSR reports are typically presented in conjunction with disclosures on economic performance. Thus, examining the two together enables organizations to look back on their activities, how they fulfill regulatory requirements, and how they impact performance in a way.

Limitation & Future Research Direction

There are a few limitations of this study that are worth noting. The first limitation we encountered is about data itself. Since we have used yearly data over the course of data analysis, we assumed that the effect of the EU-USA BASA had begun as of 2011. If there had been available data with a smaller time interval (i.e., quarterly or monthly data) that might allow us to capture a more precise treatment effect, our analysis would have been more robust. Also, because we merged multiple data sets to estimate the impact of an external policy intervention, our overall sample size ended up being relatively small. Having said that, the power analysis indicates that our findings are robust for the sample size considered in this study. Yet, replication with larger sets would further help in strengthening the robustness of our findings. The next thing that we can think of is generalizability. Even though there have been studies that also showed the impact of regulatory action in a highly specific category of service industries (Miller et al., 2020; Spence et al., 2015), we basically concentrate on a single industry. The fact might not allow the findings to generalize to other research contexts.

In terms of our empirical analysis, our study sheds light on a few directions for future work. In this study, we opt for the EU-USA BASA as a primary external policy intervention that encompasses two geographical regions to estimate its causal inference. Our findings show that firms under the territorial applicability of the EU-USA BASA collectively comply with the safety regulatory requirements as well as the requirements for environmental testing by reducing harmful impacts on the environment. However, Europe and US represent regions that have relatively advanced systems and processes. The level of maturity in these systems and processes make it easier for organizations to comply in such joint regulations. Airlines situated in these geographical regions share relatively similar business practices. As a future research, it would be insightful to see how regulations covering regions that are different in terms of the underlying processes and systems, but are intricately tied together due to the globalization of supply chains, would influence firm behavior in these regions. Another avenue for future research is to further examine the effect of the regulation by considering other safety performance measures such as service failure and flight accidents (Barnett et al., 1979; Barnett & Higgins, 1989; Braithwaite et al., 1998). In addition, focusing on a specific industry helps us in understanding the mechanism at work within the industry (Joglekar et al., 2016; Scott et al., 2021). Future researchers should consider the impact of such regulations that span multiple geographical contexts in other industries for ascertaining the generalizability of the findings. Last but not least, we adopt institutional theory as an underlying rationale for explaining the collective compliance behavior. However, institutionalization process may not be the same over the course of time. To reflect this, a few preceding studies further take the passage of time into account in the institutional process, which is also known as the new institutional theory (Lawrence et al., 2001; Miller et al., 2020). This would be able to give a more in depth understanding of how the institutional effects are diffused over time.

CONCLUSION

This study is unique in the sense that it investigates multiple firms across years under regulation along with corporate transparency. It is surely imaginable that firms that reside in different geographical regions may encounter such a policy change with multiple objectives in the modern business world. Further, as a form of self-regulation, there has been surrounding pressure for firms to disclose not only their financial information but also non-financial performance to the public. Prior literature on the impact of a new regulation has mostly focused on a single intervention implemented in a certain region with a unique objective together with no further consideration of corporate responsibility as a whole. Thus, its implication may be too simple to be applicable to other contexts with different properties. In an effort to overcome this vulnerable point in giving a comprehensive assessment, throughout this study, we aim to investigate a geographically inclusive agreement with multiple objectives in operations under the extra pressure of corporate social responsibility so that we can examine how firms respond to the intervention by taking advantage of causal estimation methods. In particular, studies that adopt DDD estimation that extends DiD estimation have not been so common in the studies of operations management. In this light, a relatively novel empirical approach would contribute to providing a multilateral interpretation of causal inference. Even so, it is undeniable that our results would be much more robust if we were to utilize the greater volume of relevant data that may have a shorter interval. In a content-wise manner, unlike a worry shared by firms under regulation, even if companies put additional efforts into complying with the regulatory requirements, implementing a new regulation often results in considerable benefits in different aspects of operational performance. In this sense, the focus of this study consists in the interface between public policy and business decision making, so this research could help a firm that contemplates joining a new regulation particularly in the aviation industry to make a conclusive decision. In addition, unlike the previous belief, our findings imply that firms could secure an opportunity to bring in a firm-led voluntary initiative by putting more energy into transparent reporting under regulation. In other words, multiple firms that come under the purview of the same regulation seize the benefits of sustainability disclosure, but it can also be seen that the levels of potential achievement that firms can look forward to may vary depending on the managerial decision as to a desire for CSR. To this end, this study attempt to investigate corporate compliance with regulation together with CSR as a means of corporate communications, so we firmly believe that this study will help comprehend and address a business situation in which firms are under institutional pressure for societal and environmental issues.

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DECISION SCIENCES INSTITUTE

ERM value-creating effects on strategic flexibility through Information systems infrastructure integration and strategic enterprise management practices in the context of a developing economy.

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ABSTRACT

The study examines the relationship between enterprise risk management (ERM), information systems (IS) infrastructure integration (ISII), IS-enabled strategic enterprise management (IS_SEM), and strategic flexibility (SF). The structural equation modeling is applied to the data collected from 174 Brazilian firms. The results revealed the complex interrelationships that tie ERM among ISII and IS-SEM together to enhance strategic flexibility. Moreover, manufacturing demonstrated more influence (54%) than service firms in the relationship between ISII on IS-SEM. Furthermore, these findings contribute to executives' understanding of how accounting information systems (AIS) can break the paradox that ERM can be rigid and restrict SF in the context of a developing economy.

KEYWORDS: Enterprise risk management, Information systems (IS) infrastructure integration, IS-enabled strategic enterprise management, and strategic flexibility.

INTRODUCTION

Practitioners ask how organizations can perform well and deal effectively through strategic flexibility with time constraints and uncertainty through managing risk (Beek, Bout and Keutel, 2021; Natale, Poppensieker, and Thun, 2022). Because enterprise risk management (ERM) can contribute to building great potential to improve the efficiency and effectiveness of operational capabilities; and at the same time, ERM may be rigid and restrict the effective strategic flexibility to reconfigure resources and capabilities of firms to quickly respond to customer requirements by innovation (Anton and Nucu, 2020).

However, recent studies of information systems (IS), accounting management, and strategy can play together to break this possible paradox that ERM can restrict strategic flexibility (Arnold *et al.*, 2015; Peters, Wieder and Sutton, 2018; Weeserik and Spruit, 2018). These studies argued that to firm needs to build the ability to maintain organization-wide information sharing to lead with organizational response to risks, and the technology is a critical role to provide the capability to integrate data and information across the business units and business processes to effectively manage risk.

Additionally, although the discussion about ERM has been growing related to the integration of strategy management, IT capabilities, organizational change, and other disciplines, it is recognized that the lack of studies integrating these contents (Bromiley *et al.*, 2015; Anton and Nucu, 2020). This integration approach consist to investigate ERM as a holistic organization view integrating four components through strategy, people, processes, and technology (Weeserik and Spruit, 2018).

Therefore, this study develops the idea that the role of ERM in managing and supporting the integration of information systems and strategy to coordinate organizational resources by ethically correct behavior, improvements in efficiency, and effectiveness to leverage strategic flexibility in the context of a developing country. According to Anton and Nucu (2020) research in developing countries has concentrated to investigate the effects of ERM on firm performance, and there is insufficient research addressing how the ERM process can create value effects on other metrics (such as information systems and management strategy) that represents a promising avenue for future research. Thus, to respond to the practitioners and scholars was developed the first research question:

RQ1: How does ERM influence IS infrastructure integration, IS-enabled strategic enterprise management practices, and what is their effect on strategic flexibility in the context of a developing country.

Once that, ERM has a distinct influence, depending on the type of organization, such as its business model, business processes, and value chain through the characteristics of the sector (Weeserik and Spruit, 2018; Anton and Nucu, 2020), this study proposes the second research question:

RQ2: Are there different effects on the proposed model by sector?

Because the service and manufacturing sectors are most representative of more than 90% of Brazilian GPD (CIA, 2020), the RQ2 concentrated on analyzing these two sectors.

Therefore, this study fills gaps knowledge of practitioners (Beek, Bout and Keutel, 2021; Natale, Poppensieker and Thun, 2022) and scholars (Arnold *et al.*, 2015; Peters, Wieder and Sutton, 2018; Weeserik and Spruit, 2018; Anton and Nucu, 2020), and propose together three disparate theoretical frameworks to provide an amplified understanding of the interrelationships between ERM, IS infrastructure integration, IS-enabled strategic enterprise management practice, and strategic flexibility. Thus, the study proposes that higher levels of ERM have a positive influence on IS infrastructure that together increases IS-enabled strategic enterprise management practices and in turn strategic flexibility in the context of a developing economy.

THEORY DEVELOPMENT AND HYPOTHESES

Enterprise Risk Management

The enterprise risk management (ERM) process is a dominant strategic management approach within firms as the social phenomenon signalizes that is necessary to evaluate the risk management of everything (Arnold et al., 2015; Anton and Nucu, 2020). Additionally, with complexity and a growing volume of risks, consequently, increase requirements, and information systems (IS) can provide benefits for integrating risk management activities and strategic management (Weeserik and Spruit, 2018; Elbashir et al., 2021).

ERM has been studied for forty years, and in the last few years, it is at the top agenda of the C-level (Natale, Poppensieker and Thun, 2022). In the beginning, ERM was described into different silos of risk management practices and managed independently, creating redundancies in double activities and other inefficiencies. Nowadays, organizations enable concepts of integrating organization-wide risk management practices through human actions, internal processes, systems, and external events (Bromiley *et al.*, 2015; Anton and Nucu, 2020).

In 2004, ERM was defined by the Committee of Sponsoring Organizations of the Treadway Commission (COSO) (Kaya, 2018). These days, the framework of COSO aims at corporate-wide governance, including the chapter on ERM, and is used within many organizations (Weeserik and Spruit, 2018). In 2009, The International Organization for Standardization (ISO) wrote the ISO Committee for risk management published as the ISO 31000.

The COSO ERM and ISO 31000 appear to have a similar structure of risk management processes. Both COSO and ISO support organizations to balance growth and risks and when management correctly uses resources as it pursues strategies and objectives and manages the related risk to enhance corporate performance (Gates, Nicolas and Walker, 2012).

Hence, this study adopted process activities described by COSO ERM and ISO 31000, because both are the predominant framework used by firms that adopted ERM practices. The processes activities are comprised of: analyzing the internal and external environment; identifying and setting strategy objectives; identifying, analyzing, responding, treating risk; communicating and monitoring of actions (Gates, Nicolas, and Walker, 2012; Weeserik and Spruit, 2018; Anton and Nucu, 2020).

Enterprise Risk Management and IS Infrastructure Integration

As stated, the strategic approach to ERM is related to the organization's ability to maintain organization-wide information to identify, analyze, treat, respond and monitor risks (Gates, Nicolas and Walker, 2012; Bromiley *et al.*, 2015). Arnold, Elbashir, and colleagues (Arnold *et al.*, 2015; Elbashir *et al.*, 2021) have investigated the essential role information systems play in enabling the capability to integrate data across the business processes and various business units to deliver data to create information and strategic knowledge to effectively manage risk.

Previous studies have demonstrated that without IS infrastructure integration of data and systems, executives (C-level, seniors and middle level of managers, etc.) can take a holistic view of the risks the organization faces (Belfo and Trigo, 2013; Weeserik and Spruit, 2018).

IS infrastructure integration shares understanding between employees and managers to achieve strategic goals and manage the organizational risks (Reinking, Arnold and Sutton, 2020). Therefore, theory from the information technology (IT) capabilities integration perspective can concept insights into the nature of IS infrastructure integration needed to support strategic management efforts to enable risk management on environmental uncertainty (Li and Chan, 2019). Because management of risk by silos limits the organization's ability to respond to and manage risks (Arnold *et al.*, 2015; Anton and Nucu, 2020). Thus, firms need to provide IS infrastructure integration of data and systems (Elbashir *et al.*, 2021) to build the capacity to disseminate information to support strategic management decision-making (Peters, Wieder and Sutton, 2018; Aydiner *et al.*, 2019).

Hence, strategic ERM dictates that firms build integrated data and information systems to achieve strategic goals and target leverage outcomes performances (Gates, Nicolas and Walker, 2012; Arnold *et al.*, 2015; Peters, Wieder and Sutton, 2018), proposing the following hypothesis.

H1. ERM has a positive influence on Information Systems infrastructure integration.

Enterprise Risk Management and IS-enabled Strategy Enterprise Management Practices

IS-enabled strategic enterprise management (IS-SEM) is based on data collection through a transactional system that can be the primary enabler of change in strategic analysis, budgeting, non-financial, external, and ad hoc management accounting, and allocation of costs through the reporting and analysis (Belfo and Trigo, 2013).

The adoption of ERM with a risk concerned with the strategic vision can positively influence business processes and organizational performance, necessitated by a forward-looking stance (Arnold *et al.*, 2015).

According to Peters and colleagues (Peters, Wieder and Sutton, 2018) IS-SEM depends strongly on IS infrastructure integration by multidimensional data hierarchies to enable the ability to interact and model to consider strategy versus risks. Thus, the IS infrastructure integration has the essential foundation for firms to provide data and information that allows firms to establish consistent and understandable dialogues vertically and horizontally to build strategy and manage risks (Reinking, Arnold and Sutton, 2020).

Therefore, ERM can influence the firm's ability to increase levels of IS infrastructure integration to enable organizational actors to forward in the same direction to achieve organizational objectives (Weeserik and Spruit, 2018). Hence, ERM integrated risk management enables better collaboration leading to more mature risk management related to the planning and Control cycle, aligned with the strategic goals of the organization. Thus, this study proposes the following hypothesis:

H2. ERM has a positive influence on IS-strategy enterprise management.

IS Infrastructure integration and IS-enabled Strategy Enterprise Management Practices

In this study, IS infrastructure integration (ISII), refers to the database structures and processes, which provide reliable, accurate, multi-dimensional data, and are ready to support decision-making through the performance measurement through data dimensions of objects, attributes, time, and plan versions (Peters *et al.*, 2016).

Recent studies of emergent technologies of accounting information systems (AIS) related to business intelligence (BI) and analytics (BA) (Appelbaum *et al.*, 2017; Rikhardsson and Yigitbasioglu, 2018), and big data (Mikalef *et al.*, 2017, 2020) have demonstrated that strategic enterprise management practices depend on strong ISII. According to Appelbaum and colleagues (Appelbaum *et al.*, 2017), and Mohamad and colleagues (Mohamad *et al.*, 2017) business intelligence (BI), business performance management (BPM), and business & analytics (BA) from a management accounting perspective enable analytics techniques for measuring company performance using the balanced scorecard (BSC) framework.

The strategic objectives and targets of organizations are translated into a coherent set of performance measures (Elbashir *et al.*, 2021), combining components of strategy, and financial and non-financial measures through the BSC framework (Mohamad *et al.*, 2017; Yoshikuni and Albertin, 2018). Hence, transitional systems available structured data, and strong ISII enables IS, such as BI, BA, and BPM tools that provide firms the ability to scan, interpret and analyze various sources and types of data, supporting companies to gain competitive advantage by adjusting the responsibility of management (Appelbaum *et al.*, 2017; Mikalef *et al.*, 2020)

Therefore, ISII support IS-enabled SEM practices with an organization's holistic view to plan, execute and monitor strategic and accounting actions (Belfo and Trigo, 2013; Appelbaum *et al.*, 2017). The strong ISII supports IT applications to simulate strategic planning, communication, and monitoring targets performed by proper use of organizational resources (i.e., by strategic analyses, budgets, and forecasting processes) (Weeserik and Spruit, 2018; Elbashir *et al.*, 2021).

However, when ISII is “low”, data are available across an array of fragmented and dispersed spreadsheets (Peters, Wieder and Sutton, 2018), which with other data sources, they are manually integrated both, on the other hand when ISII is "high" has a common database configuration (Peters *et al.*, 2016). Thus, strong integration of IS infrastructure enables a firm’s Planning & Control cycle in line with strategic objectives and targets leading to better collaboration to achieve outcomes performance (Weeserik and Spruit, 2018). Thus, this study proposes the following hypothesis:

H3. The strong IS infrastructure integration enhances IS-enabled strategic enterprise management practices.

Effects on strategic flexibility

Strategic flexibility (SF) refers to an organization’s ability to reallocate and reconfigure its resources and capabilities to capitalize on the market opportunities and develop operational adjustments to address customers' requirements (Chen *et al.*, 2017). Recent studies of IS strategies (ISS) have demonstrated that strategic knowledge and IT capabilities are the most important resources that enable a firm’s ability to innovate, adapt to change, and create change that is favorable to customers (Yoshikuni and Lucas, 2021,2022; Yoshikuni, Galvão and Albertin, 2021).

Hence, strategic flexibility develops the capacity for organizations to quickly respond and capitalize on market changes to address customer needs through improving products and services; and rapidly restructuring business processes in response to customers' requirements by IT capabilities (Mikalef and Pateli, 2017; Yoshikuni, Almeida and Dwivedi, 2022).

According to Yoshikuni and colleagues (Yoshikuni and Dwivedi, 2022; Yoshikuni and Lucas, 2022; Yoshikuni, 2021), the direct relationships between resource orchestration (RO) of information systems strategies and knowledge strategy enable strategy-making to build dynamic and improvisational capabilities in innovation. As mentioned, in line with current studies, this study proposes that IS-enabled strategic enterprise management practices leverage strategic flexibility by sensing, seizing, and reconfiguring processes, and propose the hypothesis:

H4. IS-enabled strategic enterprise management practices positively influence strategic flexibility.

Organizational capabilities to market capitalization and operational adjustment to gain firm performance (Mikalef and Pateli, 2017; Mikalef, Pateli and Van de Wetering, 2020; Yoshikuni and Lucas, 2022) through IS application and ERM process. Together ERM and IS provide data and information to understand the opportunities and/or risks to the organization (Arnold *et al.*, 2015). ERM disseminates the strategic knowledge for maximizing organizational resources to strategy-making and improving proximate and distal outcomes (Elbashir *et al.*, 2021). Hence, the strategic ERM as a holistic approach to risk management provides data and information from across the firm through scanning of the external environment that presents opportunities and threats to the firm (Weeserik and Spruit, 2018).

Therefore, this study proposes that strategic ERM direct influence the higher levels of IS infrastructure integration to enable strategic enterprise management practices (Arnold *et al.*, 2015; Peters, Wieder and Sutton, 2018) that should flow through to the business processes to leverage strategic flexibility.

Thus, ERM becomes a critical moderator influencing strategic enterprise management practices to facilitate strategic flexibility by the capacity to acquire, assimilate, and transform data and information into the strategic knowledge necessary to leverage the information and the ability to respond to the market and reconfigure business processes (i.e. strategic flexibility). This leads to the hypothesis:

H5. ERM moderates the relationship between IS-enabled strategic enterprise management practices and strategic flexibility.

Competitive Environment by Sectors

Previous studies have examined the influence of industry characteristics in the competitive environment, linked via information systems spanning firm boundaries (Akter *et al.*, 2016; Mikalef and Pateli, 2017; Yoshikuni and Albertin, 2018; Aydiner *et al.*, 2019). There is evidence of structural differences across industries regarding the ability to use IS for improved proximate and distal outcome performance (Melville, Kraemer and Gurbaxani, 2004).

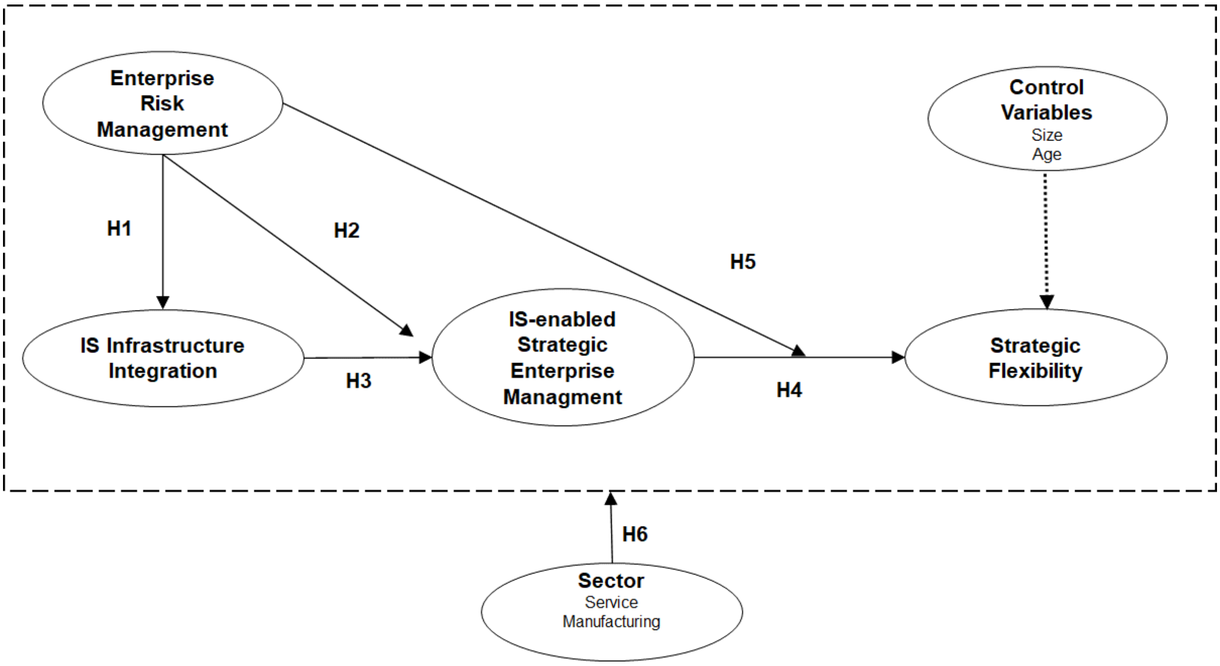
Moreover, there are no studies examining the influence of ERM on the relationship of ISII, and IS-enabled SEM on strategic flexibility in a developing economy, such as Brazil, and it represents a promising avenue for future research (Anton and Nucu, 2020). According to Alamro and colleagues (Alamro, Awwad and Anouze, 2018), several studies have investigated the effects of strategic flexibility, moreover, on manufacturing firm performance in developed countries; however, less empirical research has investigated the antecedents of strategic flexibility by practices of strategic enterprise management in developing countries in manufacturing, and even more in service firms.

Thus, some characteristics of competitive product markets by sectors could influence the organizational practices of ERM, ISII, and IS-SEM to achieve strategic flexibility in the context of a developing economy. Thus, this study proposes the following:

H6. Sector influences the relationship of the proposed model

The proposed model research demonstrates the hypotheses and assumes that ERM influences ISII and IS-SEM to leverage SF, see Figure 1.

Figure 1.
Proposed model research



RESEARCH METHODS

Scale

The constructs had been previously validated from the current literature, and the novel constructs were developed in multi-item measures, through the draft instrument with three rounds of card sorting carried out, as recommended by Moore and Benbasat (1991). The ERM was adopted from Gates et al. (2012), Arnald et al. (2015), ISO31000 and COSO ERM (Weeserik and Spruit, 2021), and IS-enabled SEM (IS-SEM) was based on existing literature in accounting information systems and strategy management (Atkinson *et al.*, 2011; Belfo and Trigo, 2013; Peters, Wieder and Sutton, 2018) with pre-tests by practitioners and academics.

The construct of IS infrastructure integration (ISII) was adopted by Peters and colleagues (Peters *et al.*, 2016). The strategic flexibility (SF) construct was adapted to service industries adopted by Chen and colleagues (Chen *et al.*, 2017), and age, size, and sector were defined as control variables. All constructs were operationalized by Likert scale scores were coded from 1 to 7 (from 1 = “strongly disagree” to 7= “strongly agree”), see Appendix II.

Sample

The data was collected in Brazilian by convenience sampling data collection. The authors contacted the respondents in each firm using different sources and networks; such as personal contacts, professional association contacts, forums, mailing lists, and directories, in line with current research on empirical AIS studies. The respondents were executives that know about management activities that involved activities related to all constructs. Additionally, the survey instructions asked respondents if they were not highly knowledgeable of specific information to consult other members.

The final sample of 174 cases, which is satisfying the minimum sample size requirements for PLS-PM (partial least squares path modeling) (Henseler, Hubona and Ash, 2016). As per PLS-PM literature, the minimum sample size should be 10 times of maximum number of arrowheads pointing to a dependent variable and 10 times the largest number of formative indicators used to measure one construct (Hair *et al.*, 2017).

Statistical technique

The research used the structural equation modeling based on the partial least square method (PLS-SEM) by SmartPLS version 3.3.3 because i) allow flexibility related to the assumptions on multivariate normality; ii) handling of structural model complexity and using smaller samples; iv) uses as a predictive statistical power tool for theory building (Hair et al., 2017).

Table 1 shows the demographic data and reveals that 67% (113) of the participants were middle or 1st line-managers. The industries were composed of manufacturing (53%), and services (47%). The size firm was primarily represented by large-size (58%) and mature firms (57%).

Table 1
Demographic data

		Brazil	
Characteristics		Number	%
Respondent's position	Senior/executive manager	61	33%
	Middle/first line manager	113	67%
Age firms (years of operation)	Young firms (1 to 5)	25	14%
	Middle-age firms (6 to 20)	50	29%
	Mature firms (more than 21)	99	57%
Firm size (number of employees)	Small-size (1 to 99)	36	21%
	Medium-size (100 to 499)	37	21%
	Large-size (above 500)	101	58%
Industry sectors	Manufacturing	93	53%
	Services	81	47%

Measurement model

The test was conducted in reliability, convergent validity, and discriminant validity. The reliability at the level of the construct was assessed by examining Composite Reliability (CR), and Cronbach Alpha (CA) values, both values were above the threshold of 0.70, indicating acceptable construct reliability (Fornell and Larcker, 1981), see Table 2. Convergent validity was examined whether AVE values were above the lower limit of 0.50, the lowest AVE value was 0.64, see Table 2.

The discriminant validity was examined in three ways. First, it was verified if each construct's AVE square root values are greater than its highest correlation with any other construct (Fornell-Larcker criterion). Second, it was tested if each indicator's outer loading was greater than its cross-loadings with other constructs (Bido and Silva, 2019). The heterotrait-monotrait ratio (HTMT) was analyzed, and their values were below 0.80, indicating discriminant validity as recommended by Hair, Henseler and colleagues (Henseler, Ringle and Sarstedt, 2015; Hair *et al.*, 2017). Hence, all items were appropriate indicators for the respective latent variables, see Table 2 and Appendix I. The model fit was performed on composite-based standardized root mean square residual (SRMR), and the SRMR value is 0.07, which is below the threshold of 0.08, confirming the overall fit of the PLS path mode

Table 2
Assessment of convergent and discriminant validity

Constructs	1	2	3	4
1-ERM	0,870			
2-ISII	0,404	0,873		
3-IS-SEM	0,687	0,646	0,799	
4-SF	0,546	0,451	0,573	0,833
Cronbach's Alpha	0,919	0,896	0,886	0,890
Rho_A	0,920	0,900	0,888	0,896
CR	0,940	0,927	0,914	0,919
AVE	0,757	0,761	0,639	0,694

Empirical results

The PLS analysis in Table 3 shows the structural model, and the variance of endogenous variables was explained (R^2) and the standardized path coefficients (β). The hypotheses were confirmed for H1, H2, H3, and H4. It was demonstrated a large and strong positive effect of enterprise risk management (ERM) on IS infrastructure integration (ISII) (f^2=0.195, β = 0.404, t = 5.621, p < 0.001) and ERM on IS-enabled strategic enterprise management (SEM) practices (f^2=0.853, β = 0.509, t = 7.700, p < 0.001), supporting H1 and H2. In support to H3 was found a positive relationship between a firms' level of IS infrastructure integration (ISII) on IS-SEM practices (f^2=0.440, β = 0.477, t = 6.715, p < 0.001). The findings showed strong effects of IS-SEM practices on strategic flexibility (SF) (f^2=0.097, β = 0.364, t = 5.140, p < 0.001), supporting H4. The structural model explains 16.3% of the variance for ISII (R^2=0.163), 63.4% for IS-SEM (R^2=0.634), and 38,1% for SF (R^2=0.381). All coefficients of determination represent moderate to substantial predictive power (Hair *et al.*, 2017). The effect size (f^2) of all direct values is above thresholds of 0.097, indicating moderate to substantial effect sizes.

Table 3
Relationships between all latent variables.

Structural path	f^2 effect size	Path coefficient	*t* value	Bias corrected 95% confidence interval	R^2
ERM → ISII	0,195	0,404	5,621***	[0,260-0,554]	0,163
ISII → IS-SEM	0,440	0,477	6,715***	[0,314-0,567]	0,634
ERM→ IS-SEM	0,853	0,509	7,700***	[0,378-0,637]	
IS-SEM → SF	0,097	0,364	5,140***	[0,202-0,507]	0,400

ERM*IS-SEM → SF	0,000	-0,043	0,838	[-0,130-0,167]
AGE → SFO	0,006	0,755	0,450	[-0,084-0,238]
SIZE → SFO	0,000	0,505	0,614	[-0,163-0,057]

The moderation influence of ERM in the relationship between IS-SEM on SF was analyzed, and the ERM was not found a significant ($p>0.05$) influence on this relationship, not supporting H5.

To examine hypothesis H6 the database was separated into industries of services (93 cases) and manufacturing (81 cases). To analyze whether there are differences between firms from two-sector. Multi-group analysis (MGA-PLS) was used as a parametric approach as suggested by Hair and colleagues (Hair *et al.*, 2017). Table 4 demonstrates the major variance of PLS path coefficients does not differ significantly across services and manufacturing, just the relationship between ISII on IS-SEM showed a difference of 0.299 (45%) statistically significant (p-value < 0.05). Thus, hypothesis H5 was partially supported.

Table 4
Difference in the path coefficients between industries of manufacturing and services

Variables relationship	Global	Manufacturing (S1)	Service (S2)	Path Coefficients Diff. |S1-S2|	PLS-MGA	Parametric Test	Welch-Satterthwait Test
ERM → ISII	0,404	0,363***	0,425***	0,062	n.sig	n.sig	n.sig
ISII → IS-SEM	0,477	0,553***	0,254***	0,299	Sig. *	Sig. *	Sig. *
ERM→ IS-SEM	0,509	0,431	0,633	0,201	n.sig	n.sig	n.sig
IS-SEM → SF	0,364	0,298**	0,419***	0,121	n.sig	n.sig	n.sig
ERM*IS-SEM → SF	-0,043	-0,137	0,036	0,173	n.sig	n.sig	n.sig
AGE → SF	0,027	0,086	0,042	0,044	n.sig	n.sig	n.sig
SIZE → SF	0,065	0,176	-0,081	0,257	n.sig	Sig. *	Sig. *
R^2 (ISII)	0,163	0,132	0,181	0,049	n.sig	n.sig	n.sig
R^2 (IS-SEM)	0,634	0,664	0,618	0,046	n.sig	n.sig	n.sig
R^2 (SF)	0,400	0,365	0,448	0,083	n.sig	n.sig	n.sig

The control variables were not found a significant influence on the relationship of the proposed model research by age and size ($p > 0.05$), see Table 3.

DISCUSSION AND CONCLUSIONS

The theoretical model was tested through gathered survey responses from 174 executives from Brazilian organizations in the manufacturing and services sectors. The findings of the study indicated that there were direct relationships between enterprise risk management (ERM) on IS infrastructure integration (ISII) and IS-enabled strategic enterprise management (IS-SEM) practices, which in turn led to strategic flexibility (SF). The test for the proposed model demonstrated that the research model using the survey measures model is robust, indicating the relationship relationships among the constructs were significant and relevant. Moreover, the relationship between ISII on IS-SEM demonstrated more influence on manufacturing than services firms, respectively 54%, in the context of a developing economy.

The research provides three contributions to the accounting information systems literature related to ERM. First, it was developed and validated a set of constructs that effectively capture ERM and IS-SEM. The ERM and IS-SEM were significant, and each construct exhibited strong validity and reliability. Second, the study indicated that higher IS infrastructure integration and data sharing by strategic enterprise management enabled by wide information systems is critical to maximizing the value of ERM activities in enhancing strategic flexibility, even more in the relationship between ISII and IS-SEM for manufacturing firms. Third, ERM didn't show moderation in the relationship between IS-SEM on strategic flexibility, indicating that the level of ERM didn't influence an organization's capability to leverage flexibility.

Finally, this research responded to practitioners and scholars to fill knowledge gaps to explain the conflict between rigid versus flexibility in enterprise risk management research, contributing to extending the knowledge of ERM and AIS literature. This study demonstrated the role of accounting information systems for strategic-oriented organizations and their associated need for strategic flexibility through managing risk in the context of developing economies.

APPENDIX I

Factor loadings (bolded) and cross-loadings

Items	ERM	ISII	IS-SEM	SF
ERM_1	**0,843**	0,325	0,571	0,473
ERM_2	**0,900**	0,290	0,580	0,470
ERM_3	**0,918**	0,333	0,609	0,510
ERM_4	**0,898**	0,387	0,625	0,509
ERM_5	**0,784**	0,412	0,594	0,479
ISII_1	0,406	**0,859**	0,602	0,416
ISII_2	0,350	**0,889**	0,597	0,388
ISII_3	0,338	**0,872**	0,508	0,415
ISII_4	0,306	**0,869**	0,535	0,409
IS-SEM_1	0,547	0,492	**0,789**	0,493
IS-SEM_2	0,540	0,460	**0,764**	0,468
IS-SEM_3	0,558	0,523	**0,816**	0,524
IS-SEM_4	0,508	0,548	**0,829**	0,371
IS-SEM_5	0,606	0,578	**0,879**	0,473
IS-SEM_6	0,523	0,490	**0,708**	0,486
SF_1	0,405	0,344	0,420	**0,645**
SF_2	0,375	0,413	0,473	**0,797**
SF_3	0,364	0,316	0,410	**0,814**
SF_4	0,476	0,373	0,516	**0,854**
SF_5	0,531	0,432	0,523	**0,821**
SF_6	0,500	0,335	0,450	**0,824**

APPENDIX II

Measurement items for constructs

Enterprise Risk Management-ERM is adopted by ISO31000 and COSO ERM (Weeserik and Spruit, 2021).

Please rate how well the company has

[ERM_1] the ability to identify business risks in processes, information systems, and employee actions.

[ERM_2] the capacity to assess business risks in methodology, quantitative or qualitative assessment, and interrelationship of risk cause.

[ERM_3] the ability to respond to business risk events in contingency plans and mitigation of risk events, and insurance.

[ERM_4] ability to monitor and control business risks (risk indicators).

[ERM_5] ability to communicate business risks to stakeholders (employees, partners, customers, partners, etc.) through various channels.

IS infrastructure integration-ISII as adopted by Peter and colleagues (Peters *et al.*, 2016)

Please rate how well IS infrastructure integration is (to support strategic planning, budgeting, and forecasting systems).

[ISII_1] are purely based on spreadsheets (1) versus (against) and have a fully integrated IT systems architecture (7).

[ISII_2] consist solely of isolated and individualized spreadsheets (1) vs. are integrated by a common, shared online platform and database (7).

[ISII_3] use highly manual processes to extract data from transactional systems (1) vs. having fully automated integration with all relevant transactional systems (7)

[ISII_4] is based on data from disparate spreadsheets (1) vs. sourcing all data from a single data warehouse (7).

IS-enabled strategic enterprise management (SEM) practices -IS-SEM

Please rate how well…

[IS-SEM_1] Strategic management systems enable the company to formulate the content of the strategy through environmental analyzes (external and internal).

[IS-SEM_2] The company discloses strategic objectives and goals for all employees supported by strategic management systems.

[IS-SEM_3] Strategic management systems support managers in simulating scenarios for critical resource bottlenecks and analyzing their economic and financial impacts.

[IS-SEM_4] The company coordinates and distributes the top-down and bottom-up strategic planning, budgeting, and forecasting process through strategic management systems.

[IS-SEM_5] Strategic management systems support monitoring strategic objectives, progress and goals direction, and significant deviations analysis

[IS-SEM_6] Strategic management systems allow the company to consolidate information through accounting and management reports.

Strategic flexibility – SF was adapted to service industries adopted by Chen and colleagues (Chen *et al.*, 2017).

Please rate how well our firm…

[SF_1] could allocate marketing resources (including advertising, promotion, and distribution resources) flexibly to market a diverse line of services/products
[SF_2] could allocate resources flexibly to manufacture, deliver and support a broad range of service/product variations
[SF_3] could design services/products (such as modular design) flexibly to support a broad range of potential product/service applications
[SF_4] is redefining service/product strategies in terms of which services/products the firm intends to offer and which market segment it will target
[SF_5] is reconfiguring chains of resources the firm can use in developing, manufacturing, delivering, and supporting its intended services/products to targeted markets
[SF_6] is redeploying organizational resources effectively to support the firm's intended service/product strategies.

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DECISION SCIENCES INSTITUTE

Factors affecting tour packages continued use and positive word-of-mouth on social commerce: Perspectives of socio-technical system

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ABSTRACT

Using socio-technical theory, the study explores the positive word-of-mouth and continued use in the setting of travel agencies on social commerce. In addition, influences of technical enablers (such as transaction safety and information quality) and social enablers (such as social referrals) on trust are investigated. The present research also looks into the mediating effects of perceived price and travel agency loyalty in the relationship between trust, continued use, and positive word-of-mouth. Finally, focal points for travel agencies in social commerce are given to succeed long-term.

KEYWORDS: Social commerce, Socio-technical system, Continued use, Positive word-of-mouth, and Trust

INTRODUCTION

Tourism unquestionably is among the hardest-hit sector after Covid-19 (Palacios-Florencio et al., 2021). The aftermath was visible all over the world. For instances, more than 40 thousand people lost their jobs in just two months into the pandemic in Ghana (Aduhene & Osei-Assibey, 2021). Meanwhile, decrease in international travel translated to a 0.58% and 4.54% decrease in GDP in Germany and Spain in 2020 (Rodousakis & Soklis, 2022). There was a long wait for flights to take off and borders to be opened. The industry had counteracted to the situation with new technologies, such as virtual reality (AR), or artificial intelligence (AI). In fact, technologies are essential in the medium term (Toubes et al., 2021). However, it cannot permanently alter the original experience in which voyagers can indulge in the all-rounded senses in the visited places. Thus, as the economy and tourism across nations started to kick off after the pandemic, people are eager to pack their bag again. Yet, market conditions and customers preferences did not hold constant as compared to what was before the pandemic. Customers are reluctant to transact with over-the-counter travel agencies due to fear of transmission (Toubes et al., 2021). Technologies also prevailed in the tourism industry. Not only did it offer the virtual experiences during the services consumption stage, it also facilitated transactions in the pre-purchased stages. Tourists are found to adopt the digitalization trend, booking and transacting over the e-marketplace. This could also be attributed to the newly found habits of buying online during pandemic time. For instance, people started to shop online for necessities, groceries goods, machinery, PC applications (Kawasaki et al., 2022), organic foods (Śmiglak-Krajewska & Wojciechowska-Solis, 2021), even plants (Campbell et al., 2021), and many other products that they normally would purchase in brick-and-mortar stores (Stewart & Stewart, 2021). The move of travel agencies from physical space to cyberspace, thus, is imminent. Some services, such as specialized and advisory services, still need to be conducted offline. However, as the economy adopt the digitalization move at an unprecedented speed, market participants are jumping on the bandwagon to not be left behind.

Potential buyers can access different parties to accommodate their travel, such as transportation (i.e., airlines, rental car services), accommodation (i.e., hotels, AirBnB), and tourist attraction sites (i.e., restaurants, amusement parks). Consumers may choose to contact these parties on their own, depending on different needs of the trip. Or, they can opt to buy the separate or bundle, customized or readily-made available services, through a third-party – a travel agency. This can save time and efforts as travel agency can offer their profession know-how and experience (Tsaur et al., 2006). Family, group, or elderly people travel can also benefit from travel agency due to reduced planning and overall simplicity (Dolnicar & Laesser, 2007). Also, a travel agency, with its connected networks, can offer the same set of services at a cheaper price due to economies of scale (Lai, 2014). Apart from having their own websites, travel agencies also set up their presence on social media, as a means to connect with larger audience base. As a matter of fact, social media can also be seen as the main touchpoint for tourism companies (Hu & Olivieri, 2020). With the changing market landscape due to Covid-19, more and more travel agencies can be seen active on social commerce. This phenomenon has called us to explore the factors that may help contributing to success of travel agency on social commerce platform.

The research context focused on the continued use and positive word-of-mouth intention of tourists, after purchasing tour packages of travel agency on social commerce. Previous studies also placed focus on the importance of continued use and positive word-of-mouth to success (Kong et al., 2020). However, little is known in social commerce space. As users of social commerce is identifiable, information on social commerce can be propagated through different users and potentially go viral quickly (Balaji et al., 2016; Cutshall et al., 2022; Eisingerich et al., 2015). Thus, we would like to choose positive word-of-mouth intention and continued use as measurement for success on social commerce. Relying on socio-technical theory, the study also aims to investigate factors that contribute to trust, which may translate to success of the travel agency. As consumers are more price-conscious after Covid-19 (Gültekin, 2022; Kitz et al., 2022), we added loyalty and perceived price as mediating factors, examining part of consumers' intrinsic and extrinsic motivations in the tourism industry. The study is expected have theoretical and practical contributions. Social enabler and technical enabler of different platforms may work differently. Therefore, the study provides better understanding of socio-technical system in the social commerce space. In practice, our study hopes to provide comprehensive understanding of key enablers in social commerce and consumers' motivation to travel agencies. As a result, they can grasp which features in social commerce should be focused on to gain success. Moreover, the present study also provides insights into consumers' behaviors, which travel agencies can customize their activities to sustain and benefit in the long run.

LITERATURE REVIEW

Social Commerce

The advent of social networking sites such as Facebook, Instagram, and Twitter has changed the novel paradigm of e-commerce into social commerce ((Riaz et al., 2021). Social commerce was defined by Liang and Turban (2011) as the presence of both social media and commercial activity. In 2013, according to Yadav et al. (2013), social commerce is a collection of "exchanged activities that occur in, or are influenced by, an individual's social network in computer-mediated social environments, where the activities correspond to the need recognition, pre-purchase, purchase, and post-purchase stages of a focal exchange". Scholars may perceive social commerce as a branch (Aladwani, 2018), a new aspect (Hajli, Sims, et al.,

2017) of e-commerce, or a subcategory of social media where users may not only shop but engage in other activities such as promotion and advertisement (Stephen & Toubia, 2010). However, commonly, a large bodies of research still exhibits a differing pattern between e-commerce and social commerce. Fundamentally, Shih-Chieh Hsu et al. (2022) provided three aspects that social commerce is inherently different from traditional e-commerce. First, the traditional e-commerce platform focuses on search engine optimization, maximizing one-click purchasing, and users' previous shopping experiences that lead to system recommendations. Meanwhile, social commerce coupled with social interactions and business activities using social media (Wang & Zhang, 2012). Second, within social commerce, customers can share their products' ratings and reviews, exchange recommendations, communicates via forums and communities (Marsden, 2009). Third, social commerce, according to Farivar et al. (2017), takes the traditional e-commerce platform but with built-in social media features, enabling users to a more social-interactive shopping experience.

Nevertheless, other scholars present another holistic view, as social commerce is different from e-commerce in terms of business models, system interaction, design, users' communication and connectivity, platform, and design (Baghdadi, 2013; Balaraman & Chandrasekar, 2016; Busalim, 2016). Social commerce and e-commerce essentially are different in business model. The former focuses on Web 2.0 technology with cloud computing directing at social goals (users' interaction, networking, and information sharing). The latter mainly focuses on sales with a tradition Web 1.0 (Baghdadi, 2013; Busalim, 2016; Zhang & Wang, 2012). Heinonen (2011) distinguished the value creation between the two platforms: e-commerce with a network of firms and businesses, and social commerce involving users in collaborative social interactions through assisting others' to finalize their decisions, participating and cooperating within the platform. Regarding connections and communication, e-commerce placed importance on navigational search through Web2.0 (business-to-consumers), and Electronic Data Interchange technologies. Social commerce regimes allows the presence of online community, emphasizing the relationship between companies/ sellers with consumers to increase sales through collaboration and information sharing (Balaraman & Chandrasekar, 2016; Stephen & Toubia, 2010). The system interaction of social commerce also included more diversity than that of e-commerce. Buyers in social commerce can share experiences, expressions, and information with other users while proactively creating content for consumers and even enterprises.

THEORETICAL DEVELOPMENT

Trust

Trust exists" when one party has confidence in an exchange partner's reliability and integrity" (Morgan & Hunt, 1994). Trust is a relevant result of business and social interactions associated with dependency, uncertainty, and possible danger across disciplines, and trust helps to lower perceived risk (Ter Huurne et al., 2017)). Akhmedova et al. (2021) provides a systematic approach to define and conceptualize trust in three directions. First, trust can be viewed as a one-dimensional notion, referring to the truster's level of confidence and positive expectation (Colquitt et al., 2012). Second, trust is viewed as a multidimensional concept that refers to the degree to which the truster has good expectations in the trustee. The positive expectations derived from two sources: mental-based judgment and emotion-based judgement (McAllister, 1995; McKnight & Chervany, 2001). Third, (Mayer et al., 1995) also approach trust conceptualization as a multidimensional concept but grounded on three factors: ability, integrity, and benevolence. Studies have found that trust is antecedents to numerous behaviors (Hajli, Wang, et al., 2017; Klaus, 2013; Tajvidi et al., 2020; Wang & Herrando, 2019), such as consent to disclose personal health information online (Bansal & Gefen, 2010), or consistent use of online platform (Kim et al., 2008; Klaus, 2013). In social networking sites, trust plays a pivotal role, as cognitive risks and insecurity negatively associated with trust (Laaksonen et al., 2009).

Perceived Price

Price, according to (Jacoby, 1977) has two dimensions: objective price and perceived price. Objective price refers to the actual price consumers have to pay, while perceived price is the subjective perceptions (Jacoby, 1977) and feelings (Zeithaml, 1988) of the consumers. The number of previous research exploring the relationship between trust and perceived price is scarce. Hride et al. (2022) drew a positive relationship between perceived price fairness and trust. Thus, we would also like to study if it is also applicable to trust and perceived price.

H1: *Trust will have a positive impact on Perceived Price*

Continued Use

"Continued use is a post-adoption behavior that demonstrates a user's dedication to using the information system (IS) after having multiple experiences with using it" (Bhattacherjee, 2001; Kwon & Zmud, 1987; Osatuyi & Turel, 2018; Zmud, 1982). Within social commerce, continued use refers to the repeated use of social commerce platforms via browsing deal offerings, making purchases, recommending deals to other users. In a social commerce context, continued use of consumers can was also contributed by social motivation (Chiu et al., 2014). There are a number of research dedicated to continued use, unveiling its antecedents such as customer satisfaction and perceived usefulness of IS (Chong, 2013; Kim et al., 2009; Kim et al., 2013; Kuem et al., 2017; Lin et al., 2017; Osatuyi & Turel, 2018; Wang, 2008; Zhou et al., 2012), sense of belonging (Lin et al., 2014), monetary savings (Chiu et al., 2014), and trust (Kim et al., 2009; Kong et al., 2020; Ng, 2013; Wu et al., 2010). The underlying similarities of these determinants are that if pleasant experience is associated with the behavior, consumers will likely seek to relive the experience by continue such behavior (Katz et al., 1973). Thus, it is important to understand the continued use of social commerce, especially when trust is the antecedent.

As perceived price is subjective judgement of the consumers on the value of products or services they received, therefore, we assume that:

H2: *Perceived price will have a negative impact on Continued Use*

Positive Word-of-mouth

Word-of-mouth communication is defined as a form of informal communication, directing at other consumers to inform the ownerships, characteristics, and usage of a particular goods, services, or even the sellers (Westbrook, 1987). As social commerce incorporates characteristics of social media, word-of-mouth plays an essential role as it has the power of going viral (Cutshall et al., 2022). Social word-of-mouth is different from traditional e-commerce word-of-mouth (Eisingerich et al., 2015). As the information spreader communicator can be identifiable on social commerce, contrary to the anonymity of e-commerce, users tend to be more cautious due to the social pressure (Balaji et al., 2016). King et al. (2014) conducted a multidimensional analysis on electronic word-of-mouth of 190 related studies. The largest number of King et al.'s research focused on quantifying the positive and negative effects of word-of-mouth on a wide range of outcomes. For instances, individuals may share different information depending on their social structure. Negative messages are likely to be shared with weak ties, while both negative and positive communication are shared in strong ties (Sohn, 2009). On another note, negative reviews have less informational value due to consumers' irrational perceptions when reading the review (Kim & Gupta, 2012). A helpful review, according to Li and Zhan (2011), should be comprehensive, reader-friendly, clear usage experience, argument supported, with *positive* (and possibly strong) emotions. Strong negative review, on the other hand, is not useful for recipients. To elaborate on positive review, higher levels of customer involvement and engagement (Islam & Rahman, 2016), and consumers' confidence in services and products from online platforms (Hong & Yang, 2009) result in positive word-of-mouth communication. Our focal point, thus, will explicitly lies in the positive word-of-mouth on social commerce platforms. Additionally, positive word-of-mouth also plays a crucial role in leisure consumption of elderly aged 60 to 70 (Fontenla & Almeida, 2020). Meanwhile, research found that trust positively affect the continuance use of marketing sharing economy and positive word-of mouth (Kong et al., 2020; Lien & Cao, 2014). Trust, in our study, is measured as the continuance use of social commerce and the willingness to spread positive word-of-mouth. A considerable number of study also explores the relationship between word-of-mouth intention and trust in a wide range of context (Brown et al., 2005; Erkan & Evans, 2016; Wang & Yu, 2017; Wing Kuen & KW, 2014). Barreda et al. (2015) found that trust may lead to satisfaction, which partially mediated the impact of trust on word-of-mouth. On a more direct impact, a number of research displayed a pattern that trust positively influences word-of-mouth (Chu & Kim, 2011; De Matos & Rossi, 2008; Gremler et al., 2001; Ranaweera & Prabhu, 2003; Sichtmann, 2007). As a result, our study would like to look into the relationship of trust and positive word-of-mouth, with perceived price as mediator.

H3: *Perceived price will have a negative impact on Positive Word-of-Mouth*

Travel Agency Loyalty

Travel agency acted as a retail point in the tourism industry distribution channel, responsible for commercialization activities (Campo & Yagüe, 2007). The primary goal of the agency is to maximize the benefits of all brands sold via the agency (Karande & Kumar, 1995; Kopalle et al., 1999) by informing clients and encouraging the sale of packages (Campo & Yagüe, 2007). As vendors wish to maintain business continuity, customer loyalty has become increasingly important due to the information asymmetry in online environment (Srinivasan et al., 2002). Customer loyalty can be seen from two different concepts. First, from a behavioral perspective, customer loyalty is a direct product of specific consumer behaviors, regardless of consumer decisions. From an attitudinal approach, loyalty should include cognition, emotion, and intention (Oliver, 1997; Yeon et al., 2019). Anderson and Sullivan (1993) indicated that loyalty is generated after the purchasing stage. Unlike traditional e-commerce, social commerce possessed higher customer retention (Nadeem et al., 2020). Thus, loyalty in social commerce was defined as being keen on a social networking site, leading to a tendency to continue browsing and recommending it to other users in the future (Currás-Pérez et al., 2013).

Loyalty construct in our study comprises both aspects: the behavioral and attitudinal perspectives. Historically, models in tourism distribution agents and consumers loyalty covered both aspects of loyalty, yet skewing towards attitudinal component due to relationship marketing approach (Campo & Yagüe, 2007). Many studies have put emphasis on the antecedent of loyalty, which is trust (Chaudhuri & Holbrook, 2001; Elena & Jose, 2001; Laroche et al., 2013). Therefore, our hypothesis would be directing at a positive relationship between the two constructs. Other studies also did put continued use and the intention to spread positive word-of-mouth (Amin, 2021; Nevzat et al., 2016) into the picture, which trust also played as antecedents (Kim et al., 2009; Kong et al., 2020; Ng, 2013; Wu et al., 2010). As a result, our study would like to further explore if loyalty can be a mediated factor on these influences.

H4: *Trust will have a positive impact on Travel Agency Loyalty*
H5: *Travel Agency Loyalty will have a positive impact on Continued Use*
H6: *Travel Agency Loyalty will have a positive impact on Positive Word-of-Mouth*

Socio-technical Theory

Social technical theory placed a foundation for our study. The theory rooted in open systems theory, which primarily presented in physics and biology field (Von Bertalanffy, 1950). Trist and Bamforth (1951) pioneered to introduce the theory into social sciences realm to solve the discrepancies between technical and social system. The theory initially provides a balanced approach to internal organizational change structure, bridging humanity and performability aspects of institutions (JØRGENSEN, 2010). It was then adopted into a wide range of commerce, social media, and virtual communities (Hu et al., 2016; Kapoor et al., 2021; Tajvidi et al., 2020; Yu et al., 2016). Studies aim to understand the nuances in the social and technical subsystems of IS. According to Bostrom and Heinen (1977), the process, technologies, tools, and specific tasks happening between input and output formation contributed to the technical subsystems. The social subsystem dealt with the human side of the system, which comprises of relationships, values, knowledge, people and rewarding scheme. The two subsystems work jointly to optimize success of the system (Cartelli, 2007).

Social commerce constructed a system that enabled seamless incorporation of the social and technical subsystems. Regarding the social sphere, social commerce, with inherent nature of social media, enabled users to interact freely with others, collaborate through information sharing activities (Liang et al., 2011). Our study would like to delve into the social referral aspect of social commerce as social enabler, which could be unique to traditional e-commerce platforms due to its users identifiable factors and social distance (Kim et al., 2020). On the technical frontier, Liang et al. (2011) pointed out design features and social media tools that enable users to participate in the consumer-generated content process. In our paper, information quality and transaction safety are selected to represent the technical enabler.

<u>Social Referrals</u>

Referrals traditionally takes form of offline communication among friends and relatives. The advent of online social community has extended the boundary of social referrals to a broader base of audiences, such as acquaintances or even strangers (Yili et al., 2017). Social referrals indicates the process of exchanging consumption experiences of products or services, from consumers to consumers, to refurbish online research of others prior and during purchase (Wang & Yu, 2017). Kim et al. (2020) provides a more dimensional overview of social referrals, which is other-focused, requiring low effort yet garner large pool of audiences, and happening throughout the whole purchasing process. The valence of affective states of social referrals also impacted on the products or services sales. For instance, Sorensen and Rasmussen (2004), in a study of New York Time's reviews and comments, has demonstrated that positive comments and reviews generated higher sales than those of negative comments and reviews. The same applied for services. Hotel reservations are positively related to positive social referrals, which may induce positive attitude of potential guests, leading to more bookings (Priester et al., 2004). Regarding online products, positive social referrals can help online venders strengthen customers' trust (Kim & Park, 2013). Social referrals also differ depending on the shopping stages of consumers (Song et al., 2017). In a laboratory experiment environment, the study found that Chinese e-commerce consumers would navigate towards recommendations from large social distance (weak ties relationship, i.e. strangers) than small social distance (strong ties relationship, such as friends and relatives). The findings were also consistent in other study. A monetary incentive referral system can work well in a large social distance, weak ties relationships, while intrinsic motivation may induce better social referral in small social distance (Kim et al., 2020).

Information Quality

Information quality “has been applied extensively to understand utilization of online information and types most likely to elicit positive responses from online consumers” (Trehan & Sharma, 2020). Information quality refers to the extent of up-to-date, accurate, relevant, useful, and comprehensive (Mun et al., 2013). Consumers will translate such information as credible, high quality, useful and make purchase decision subsequently (Kong et al., 2020). Most studies focused on the information quality of e-commerce, such as sellers’ websites. For instances, Alam et al. (2008) demonstrated that information quality of a website, which should be easy to read and browse, is critical in contributing to users’ satisfaction, gaining customers’ trust and increased attitudes in the website(Chen et al., 2002; Liao et al., 2006), decision to use the online channels (Montoya-Weiss et al., 2003), and intention to purchase (Bharati & Chaudhary, 2006; Cao et al., 2005). However, studies of information quality on Facebook’s C2C social commerce platform is limited. Chen et al. (2016) indicated that ads with high information quality, regarding relevance, accuracy, ease of understanding, completeness, format, and currency would result in impulsive buying behaviors. According to Trehan and Sharma (2020), there are two factors differentiated C2C social commerce platform from company-driven social commerce: the freedom to post content of all users, and media choices restricted to text and images (no promotional video). Thus, the environment setting constitutes unique characteristics of information quality. The findings of the study, based on real product listings, showed that a holistic approach of all information quality dimensions (namely *objectivity, reputation, relevancy, completeness, appropriate amount of information, ease of understanding, concise representation*) is not necessary. Potential buyers are content with appropriate information – complete, concise, and objective – to make purchase decisions.

Transaction Safety

Consumers are extrinsically refrained from shopping online due to transaction security and privacy concerns (Chang et al., 2016; Salo & Karjaluoto, 2007). Many studies solidified that security and privacy were the two top concerns for online shoppers (Flavián et al., 2006; Miyazaki & Fernandez, 2001). In online platforms, consumers are required to provide card and personal information to assist in their shopping journey, which would in turn trigger their cognitive attitudes towards online shopping (Chen & Barnes, 2007; Koufaris & Hampton-Sosa, 2004; Salo & Karjaluoto, 2007), influencing cognitive trust and purchase intention (Chang et al., 2016). Inherently, online environment associated with higher security risks than the traditional brick-and-mortar interface (Featherman & Hajli, 2016), and maintain such security online will be much harder than offline. If successful, sellers can improve customers’ trust (Kim & Park, 2013).

Studies of the influences of social referrals, information quality, transaction safety were limited, and focus on the accommodation sharing platforms (Kong et al., 2020). Our paper would like to study the effects on a more interconnected space as social commerce. We posit that:

H7: *Social Referrals will have a positive impact on Trust*
H8: *Information Quality will have a positive impact on Trust*
H9: *Transaction Safety will have a positive impact on Trust*

METHODS

Data Collection Procedure

MTurk and Google Survey were used as platform for data collection. 147 responses were gathered and sufficient for analysis after data cleaning process. Participants used travel agency on Facebook to purchase tour packages. Demographics of the respondents was presented in Table 1.

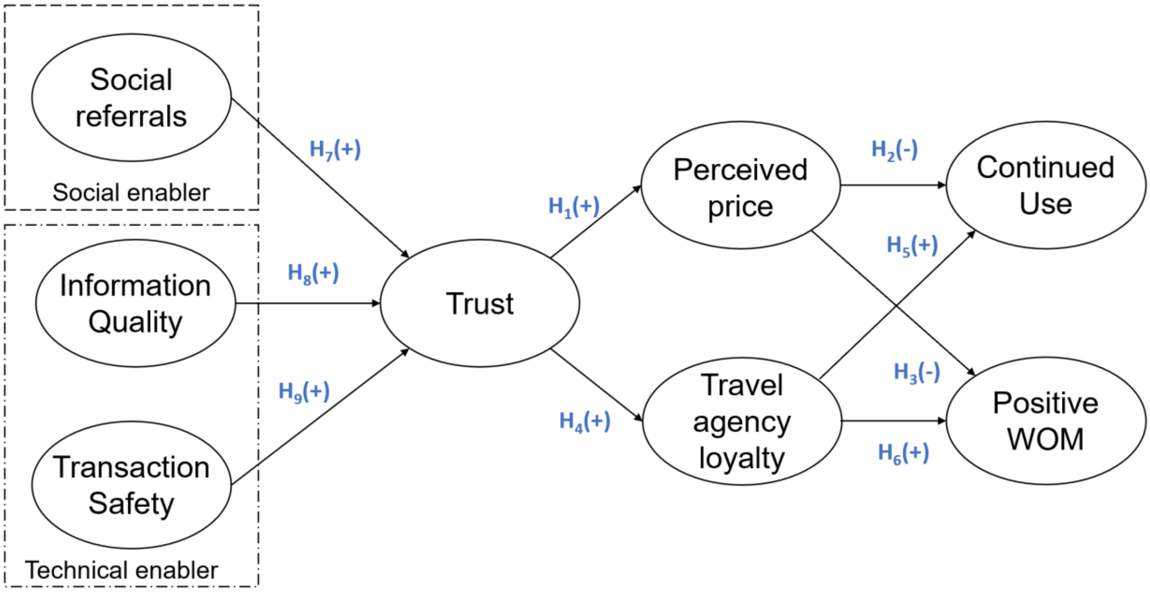

Figure 1 Research framework

Table 1. Demographics

Characteristics	Frequency (N=147)	Percent (100%)
Gender		
Male	58	39.5
Female	89	60.5
Age		
Under 20	12	8.2
20–30	57	38.8
31-40	47	32.0
41-50	21	14.3
51-60	7	4.8
Above 60	3	2.0
Nationality		
Vietnam	52	35.4
US	89	60.5
Other	6	4.1
Education		
High school or equivalent	6	4.1
Bachelor’s degree	109	74.1
Postgraduate	32	21.8
Monthly income		
Under $500	20	13.6
$500 - $1000	27	18.4

Characteristics	Frequency (N=147)	Percent (100%)
$1000 - $1500	24	16.3
$1500 - $2000	27	18.4
$2000 - $3000	19	12.9
$3000 - $4000	16	10.9
More than $4000	14	9.5
Average daily use of social media		
Less than 1 hour	6	4.1
1-2 hours	42	28.6
2-4 hours	60	40.8
4-6 hours	24	16.3
More than 6 hours	15	10.2
Frequency of travel annually		
Less than once a year	14	9.5
Around once a year	33	22.4
2 -3 times a year	64	43.5
4 - 6 times a year	24	19.0
More than 6 times a year	8	5.4

Measurement Items

Measurement items of previous studies was used and adapted on a 7-point Likert scale (ranging from Strongly disagree to Strongly agree (Table 2).

Table 2. Measurement items

Construct	Measurement	Source
Perceived Price	prc1. "How ***expensive*** is tour package(s) you booked on Travel Agency Facebook Page?" (with 1 being "Very Inexpensive" and 7 being "Very expensive")	(Chua et al., 2015; Dodds et al., 1991; Oh, 2000)
	prc2. "How ***pricey*** is the tour package(s) you booked on Travel Agency Facebook Page?" (with 1 being "Not pricey at all" and 7 being "Very pricey")	
	prc3. "How ***high*** is the tour package's price you booked on Travel Agency Facebook Page?" (with 1 being "Very low" and 7 being "Very high")	
Social referrals (SOR)	sor1. "I have heard from others that the Travel Agency Facebook Page is very ***useful***"	(Kim & Park, 2013)
	sor2. "I have heard from others that the Travel Agency Facebook Page is very ***easy to use***"	
	sor3. "I have heard from others that the Travel Agency Facebook Page is very ***reliable***"	
	sor4. "I have heard from others that Travel Agency Facebook Page is NOT ***worth the effort*** (R)"	
Information quality (IQ)	iq1. "The Travel Agency Facebook Page provides ***accurate*** information on the room/product that I want to book"	(Kim & Park, 2013)
	iq2. "Overall, I think the Travel Agency Facebook Page provides ***useful*** information (e.g. hotel information)"	
	iq3. "The Travel Agency Facebook Page provides ***reliable*** information"	
	iq4. "The Travel Agency Facebook Page provides ***sufficient*** information when I try to make a transaction"	

Transaction safety (TS)	ts1. "The Travel Agency Facebook Page implements ***security*** measures to protect its online users"	(Kim & Park, 2013)
	ts2. "The Travel Agency Facebook Page has the ability to ***verify*** online users' identity for security purposes"	
	ts3. "The Travel Agency Facebook Page usually ***ensures*** that transaction-related information is protected from being accidentally altered or destroyed during transmission over the Internet"	
	ts4. "I feel ***secure*** about the electronic payment system of the Travel Agency Facebook Page"	
Trust (TRU)	tr1. "I believe that the Travel Agency Facebook Page have enough ***safeguards*** to make me feel comfortable using it"	(McKnight et al., 2002)
	tr2. "I feel assured that ***legal*** and ***technological*** structures adequately protect me from problems on the Travel Agency Facebook Page"	
	tr3. "I feel confident that ***encryption*** and other technological advances on the Travel Agency Facebook Page make it safe for me to use"	
	tr4. "In general, the Travel Agency Facebook Page provides a robust and ***safe*** environment to share private information"	
Continued use (CU)	cu1. "I intend to ***continue using*** the Travel Agency Facebook Page in the future"	(Bhattacherjee, 2001)
	cu2. "I predict I will ***continue to use*** the Travel Agency Facebook Page in the future"	
Positive word-of-mouth intention (PWOM)	wo1. "I would tell others ***positive*** things about the Travel Agency Facebook Page"	(Kim & Park, 2013)
	wo2. "I would provide others with information the Travel Agency Facebook Page"	
	wo3. "I am likely to ***recommend*** the Travel Agency Facebook Page to my friends or others"	
	wo4. "I am likely to ***encourage others*** to consider using the Travel Agency Facebook Page"	
Travel agency loyalty (TAL)	tal1. "I would feel completely ***comfortable*** travelling with the same Travel Agency again"	(Campo & Yagüe, 2007)
	tal2. "I would travel with the ***same*** Travel Agency again, even if they changed tour operators"	
	tal3. "If someone asked me for a recommendation, I would ***recommend*** travelling with this Travel Agency"	
	tal4. "I am likely to ***encourage*** others to consider using the Travel Agency Facebook Page"	

RESUTLS AND ANALYSIS

Descriptive Statistics, Reliability, and Discriminant Validity

SmartPLS 3.0 (Ringle et al., 2015) was used to compute CFA results. All standardized indicator loadings were greater than 0.7, except for a mere 0.697 factor loading in iq2, which should be acceptable according to criteria suggested by Hair et al. (2011). Value of Composite Reliability (C.R.) and Cronbach's Alpha of all constructs, according to Fornell and Larcker (1981), and Bagozzi (2011) should be greater than 0.7 to reflect high reliability of measurements. Our results satisfied the criteria. Similarly, all constructs' average variance extracted (AVE) were greater than 0.50, satisfying the convergent validity requirement (Chin, 1998).

Table 3. Descriptive Statistics and PLS-CFA Results

Construct	Items	Mean	SD	Factor Loading	AVE	C.R.	Cronbach's Alpha
Perceived Price (PRICE)	prc1	5.03	1.347	0.907	0.823	0.933	0.893
	prc2	5.06	1.341	0.904			
	prc3	5.06	1.245	0.910			
Travel Agency Loyalty (TAL)	tal1	5.54	1.154	0.772	0.644	0.878	0.814
	tal2	5.27	1.317	0.734			
	tal3	5.52	1.167	0.861			
	tal4	5.48	1.284	0.837			
Continued Use (CU)	cu1	5.54	1.273	0.917	0.821	0.902	0.783
	cu2	5.52	1.268	0.895			
Positive Word-of-mouth (WOM)	wo1	5.42	1.199	0.868	0.699	0.903	0.857
	wo2	5.59	1.192	0.807			
	wo3	5.52	1.268	0.835			
	wo4	5.42	1.170	0.835			
Trust (TRU)	tr1	5.29	1.453	0.851	0.746	0.922	0.886
	tr2	5.23	1.439	0.862			
	tr3	5.27	1.351	0.858			
	tr4	5.24	1.398	0.883			
Social Referrals (SOR)	sor1	5.39	1.268	0.860	0.589	0.845	0.743
	sor2	5.56	1.360	0.842			
	sor3	5.29	1.325	0.843			
	sor4	4.24	1.953	0.443			
Information Quality (IQ)	iq1	5.63	1.074	0.777	0.599	0.856	0.777
	iq2	5.68	1.066	0.697			
	iq3	5.56	1.041	0.765			
	iq4	5.67	1.075	0.850			
Transaction Safety (TS)	ts1	5.22	1.359	0.880	0.706	0.905	0.861
	ts2	5.31	1.369	0.838			
	ts3	5.28	1.374	0.822			
	ts4	5.21	1.420	0.818			

Table 4. Correlations between research constructs

	CU	IQ	PRICE	SOR	TAL_	TRU	TS	WOM_
CU	0.906							
IQ	0.643	0.774						
PRICE	0.303	0.396	0.907					
SOR	0.736	0.672	0.467	0.767				
TAL_	0.849	0.690	0.378	0.734	0.803			
TRU	0.689	0.607	0.495	0.727	0.692	0.864		

TS	0.663	0.662	0.508	0.714	0.676	0.852	0.840	
WOM_	0.814	0.573	0.400	0.724	0.873	0.672	0.655	0.836

** Diagonal elements (in bold) are the square root of the average variance extracted*

Fornell-Larcker criterion was used to assess the discriminant validity of the research model. Each construct's square root of AVE was greater than other inter-construct correlations, suggesting discriminant validity requirement were met.

Common Method Bias

All VIF values results from SmartPLS 3.0 is smaller than 3.3 threshold, indicating that the model is free from Common Method Bias (Kock, 2015).

Hypotheses Testing Results

The path coefficient was drawn to test the hypotheses under SmartPLS 3.0 software (Ringle et al., 2015). The guidelines of (Hair et al., 2011) was followed to assess the significance of the path coefficient, by bootstrapping 5,000 samples. Table 5 depicted the findings of SmartPLS 3.0 data analysis and hypotheses testing.

Table 5. Results of the PLS Data Analysis and Hypotheses

Hypo-thesis	Relationship	β	t	Results
H1	Trust (+)→ Perceived Price	0.495***	5.606	**Supported**
H2	Perceived Price (-)→ Continued Use	-0.021	0.373	Not supported
H3	Perceived Price (-)→ Positive WOM	0.082	1.435	Not supported
H4	Trust (+)→ Travel Agency Loyalty	0.692***	13.164	**Supported**
H5	Travel Agency Loyalty (+)→ Continued Use	0.857***	25.716	**Supported**
H6	Travel Agency Loyalty (+)→ Positive WOM	0.843***	22.974	**Supported**
H7	Social Referrals (+)→ Trust	0.247	1.544	Not supported
H8	Information Quality (+)→ Trust	-0.011	0.168	Not supported
H9	Transaction Safety (+)→ Trust	0.684***	5.442	**Supported**

** Note: ***p <0.001, **p < 0.01, *p < 0.05; using a significance level of 0.05, critical ratios (t-value) > 1.96*

H1 was supported as trust positively impacted perceived price (β=0.495, p<0.001). However, the influences of perceived prices on continued use of Facebook tour buyers (β=-0.021, p>0.05) and their intentions to spread positive WOM (β=0.082, p>0.05) were not supported. Therefore, H2 and H3 were not supported. On the other hand, trust had positive impact on travel agency loyalty (β=0.692, p<0.001). The same went for the influences of travel agency loyalty to continued use (β=0.857, p<0.001) and intention to spread positive word-of-mouth (β=0.843, p<0.001) by consumers. H4, H5, and H6 were all supported. Social referrals did not have significant impact on Trust (β=0.247, p>0.05), so did Information Quality (β=-0.011, p>0.05). H7 and H8 were not supported. However, the last construct of technical enabler, Transaction Quality, did place an important role in consumers' trust antecedents (β=0.684, p<0.001). H9 was supported. The results of hypotheses testing are presented in the conceptual model as per Figure 2.

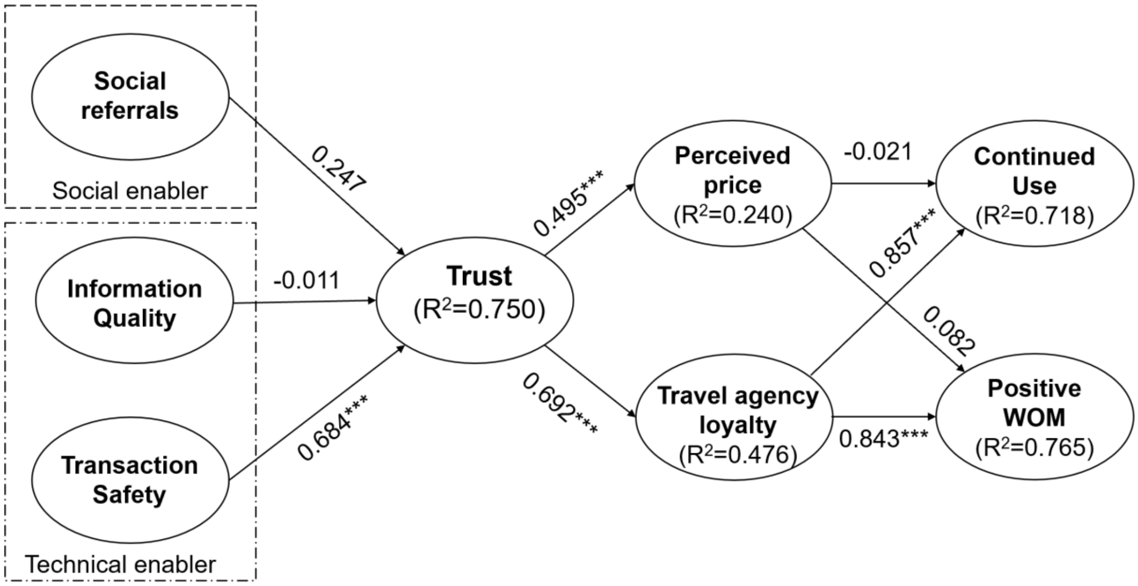

Figure 2. Results of SmartPLS 3.0 hypotheses testing

DISCUSSION AND CONCLUSIONS

In the context of tourism recovery after the pandemic, it is essential to explore what can travel agencies do to stimulate more sales and understand the contributing factors. Our study investigated component that may play important roles – consumers' trust. By dividing into two stages: pre-purchase and post-purchase, we hope to understand the implied motives that maybe of benefits to the travel agencies. In the post-purchase stage, perceived price and travel agency loyalty were studied as mediating factors between trust and consumers' intention to continual use as well as positive word-of-mouth. Although trust had positive and significant impact on perceived price, the perception of price did not translate to future use and positive word-of-mouth. This finding is interesting, especially at the dawn of post-pandemic. Customers are more price-conscious after Covid-19 (Gültekin, 2022; Kitz et al., 2022). Perhaps the discounted deals mushrooming all over social media did not stimulate tourists to extend their use and positive word-of-mouth to others. Further studies may also explore other factors instead that may lead to sustainable buying behaviors of tourists in social media. On the other hand, loyalty to travel agencies contributed to more sustainable sales. Travel agencies on social media, who acquire a loyal customer base, tend to benefit in the long run. Instead of giving out discounted deals, which should be seen as a norm in the post-Covid stage, travel agencies should focus on maximizing the pool of loyal customers. In doing so, gaining trust is important, as H6 is supported. Antecedents of trust exist in the pre-purchase stage. Theory of socio-technical was used to provide breeding ground to understand the impacts that social commerce may have on consumers. It is interesting to note that even though social commerce is distinctive to other traditional e-commerce cyberspace due to its social enabler, social referrals did not have significant impact on consumers' trust. Our finding is consistent with other study (Toubes et al., 2021) conducted in the post Covid-19 timeframe. Social referrals, consulting with friends and relatives, may not be as highly valued as before. The same went for information quality. However, within the technical enablers, transaction safety gained importance in building trust. There is a number of studies on e-commerce and social commerce fraud (Abdul Talib & Rusly, 2015; Batista et al., 2021; ROMERO, 2020; Whitehead, 2021). As people move to cyberspace to shop more after Covid 19(Kawasaki et al., 2022), especially in tourism (Toubes et al., 2021), there is a need for travel agency in social commerce space to ensure transaction safety, which can eventually lead to long-term customer base.

Our study did have certain shortcomings. With limited number of respondents, our study suggests room for improvement. The unsupported hypotheses (H2, H3, H7, H8) can be further investigated with larger sample size. Contradicting to our assumptions, social referrals did not have significant impact on consumers' trust. It is worth noting to find other aspects of social enablers in social commerce as antecedents of trust. Perceived price in the forms of tour packages discounts may not have significant impact on consumers' long-term use. Instead, the technical aspect won over tourists' trust during post-Covid era. Setting up a credible presence and transaction-safe procedures could bring long-term benefits to the travel agencies on social commerce.

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Factors Correlated with Time on the Market in Real Estate Marketplace

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ABSTRACT

We examine the association of various determinants of "Time on the Market," i.e., how long it takes to sell the house as a measure of housing market dynamics. Although macroeconomic factors that reflect the health of the economy are commonly viewed as important causes of housing market movements, other factors are also important drivers. The incorporation of the market and macroeconomic factors together may enhance the models' performance. Understanding this complex phenomenon between these factors would assist housing lenders in assessing the risk of default and investment portfolio managers in assessing the direction of market movements.

KEYWORDS: Time on the market; Housing market; Unemployment rate

INTRODUCTION

Improvements in the health of the economy increase housing demand and home sales. This, in turn, reduces the average length of time houses are on the market. Therefore, an increase in the unemployment rate should increase the length of time houses are on the market. Thus, we examine the association of the unemployment rate with the time on the market (TOM), i.e., how long it takes to sell a house, as a measure of the housing market in relationship with the economy. Therefore, we expect length of time houses are on the market have a positive relationship with the unemployment rate. In addition, long-term momentum may be additionally associated with other factors, such as the inventory of houses. While some interactions between these forces are observable, others are not. Some of the unobservable factors are rooted in the number of houses that are for sale, and inventory may be shaped by economic and other factors. Capturing these unobserved components' effects is the goal of this study. We propose a bivariate cross-correlation time-series approach.

Using simple regression analysis, we found that the relationship between TOM and the unemployment rate is positively correlated (as the unemployment rate increases, time on the market increases). Moreover, the data show a strong lead-lag relationship between TOM and the unemployment rate even after several months' delay. This exhibits a long-term statistical dependency (Diaz & Jerez 2013). Cross-correlation analysis reveals that the association between the length of TOM and the unemployment rate is strongly positive and immediate, and the association persists for a year before it becomes statistically insignificant. In addition to the cross-correlation analysis, we performed a time-series regression analysis (see, Choudhury, Hubata, & St. Louis, 1999 for more on time-series regression) to identify whether there is an autocorrelated lag effect.

Unlike most studies in the literature that only estimate the contemporaneous relationship (Levitt & Syverson, 2008), this paper also explores the dynamic relationships between TOM and the unemployment rate. In that regard, the framework of the vector error correction model (VECM) of Johansen's procedure was applied to assess both the short-run inter-temporal co-movement between these two variables and their long-run equilibrium relationship. It also facilitates a richer understanding of the dynamic short-run and long-run relationship.

We also explore the cointegrating relationship between these two factors for estimating the long-run relationship. This research primarily focuses on identifying the causality of the length of time houses are on the market. By identifying the potential influence of when TOM will increase or decrease, homebuilders are in a better position to maximize their return on investment.

The next section provides a literature review. We then discuss an overview of a generalized regression model, Granger causality, and cointegration. Next, we describe and explain our empirical results and findings and provide concluding remarks.

LITERATURE REVIEW

Due to the housing market's importance, many studies on the industry have been undertaken. Much of this research focuses on the source of unusual pricing changes during housing market crashes. This work has led to a number of different arguments concerning the main indicators of price determinants. However, housing price changes, especially those experienced during the housing bubble, remain dynamic (Choudhury et al., 2018). Researchers have dedicated much of their efforts to identifying factors that are determinants of housing market mechanisms (Sander & Testa 2009; Lyytikäinen, 2009; Fratantoni & Schuh, 2003; Taylor, 2007; Bradley, Gabriel, & Wohar, 1995; Vargas-Silva, 2008). Factors have been identified (Ewing & Wang, 2005; Baffoe-Bonnie, 1998; Huang, 1973; Thom, 1985) as sources of housing market dynamics; among these, housing price (Rapach & Strauss, 2009) and housing starts (Lyytikäinen, 2009; Ewing & Wang, 2005; Puri & Lierop, 1988; Huang, 1973) play important roles. Other studies have been designed to examine particular aspects of these markets, such as the determinant of housing starts (Rapach & Strauss, 2009; Addison-Smyth, McQuinn, & O'Reilly, 2008; Dipasquale, 1999; Kearl, 1979; Maisel, 1963) and TOM (Diaz & Jerez, 2013; Bian, Waller, & Wentland, 2016).

In addition, research studies have attempted to identify the determinants of the length of time houses are on the market, and most of these research studies primarily examined the relationship between TOM and price (Diaz & Jerez, 2013; Knight, 2002; Asabere & Huffman, 1993; Geltner et al., 1991). The asymmetric effect of price and TOM in the residential real estate market was explored by Cheng, et al. (2015).

In a study of high-rise housing flats, Ong and Koh (2000) observed that the floor level of housing units affects TOM. Therefore, TOM factor has the potential to be valuable and useful for home builders, home purchasers, and sellers attempting to choose the optimal time. Homebuilders could maximize their investment by identifying when an increase in TOM may occur.

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Faith in Disasters: The Influence of Religion on Humanitarian Relief Operations

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ABSTRACT

In this study, we examine how non-governmental organizations (NGOs) religious affiliations influence their volunteer relations and operational outcomes. Employing social capital and person-organization fit theories, we examine the influence of NGO religiousness on volunteer behaviors and performance outcomes and how NGO and volunteer religiousness 'fit' influences these relationships. Using a 2x1 factorial video experiment to collect data from 110 students and 198 volunteers to examine our hypotheses, we find that increases in NGO religiousness diminish volunteer-NGO behavior and performance outcomes. However, NGO and volunteer religiousness 'fit' improves these outcomes.

KEYWORDS: Humanitarian Relief Operations, Volunteer Management, Social Capital, Religion, Person-Organization fit Theory

INTRODUCTION

The main goal of humanitarian supply chain management is to save lives and reduce human suffering by assisting those in need (Beamon & Balcik, 2008). This goal is often difficult to achieve as the need for relief occurs when a society's ability to function is disrupted or unable to cope with the needs of its people (Day, Melnyk, Larson, Davis, & Whybark, 2012; Kovács & Spens, 2009). To respond to disruptions and cope with the needs of individuals, societal systems have become dependent on the support of non-governmental organizations (NGOs). NGOs differ from other humanitarian supply chain management stakeholders as they are considered voluntary and independent of government, operating under a public mission to provide humanitarian services to all in need (Beamon & Balcik, 2008; Berger, 2003). They are considered one of the main drivers of the global relief chain (Beamon & Balcik, 2008) and continue to grow in numbers, providing relief throughout the world.

While NGOs are considered voluntary and independent organizations, they are often dependent on donations and the goodwill of others (i.e., governments, corporations, and individuals) to attain the resources they need to remain operational. Increases in the number of disruptive events, people in need of aid, and competition for scarce resources have led to increased criticisms of and pressure on NGOs, from donors and society, to improve deficiencies in the effectiveness of their relief operations (Kovács & Spens, 2009). Volunteers represent an invaluable resource for NGOs. Due to limitations in funding, NGOs are highly dependent on the human capital of volunteers (Boezeman & Ellemers, 2008). For example, the American Red Cross utilizes over 90% of volunteers in their relief efforts, with at least 30% having no prior aid experience (American Red Cross, 2020). Difficulties in maintaining volunteer satisfaction and commitment have created environments of high volunteer turnover. As such, it is critical to better understand how NGO factors might engender or diminish volunteer satisfaction and commitment (Paciarotti & Valiakhmetova, 2021; Urrea & Yoo, 2021), collaborative behaviors (Zayas-Cabán et al., 2020), and performance. Considering the operational context of NGOs, religion is a unique and important organizational factor capable of influencing volunteers and their performance that warrants investigation.

We utilized the concept of religiousness to understand the role religion plays in how volunteers view the NGO and operational outcomes. Religiousness is defined as the adherence to an organized system of beliefs, rituals, and practices of a specific institution or tradition (Karakas, 2010; Stratta et al., 2013). It is a dimension characterized by the interaction between religious identity and religiosity. Religious identity is the dynamics associated with a social identity involving membership in a specific religious group. It is an affiliation with a specific religious group, incorporating their beliefs, values, and practices (Héliot, Gleibs, Coyle, Rousseau, & Rojon, 2020). Religiosity is defined as the endorsement of a religion's doctrine and values (Héliot et al., 2020). It reflects how devoted an individual is to religion or the extent to which an organization's religious identity defines its organizational structure, strategies, and services (Berger, 2003). We also examine the interaction between NGO religiousness and volunteer religiousness. While the literature underlines that religiousness often garners a sense of community and trust amongst its members, it can also be exclusive and alienating for that outside of its social group (Chan-Serafin, Brief, & George, 2013).

Thus, in this study, we formulate the following research questions. *How does the Religiousness of NGOs influence the development of social capital, volunteer satisfaction, volunteer commitment, and volunteer performance? How does volunteer Religiousness influence these relationships?* To examine these research questions, we rely on the theoretical frameworks of social capital theory (SCT) and person-organization (PO) fit theory. SCT views knowledge or intellectual capital as the most salient resource to gain a sustainable competitive advantage (Ataseven, Nair, & Ferguson, 2018). It postulates that organizations gain intellectual capital through social capital created by their social networks or embeddedness (Nahapiet & Ghoshal, 1998; Subramaniam & Youndt, 2005). Ultimately, social capital and social networks facilitate integrative behaviors, leading to increased efficiency and effectiveness (Ataseven et al., 2018; Nahapiet & Ghoshal, 1998). P-O fit posits that behavior and attitudes result from the congruence and integration of values between persons and organizations (Kristof-Brown, Zimmerman, & Johnson, 2005). It reflects the degree to which persons and organizations share values, goals, and priorities (Erdogan, Karaeminogullari, Bauer, & Ellis, 2020). As fit increases, concepts such as shared understanding, trust, communication, satisfaction, and engagement are enhanced. Subsequently, this leads to increased performance outcomes. Based on SCT and PO fit, we examine how religiousness differentiates faith-based NGOs from non-faith-based NGOs in terms of their development of social capital through volunteers and influence volunteer behaviors and performance. Furthermore, we examine how volunteer religiousness moderates the effect of NGO religiousness.

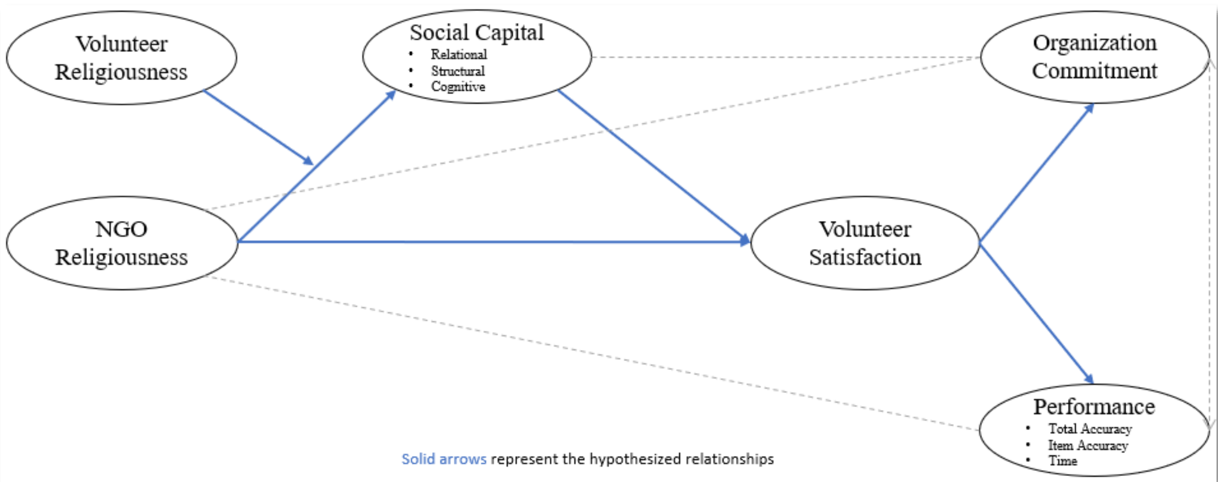
To inform our research questions, we administered two 2 x 1 full factorial scenario-based video experiments on 110 students and 198 volunteers to assess the influence of religiousness. This method is appropriate as it allows us to observe the behaviors and decisions of real humans in a complex phenomenon that are not easily or readily observable as they unfold and allowed us to capture aspects of the scenario better than a written vignette (Li, Choi, Rabinovich, & Crawford, 2013; Rungtusanatham, Wallin, & Eckerd, 2011; Victorino, Verma, & Wardell, 2013). Overall, results show that NGO religiousness has a significant influence on the development of social capital and is linked to volunteer attitudes, behaviors, and performance. The findings further show that volunteer religiousness plays a significant role in the influence of NGO religiousness.

THEORETICAL DEVELOPMENT/HYPOTHESES/MODEL

The main premise of social capital theory (SCT) is that networks of relationships create a valuable resource to conduct social affairs by providing collectively owned capital (Nahapiet & Ghoshal, 1998). It contends that knowledge or intellectual capital is the most salient resource in providing a competitive advantage and that this resource is gained through social capital (Ataseven et al., 2018). Social capital is the sum of the actual and potential resources embedded, available, and derived from a network of relationships (Nahapiet & Ghoshal, 1998). It is the interaction between human capital (knowledge, skills, and abilities residing in and utilized by individuals) and organizational capital (institutionalized knowledge and codified experience residing with and through structures, systems, and processes) highlighting that knowledge resides primarily within individuals but can be accumulated and stored by organizations to develop established networks (Ataseven et al., 2018; Subramaniam & Youndt, 2005).

Furthermore, social capital, and subsequently human and organizational capital, are influenced by three dimensions of embeddedness: structural, relational, and cognitive. Structural embeddedness revolves around the properties of the network and the pattern of connections. It is concerned with the who and how of the network and is described by the configuration, presence or absence of ties, and morphology (Nahapiet & Ghoshal, 1998). Relational embeddedness describes personal relationships developed over time by individuals. These relationships influence individual behavior through social motives such as sociability, approval, and prestige (Nahapiet & Ghoshal, 1998). Cognitive embeddedness focuses on shared representation, interpretation, and meaning. This dimension alludes to the influences of shared languages and shared narratives (Nahapiet & Ghoshal, 1998). Though social capital can be developed in different forms, overall SCT contends that it is developed through social structures which facilitate individual attitudes and behaviors, the efficiency of action, and the effective use of knowledge (Ataseven et al., 2018; Nahapiet & Ghoshal, 1998). Figure 1 shows the overall theoretical framework.

Figure 1: Theoretical framework



NGO religiousness and social capital

We contend that faith-based NGOs have a competitive advantage over non-faith-based NGOs through their affiliation and connection to established religious networks. Religion represents structural, relational, and cognitive embeddedness in which these networks are highly connected and dense, provide a sense of identity, trust, and adherence to norms and obligations, and constitute a shared language and shared interpretations that ultimately impact the behavior of the individuals involved (Heist & Cnaan, 2016).

H1: NGO religiousness has a positive relationship with social capital.

In line with SCT, we further contend that social structures influence individual attitudes and behaviors. Specifically, we focus on the influence of religiousness and social capital on volunteer satisfaction and organization commitment. Volunteer satisfaction highlights the degree to which a volunteer is happy with their volunteer experience (Bond & Bunce, 2003), while organization commitment is defined as a volunteer's emotional attachment to and perceived obligation to remain or reenlist with an organization (Allen & Meyer, 1990). These constructs represent two important behavioral outcomes in relief settings.

H2: NGO religiousness has a positive relationship with volunteer satisfaction.

H3: Social capital mediates the relationship between NGO religiousness and volunteer satisfaction.

H4: Volunteer satisfaction has a positive relationship with (a) organization commitment and (b) volunteer performance.

METHODS

To test our hypotheses, we collected data utilizing scenario-based video experiments. A scenario-based experiment is an appropriate method of choice, given our aim to examine how the organizational environment influences individual behaviors and actions (Eckerd, DuHadway, Bendoly, Carter, & Kaufmann, 2020). In this type of experiment, human participants assume a defined role that includes cues to manipulate levels of a factor of interest and control for factors not under investigation (Polyviou, Rungtusanatham, Reczek, & Knemeyer, 2018). In their assumed role, participants react to varying versions of scripted information and respond to questions or tasks regarding the dependent variables (as well as controls and checks) that mirror reality as closely as possible (Polyviou et al., 2018; Rungtusanatham et al., 2011). In turn, reactions and responses are analyzed to gathered to examine how the levels of factors of interest influence participant reactions and responses (Rungtusanatham et al., 2011).

EXPERIMENT 1

Dependent, independent, and control variables

Experiment 1 was conducted in a laboratory setting. Following the presentation of the videos, participants were asked to complete a series of repeated tasks and answer questions related to potential variables of interest. Effective service quality accuracy highlights one of the most important performance outcomes for NGOs (Charles, Lauras, Van Wassenhove, & Dupont, 2016). To appropriately gauge performance and address our research questions, we asked participants to engage in a volunteer sorting task. This task asked participants to create relief hygiene kits for individuals in need and was chosen as the best way to realistically reflect a volunteer task experience. The hygiene kit items were provided through collaboration with the American Red Cross and a large consumer packaged goods firm which were confirmed to be actual items provided to disaster relief victims on a regular basis. In Experiment 1, participants were asked to sort through a bin of hygiene products and create five hygiene kits with products donated by a large consumer packaged goods firm. The quality of the relief kits reflected kits that included the right number of products (total accuracy) and the right amount of each product (item accuracy). The kits did not require the participants to have the correct number of items or the correct amount of each item. A list of the correct products and the number of each product needed to produce an accurate hygiene kit were provided to each participant throughout the duration of the volunteer task assignment. Additional information about the measures will be discussed at the conference.

Participants, procedure, and checks

Experiment 1 consisted of a 2 x 1 between-subjects laboratory experiment, conducted in a university behavioral research lab. A total of 143 student participants were recruited via the behavioral research lab's participants portal, which is continuously vetted by the behavioral research lab to ensure high-quality participants. The behavioral lab participant portal allowed us to recruit a diverse group of students based on their religious identity and demographics, as well as include the necessary checks to ensure the collection of high-quality data. Of the 143 recruited participants, 110 passed the attention checks. Each of the 110 participants was randomly assigned to one of two versions of the lab experiment, resulting in a balanced distribution of 55 per scenario (Eckerd et al., 2020; Lonati, Quiroga, Zehnder, & Antonakis, 2018).

Realism checks consisted of two questions using a 5-point Likert scale (1=strongly disagree to 5=strongly agree) (Dabholkar, 1994). The questions asked participants to measure how realistic the scenario and following decisions were and whether they had difficulty imagining themselves in the scenario. Results showed that participants found the scenarios to be realistic (μ=4.28, σ=0.71) and had little difficulty imagining themselves in the scenarios (μ=4.20, σ=0.95). Manipulation checks for NGO religiousness asked participants to rate how religiously focused they believe the organization is based on the organization's mission and goals presented in the video using a 4-point Likert scale (1=secularly (non-religiously) focused to 4=very religiously focused. Analysis showed that the faith-based NGO video reflected the highest level of NGO religiousness (μ=3.36, σ=0.73), compared to the non-faith-based NGO video (μ=1.84, σ=0.79).

Demand characteristics are defined as features of the scenario-based experiment that may lead a participant to identify, understand, and respond based on what he or she perceives is expected by the researcher (Eckerd et al., 2020; Thomas, Darby, Dobrzykowski, & Hoek, 2020). To ensure the validity of the experiment, we employed multiple techniques to minimize the potentially unfavorable effects of demand characteristics and attain reliable responses from the subjects. First, a factor capturing social desirability biases was included as a control (Lorentz, To¨yli, Solakivi, Ha¨linen, & Ojala, 2012). Social desirability bias was measured using a five-item scale adopted from the Marlowe–Crowne scale (Loo & Loewen, 2004). The mean does not appear to be higher than expected (μ=3.98, σ=0.48). Second, all participants were guaranteed anonymity, and no identifying information was collected that could potentially implicate them. In addition, clear instructions were given that there were no "right" or "wrong" answers (Thomas et al., 2020). Furthermore, we included control conditions for both manipulated variables that provided a baseline level of the manipulated variable to observe participants' behaviors in the absence of the treatment (Lonati et al., 2018). Finally, a randomized between-subjects factorial design ensured that the experiment was less susceptible to demand characteristics (Thomas et al., 2020), order effects (Abbey et al. 2017; Ta et al., 2018), as well as self-selection (Antonakis, Bendahan, Jacquart, & Lalive, 2010). Our results will be discussed at the conference.

EXPERIMENT 2

NGO and volunteer religiousness

Based on person-organization (PO) fit theory we further expand on the relationships between NGO religiousness, volunteer satisfaction, organization commitment, and performance by examining the moderating role of volunteer religiousness. PO fit posits that attitudes and behavior result from the congruence and compatibility between a person and their organization (Cable & Edwards, 2004; Kristof-Brown et al., 2005). We contend that the influence of NGO religiousness is contingent on the religious fit between NGOs and volunteers. Therefore, we hypothesize as follows.

> **H5:** Volunteer religiousness moderates the relationship between NGO religiousness and social capital.

Participants, procedure, and checks

A total of 244 participants were recruited via a professional survey research firm to participate in this experiment (Schoenherr, Ellram, & Tate, 2015). The use of a professional survey research firm allowed us to recruit a diverse group of participants based on their religious identity and degree of religiosity, as well as their age, gender, and work experience. It also allowed us to screen and only recruit participants with recent volunteer experience. Of the 250 recruited participants, 198 participants passed the attention checks and data quality checks. Each of the 198 participants was randomly assigned to one of two versions of the video experiment, which resulted in a balanced distribution of 99 participants per scenario (Eckerd et al., 2020; Lonati, Quiroga, Zehnder, & Antonakis, 2018). Our results will be discussed at the conference.

Table 1: Results overview

Hypotheses	Experiment 1	Experiment 2
Hypothesis 1	**Not supported** *significant but negative	**Not supported** *significant but negative
Hypothesis 2	**Not supported** *significant but negative	**Not supported** *non-significant
Hypothesis 3	**Not supported** *non-significant	**Supported** *negative & significant
Hypothesis 4a	**Supported** *positive & significant	**Supported** *positive & significant
Hypothesis 4b: total accuracy	**Supported** *positive & significant	**Supported** *positive & significant
Hypothesis 4b: item accuracy	**Supported** *positive & significant	**Not supported** *non-significant
Hypothesis 4b: response time		**Not supported** *non-significant
Hypothesis 5		**Supported** *positive & significant

DISCUSSION AND CONCLUSIONS

Overall, the goal of relief operations is to minimize and alleviate suffering by providing timely and effective aid. NGOs represent one of the main catalysts in achieving this goal by providing needed support to individuals when societal systems are unable to cope (Beamon & Balcik, 2008; Day et al., 2012). Increases in disruptive events, societal needs, and competition, coupled with the inherent characteristics of the aid environment, have made the ability to provide aid ever more difficult. In return, NGOs have been subjected to heightened criticism and pressure to improve the efficiency and effectiveness of aid relief (Kovács & Spens, 2009).

To address the need for improved performance in the relief operation, this study focuses on how an NGOs religious focus, and values, influence its organizational structure and the behaviors and actions of volunteers. Religion plays a vital role in the relief environment as it has historically provided understanding and been used as a coping mechanism in response to negative situations (Aten et al., 2019). Furthermore, religion has generated communities of well-connected networks, through shared values and beliefs, which NGOs can leverage to influence volunteers and improve operational outcomes (Ager et al., 2015; Berger, 2003). Grounded in social capital theory (SCT) and person-organization (PO) fit theory, we developed a model that links NGO religiousness, and the interaction between NGO and volunteer religiousness, to social capital, organization commitment, volunteer satisfaction, and service quality (accuracy, response time) performance outcomes. The contributions of the study will be detailed at the conference.

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References are available upon request.

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From Classroom to Work-Place – Seven Applied Staff Scheduling Examples

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ABSTRACT

Seven term-end projects from an individual student or group of a Staff Scheduling Excel template illustrate the complexities of the real world. These examples were from various universities in engineering and business by either graduate or undergraduate students. Each example shows an unexpected lesson in the real world of scheduling apart from standard optimization.

KEYWORDS: Spreadsheet, Staffing Model, Application

INTRODUCTION

I have been teaching OR/MS using several spreadsheet templates since Microsoft first came out with Multiplan, which was quickly swallowed up by Lotus 1-2-3. Microsoft's new spreadsheet, Excel, then crushed and put Lotus out of the spreadsheet business. I have taught Applied Management Science to undergraduates and graduate students in Engineering and Business Schools. I have used simple spreadsheet models to give students a taste of optimization and practical implementation of results for at least forty years. At the end of my courses, students must choose one of the many templates provided in class to show a practical application in their workplace or the real business world. Students apply one of the most popular templates, the Staff Scheduling template, to optimize staff coverage at call centers, grocery stores, production lines, and numerous other workplace situations.

During each semester, I first give students an example of staff scheduling in class, as shown in **Figures 1 and 2,** and explain the logic of the template and the Solver for this particular situation. Then students are given a homework problem to experience running the ILP (Integer Linear Program) using the built-in Solver in Excel. Extra constraints can limit the number of part-time employees, making sure full-time employees close the store, and so on. Near the end of the semester, each student or team must choose a template covered in the class for their final project. I help the students with their term-end assignments, regardless of which template or application they choose. The following examples demonstrate that optimization is not always the only goal or problem with the scheduling templates. The staff scheduling template has been a popular selection over the years, and this paper shows seven interesting transitions from homework in class to application in the workplace.

Briefly, the template has room (which can be expanded or made smaller) for a 12-hour day, staffed by full-time (FT) and part-time (PT) workers who have different hourly costs. Not shown is a row that can set max/min limits, so the model does not just hire all part-timers and secures a certain number of full-time workers. Not only is there a pay difference, but FTs are more productive than PTs. Also, rules for breaks can be different, with no need for lunch/dinner breaks for 4-hour PTs, and so on.

But as different students at different universities with varying work environments used these templates, I found at least seven unexpected lessons from these real-world applications.

The basic template is shown below in **Figure 1** and **Figure 2**..

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
22	Full-time Closer	1	≥	1													
23	≥ 4 full-timers	4	≥	4													
24	Full-timers can start at 8, 9, or 10 and take one-hour lunch (unpaid) within 2, 3, or 4 hours and work 8 hours. (3X3=9)																
25	Part-timers work 4 hours straight with no lunch breaks. (8 possible)																
26	Store is open from 8AM to 7PM.																

Figure 1. FT constraints

CLASS EXAMPLE: Simple Staff Scheduling Excel Template. (XXX, 1998-2022, pg 8, by YYY)

The Corner Store, a privately-owned small convenience grocery store, is open from 8 AM to 7 PM. Bob Smith has nine possible full-time shifts and eight part-time shifts available for his checkers. Each shift can have 0, 1, 2, or more checkers. The RHS in **FIGURE 1.13** estimates the number of customers served for each hour. All part-time checkers (9-17) are paid $8.00/hour and can check 16 customers/hour, and all full-time checkers (1-8) are paid $12.00/hour and can check 24 customers/hour.

Bob has been opening the store himself with two other full-time checkers on shift 3, one full-timer for shift 9, and one part-timer each for shifts 13 and 17 for a daily cost of $448.

CHECKER SCHEDULING

CHECKER

	$/hr	# hrs	#cust
Full-time	$12.00	8	24
Part-time	$8.00	4	16

HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
8-9	1	1	1							1							
9-10	1	1	1	1	1	1				1	1						
10-11		1	1	1	1	1	1	1	1	1	1	1					
11-12	1		1		1	1	1	1	1	1	1	1	1				
12-1	1	1		1		1		1	1		1	1	1	1			
1-2	1	1	1	1	1		1		1			1	1	1	1		
2-3	1	1	1	1	1	1	1	1					1	1	1	1	
3-4	1	1	1	1	1	1	1	1	1					1	1	1	1
4-5	1	1	1	1	1	1	1	1	1						1	1	1
5-6				1	1	1	1	1	1							1	1
6-7							1	1	1								1

SHIFT #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17		
Minimize Cost			$288						$96				$32				$32	$448.00	<=OPTIM
DECISIONS =>			3						1				1				1		

	SHIFTS																	USED ≥	NEED
HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	LHS	RHS
8-9			72															72	50
9-10			72															72	60
10-11			72						24									96	70
11-12			72						24				16					112	70
12-1									24				16					40	35
1-2			72						24				16					112	45
2-3			72										16					88	80
3-4			72						24								16	112	85
4-5			72						24								16	112	80
5-6									24								16	40	40
6-7									24								16	40	40
																	TOTAL	896	655

FIGURE 2. *Excel Corner Grocery Store Shift Scheduling Model Current Solution*

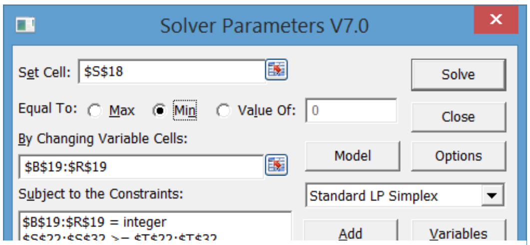

Figure 3. Solver Setup

Bob wants to minimize the total cost for the checkers scheduled and is also interested in what difference it might make if a full-time checker must close the store. Finally, since Bob has four full-time employees (including himself), what is the cost of keeping all the employees? **Figure 3** shows the setup for the Solver.

I describe this optimized model in class, ensuring each row requirement is satisfied. Additional constraints can then be added for lower and upper bounds on the number of full-time and part-time workers. Students then solve homework problems similar to this, assigned for both groups with one individual problem to help each student learn the power of the template.

In the example scenario of the Grocery Store, there are two levels of workers: either full-time (8 hours with one-hour lunch break) or part-time (4 hours with no lunch break), different pay and number of customers served for each level, shown at the top of the model.

LESSON 1: Data and wise management

One of the earliest scheduling models in Operations Research/Management Science was developed by AT&T (Ma Bell) before spreadsheets, personal computers, or even mainframe computers. Telephone operators were scheduled with "split shifts" to cover busy hours for the US's largest telephone network. An operator (usually a woman) was required to come in early for 4 hours, go home for 4, and return at the end of the busy daytime hours for four more hours. The rise of unions and pushback for double pay for split shifts ended that practice. So this scheduling problem became a pervasive optimization problem: Too many operators when not busy and not enough when phone lines were active.

In the mid-90s, I made up a call center spreadsheet model as one of the several management science models covered in my senior engineering class at Mercer University. I also had a Senior Design Team at Mercer of four engineering students, one of whom worked tor GEICO's call center in the Macon, Georgia area, during late evening and early morning hours. A few Mercer Engineering students enjoyed the hours of their late day/early night shifts and could also get some studying done while on their shift. I was connected with GEICO management to have the team study the current scheduling and use my class Lotus spreadsheet template to investigate a more efficient and economical way of covering incoming calls. GEICO kept extensive records of the number of incoming calls, duration, hold times, and abandoned calls in 20-minute intervals for the 24/7 call center. This model gave 72 rows for the model for just one day and made the model very large. The student team learned a lot about inputting data and running different scenarios. Their final suggestions did an excellent job of reallocating personnel and making up a few other shift configurations. Management could see which shifts were over and understaffed and were excited that their record-keeping could show this in the model. The team's recommendation was to see if they could get a few of the employees to change their current shift slightly. But also, since turnover (churn) is quite significant at call centers, as employees leave and new ones arrive, management could see that inefficient shifts would be eliminated and replaced with efficient ones for new employees. This method would increase the efficiency of the call center without the personal disruption of the current employees. Management had a genuine concern for their workers and an appreciation for what the Senior Design Team had accomplished. Therefore, as employees left and new hires arrived, management would fill the more optimal shifts rather than forcing current employees to take on new ones. It was a simple matter of updating the model on a computer disk and keeping an eye on efficiency each month.

LESSON 2: Unplanned Absences and Shifting Production.

"The best-laid plans of mice and men oft go astray!." (Robert Burns, idioms.thefreedictionary.com/the+best-laid+plans)

Kim, a senior engineering student at Mercer, needed a few extra credits for graduation besides her senior design project. Kim worked the second shift for Armstrong Ceiling Tiles on the production line. The problem was not just scheduling the workers but also getting them to show up! There were planned absences (vacation, jury duty, funeral, union permission) and unplanned absences (illness, injury, sickness in family, tardy, work refused). Armstrong gave her four months of data from HR, and she made up a spreadsheet to show how many workers showed up for work and how many absences were planned (excused in advance) and unplanned.

Figure 3 shows the number of actual workers and unplanned (**UP**) and Planned (**P**) absences during a typical month, January. Note that there are more unplanned than planned absences.

Observed Shift	Days Work	Unplanned Absence	Plann Absence	**Totals** **January**	**Percentages** **P(UP)**	**P(P)**
1	1382	241	197	1820	6.92%	5.66%
2	1068	348	245	1661	10.00%	7.04%
3	1363	213	188	1764	6.12%	5.40%
Totals	2450	589	442	3481	23.04%	18.10%

Figure 4. *Data for Armstrong Ceiling Tile Workers January*

Workers were scheduled for four days on, four days off, for one of three different shifts each day. Workers kept the same shift for at least three months. Eight different production lines needed 68-74 people on the three daily shifts (1, 2, 3). Not all positions and shifts are interchangeable, and if there are not enough workers, some specialty lines cannot operate.

Because the days of the week rotated for all workers, it was hard to establish that "Mondays" or "Fridays" had more or fewer absences and could predict when shortages would occur. She discovered that there were consistently more unplanned absences than planned. So regardless of the production schedule, there was no guarantee of having workers to produce the product. One thing was evident; unplanned absences were always more than planned for these four months. So at least a ballpark estimate of UP from the Planned Absences (which had two-week notices) could help estimate which specialty lines should shut down, reschedule workers and keep the main business lines uninterrupted.

LESSON 3: Management and Unions work together for a better solution.

The last example from my time at Mercer involves an individual Master of Sciences Project, in which each graduate needed to apply to the company where they worked. At TRANE, producers of HVAC equipment, this scheduling situation involved extra Saturday work at double-time pay. Union rules required that "First Right of Refusal" went in order of seniority. Although these workers were usually the most experienced and efficient (lowest error rate), problems arose with the workers doing too much Saturday work and becoming less efficient, not only on Saturdays but also during the regular workweek. Recording error rates on a spreadsheet made it evident that no more than two Saturdays should be assigned to workers before they went to the end of the queue. This change in scheduling benefitted the worker's mental health and allowed for Union protections, wise management cooperation and intervention, and increased productivity.

LESSON 4: UCLA Medical Center Reservations Call Center - Models can show warnings and change minds.

When I left Mercer in the late 90s to teach at Pepperdine in the Graziadio School of Business & Management, my Excel templates matched my second textbook, and I continued to develop more templates. Again I required an individual project from these working adult students. One of the most frequently chosen again was the Scheduling template. In this instance, the MBA student was UCLA's call center manager making appointments for doctors, lab work, and other medical services. Management had just issued an edict that there would be a staff cutback for all departments of a certain percentage of employees. This student quickly set up the scheduling template with the now reduced number of employees answering the phone and could easily show the number of calls that would be lost. Then she plugged that into the Medical Center services to show that they would lose a large number of patients, and that would slowly but surely affect the center's bottom line. She also optimized the model to show a need for a 10% increase in current workers and how that would feed into a much more profitable medical center. Her budget was increased rather than decreased by simply showing the results of a "what-if" situation, completing a tremendous term-end project.

LESSON 5: E2B MBA Project to schedule production use to minimize high energy costs by changing production days.

A San Francisco Bay Area manufacturer and designer of packaging solutions for consumer goods and medical products have been in the bay area for over 50 years. They used high-pressure, impact plastic injection molding for protective packing, requiring much energy. They have built a thriving business with annual revenues exceeding $17 million. I volunteered to do an **E2B** (**E**ducation **T**o **B**usiness) project with my MBA Quantitative Analysis class at Pepperdine with 15 students. I formed three teams of five to do their analysis. These three groups of five students were not allowed to discuss their team's findings with the others during the semester but had access to the same data and company representatives.

One of the key cost components of operation was energy. PG&E (Pacific Gas & Electric) rates had increased significantly over several years. This manufacturer operates 24 hours a day, five days a week. The company was considering switching to an alternative source of energy. Students were to research and analyze the different types of energy available to the company, such as direct power, natural gas, solar energy, Bloom Technology, and Diesel. The company's CEO wanted to determine if it should continue to use the transformer provided by PG&E or if it should invest in owning its transformer.

About halfway through the 16-week semester, each team would present to the professor, the Pepperdine director of E2B projects, and a marketing employee of the company (a recent Pepperdine MBA graduate who suggested this project to her company). All observers gave grades on different project parts and provided constructive feedback. One group, in particular, had an interesting recommendation. They suggested shifting production days to include the weekend (at much lower energy rates), keeping the five-day workweek. Also, runs that required much higher energy would be done on second and third shifts when rates were lower. I did not think that the company would even consider this. Still, a cost analysis showed that workers would receive a higher paycheck, and the company would enjoy lower energy production costs which more than paid for higher wages. This company was immediately in favor of this. There was no need for a Scheduling Template, just shifting the schedule. Before the semester was over, the company implemented this as a stop-gap measure to lower production costs by 3% and eventually 5%.

"*In the short-term, we recommend that the firm adjust the production schedule to take advantage of lower rates offered on weekends and that the company avoids production on Peak Day Pricing event days. This new schedule would allow for a minimum of 5% savings on the current energy bill.*" (GLOW Report, 2012, Project Paper). This recommendation was immediately implemented to shift their heaviest energy production during Saturdays and Sundays and gave Tuesday-Wednesday as the "weekend" for workers.

LESSON 6: Battling Accounting Department – A Win/Win Solution By Splitting Shifts.

This problem described in the box below was emailed to me by a former Pepperdine MBA student working as an administrative assistant for JPL/NASA (Hesse, R, *LUMAT 4: Applied Integer Programming Models***,** 2020, pg 12). After two disastrous Mars missions of the robot landers crashing into the planet or missing it entirely, the upcoming missions needed 24/7 monitoring for the next two years. Workers complained that with the current shift (4 days of 12-hour shifts on, 4 days off), workers received weekly paychecks for 48 hours, then the next week 36 hours. They wanted their paycheck to always be for 42 hours a week, but the accounting department refused to do this, saying it was illegal.

Shown in **Figure 5** is a portion of the email I received. I can't remember the student's name, but it's somewhere in my records.

At JPL people monitor the spacecraft 24 hours a day. Right now there are 4 crews with three people on each crew. They work 12 hour shifts 6:00AM to 6:00PM Daytime, 6:00PM to 6:00 AM Nighttime. Currently they work 4 days and then have 4 days off and at the end of each quarter the crews rotate the ones that worked daytime switch to nighttime and vice verse.

```
           M T W TH F S S M
Daylight   1 1 1 1  2 2 2 2
Nightlight 4 4 4 4  3 3 3 3
```

I am trying to come up with some different ways that the 4 crews can do this. The people are all salaried people so they do not get a different salary for working during the night and no one gets paid more than the other person. The main problem that they have is because of the way the payday falls (Saturday to Friday) some of the crews get paid 48 hrs and the other ones only get paid 32 hours. Maybe they could work 8 hour shifts instead of 12 hours and have 2 days off instead of 4.

Figure 5. *JPL Problem email*

After thinking about this problem and her suggestions, I looked at my Scheduling Template again. I realized that it was ***NOT*** an optimization problem but simply ensuring that each shift and week has 42 hours instead of 36 or 48. As shown in **Figure 6**, my solution was to allow splitting the fourth 12-hour shift into two 6-hour shifts.

Mars Mission for JPL

Mars3

	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
Shift A	12	12	12	6				12	12	12	6				12	12	12	6			
Shift B				6	12	12	12				6	12	12	12				6	12	12	12
Shift C	6	12	12	12				6	12	12	12				6	12	12	12			
Shift D	6				12	12	12	6				12	12	12	6				12	12	12
	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24

	WK1	WK2	WK3	WK4	WK5	WK6	WK7
Shift A	42	42	42	42	42	42	42
Shift B	42	42	42	42	42	42	42
Shift C	42	42	42	42	42	42	42
Shift D	42	42	42	42	42	42	42

This is a balanced model that repeats itself every 7 days and evens out the pay hours every week and would allow for a change every quarter (or sooner if desired). Each person would cycle through the 4 shifts, one shift per quarter for a complete year. Basically each person works 3 1/2 days, then is off 3 1/2 days, but pay stays equal.

Figure 6. *Professor's JPL Solution*

The next shift would come in for just 6 hours that same day and then work three 12-hour shifts on the next three days. When she sent this to the supervisor, my student said everyone was ecstatic – workers, supervisors, and even the accounting department! Thus each day is covered for 24 hours, and each worker works 3 ½ days (42 hours) per week. I would love to get a mission patch for this someday.

LESSON 7: Optimizing X-Ray Technician Schedule and Changing Career Path.

After I retired from Pepperdine but still wished to teach, I came to Lincoln Memorial University and taught in the MS Business Analytics Program (MSBA). This final scheduling example is from a graduate student working as an X-Ray Technician seeing an application for his current job. This spreadsheet led to a new job with the Analytics Department at the hospital. His term-end project scheduled full-time (F1-F10) and part-time (P1-P6) X-Ray Technicians, as shown in **Figure 7**. Full-time technicians worked five days per week, while Part-time technicians worked just three days per week. He also submitted this to his boss, who took it under consideration. Several months after the student's graduation, the hospital's analytics team invited this X-Ray technician student to be part of their Analytic team. He sent me an email thanking me for supporting his term-end project.

WEEKLY X-Ray Technologist Scheduling

FT Days 5

PT Days 3

WEEKLY			10	=	10	Full-time							6	≤	6	Part-Time		Weekly					
SHIFT #	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	P1	P2	P3	P4	P5	P6		Staff days					
Staff =>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		68	<-- Minimize				
Days	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	P1	P2	P3	P4	P5	P6		USED		NEED	F-T	P-T	Busy
Sunday	1			1	1	1	1		1	1	1					1	XXX	9	≥	6	7	2	66.7%
Monday	1	1			1	1	1	1	1	1	1	1					XXX	10	≥	10	8	2	100.0%
Tuesday	1	1	1			1	1	1	1		1	1	1				XXX	10	≥	10	7	3	100.0%
Wednesday	1	1	1	1			1	1		1		1	1	1			XXX	10	≥	10	7	3	100.0%
Thursday	1	1	1	1	1				1	1			1	1	1		XXX	10	≥	10	7	3	100.0%
Friday		1	1	1	1	1		1		1				1	1	1	XXX	10	≥	10	7	3	100.0%
Saturday			1	1	1	1	1	1	1						1	1	XXX	9	≥	6	7	2	66.7%
																		68		62			91.2%

Figure 7. *Scheduling X-Ray Technicians*

7

CONCLUSION

These seven examples of Real-World Scheduling demonstrate the many dimensions of scheduling and the need to look beyond an optimal solution in the case of unexpected consequences. Students learn much about business and management when implementing a template for their work situations. Each situation has human dynamics with workers, unions, management, and constraints not always seen on a spreadsheet.

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DECISION SCIENCES INSTITUTE

Host Information Disclosure on Accommodation Sharing Platforms: The Impact of Privacy Policy

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ABSTRACT

Users' privacy concerns over social interactions and online transactions on accommodation sharing platforms (ASPs) are escalating. This study investigates the impact of privacy policy on mitigating hosts' privacy concerns, enhancing perceived benefits, and encouraging their information disclosure on the ASPs. We find that hosts are more concerned about the other users' misappropriating the private information that the hosts disclose on the platform than the platforms' privacy invasion behaviors. However, this major concern is not significantly mitigated by the current privacy policy. Moreover, social benefit has a stronger effect than economic benefit on the hosts' intentions to disclose information on ASPs.

KEYWORDS: Privacy policy, Information disclosure, Social benefit, Economic benefit

DECISION SCIENCES INSTITUTE
How and Why Students' Perceptions of Accounting were formed:
Evidence from a GCC University

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ABSTRACT

By drawing on Belief Perseverance, this study investigates the pre-and post-perceptions about the First Accounting Course that exist between accounting and non-accounting students in a virtual learning setting at a GCC university and explains why their perceptions were formed. Adopting a case study approach, this study employs quantitative (anonymous questionnaires) and qualitative (semi-structured interviews) methods. Responses indicate that non-accounting majors did generally change their perceptions significantly, whereas accounting counterparts had relatively stable perceptions. This study also finds that a number of non-accounting students perceived the benefits of taking the course and have generally less negative perceptions of the accounting profession.

KEYWORDS: Accounting Education, Students' Perceptions, First Accounting Course, Belief Perseverance Perspective, GCC

DECISION SCIENCES INSTITUTE

How CMS Incentive Payments Influence IT Related Infrastructural Decisions, Operational Risk and Performance in Hospitals

FULL PAPER SUBMISSION

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ABSTRACT

The USA Federal Government heavily incentivizes hospitals to adopt health information technology (HIT) which is costly. Understanding how incentives influence HIT adoption is important because different types of HIT influence operational performance differently and are vulnerable to different levels of operational risks (i.e., data breaches). We adopt a complexity perspective to investigate the influence of incentives on HIT bundles and consequently operational performance/risk by analyzing 141 data breaches transpiring 544 hospital years. Incentive payments lead hospitals to invest heavily in clinical HIT which reduces breach magnitude, but also lowers EQ. However, while augmented HIT increases breach magnitude, it improves EQ.

KEYWORDS: Healthcare data breach, CMS incentive payment, Health information technology (HIT), HIT investment, Experiential quality (EQ)

INTRODUCTION

The healthcare industry is undergoing a digital transformation (Chernyshev et al, 2019, Cresswell & Sheikh, 2015) that offers a suitable context to investigate how IT investments affect both operational performance improvements and cyber risks. With the goal of taking advantage of this evolving information landscape to improve operations, the Centers for Medicare and

Medicaid Services (CMS) developed several incentive programs to stimulate healthcare organizations' adoption of advanced health information technology (HIT). The "meaningful use" (MU) or the "EHR Incentive Program" provides incentive payments for eligible acute care inpatient hospitals that adopt a certified EHR system in any year from FY 2011 to FY 2015 and demonstrate that they are "meaningfully using" their EHRs by meeting thresholds for objectives defined by the CMS. The magnitude of the incentives can be enormous, up to $63,000 per eligible physician, while failure to comply attracts penalty of up to 5% of a hospital's Medicare payment.

EHRs are expensive technologies (Poon et al., 2004, Sharma et al 2015) as initial average purchase and implementation cost of an EHR can be up to $32,606 per full time equivalent (FTE) physician and maintenance costs another $1,500 per month (Agency for Healthcare Research and Quality [AHRQ]). Hospitals across the United States have invested heavily to respond to the MU initiative. While research has shown that MU has increased EHR adoption leading to increased operational efficiency (Ko et al, 2019; Queenan, Angst & Devaraj, 2011, Wang et al, 2015; Roham et al, 2012; Çam, 2016; Xiao et al, 2012; Zhivan & Diana, 2012) and improved process quality (Wani & Malhotra, 2018; Xiao et al, 2012;), HIT adoption comes with its own downsides. One major concern is the security of the large amounts of patient data being collected and analyzed. EHRs can be targeted by hackers as they store patients' sensitive personal identifying information such as social security numbers in addition to medical histories and health information (Coventry & Branley, 2018; Cohen, 2018).

Healthcare data breaches have dire consequences for hospitals (Ke et al, 2022). Regulations (i.e., HITECH and HIPAA) provide mandatory data security guidelines and financial penalties for data breaches (Dobrzykowski, 2019; Angst et al, 2017). The cost per data breach in healthcare is the most expensive by industry, with the average cost of went up from $7.13 million per breach in 2020 to $9.23 million in 2021 (IBM, 2021; IBM, 2020; Becker's Hospital Review, 2021). In addition to financial penalties, healthcare entities are required to adopt a corrective action plan to bring policies and procedures up to the standards. All these create operational burden and additional costs, along with severe social, and reputational consequences (Ke et al, 2022; Coventry & Branley, 2018; Gerard et al, 2013). Therefore, it is important to examine how CMS incentive dollars impact hospitals' key IT infrastructural decisions on investment choices in different HITs, and how those decisions may in turn, impact operational performance such as patient experience and data breaches. In this study we aim to answer the following research questions: (a) How do HIT adoption incentives drive hospitals' IT adoption? And (b) How does hospitals' IT adoption impact data breaches? (c) How does hospitals' IT adoption impact patient experiential quality?

We draw on the institutional theory and the complex adaptive systems framework to develop our hypotheses. We inform our research questions by combining archival data from 4 different sources to examine these research problems. Our study is an exploratory investigation of 141 data breaches in US hospitals from 2012 to 2017. The main objective is to examine potential associations between incentive payments for HIT adoption, healthcare organizations' future IT adoption practices, and healthcare data breaches. To the best of our knowledge, this is the first study investigating the above relationships.

Results suggest hospitals' propensity to postpone investment into HITs primarily geared at entrepreneurial revenue generating purposes (also known as Clinical HIT) and divert funds towards adoption of HITs primarily used for information management purposes (also known as

Augmented HIT) as they strive to comply with CMS regulations. Once rewarded with incentives for successful implementation of certified Augmented HITs, hospitals tend to re-invest in Clinical HITs. However, while augmented HITs were found to increase data breaches, they improve EQ. Contrastingly, clinical HITs help to reduce the magnitude of healthcare data breaches, but they also lower EQ. As such, we unpack the differential effects of CMS incentive payments on HIT investment types, as well as differential effects of HIT types on breaches as well as on EQ. The overall implications and policy recommendations are discussed.

BACKGROUND

Health IT bundles

This study follows Sharma et al (2015) to classify HITs into three categories namely *Clinical HIT*, *Augmented Clinical HIT*, and *Administrative HIT*. Because Administrative HITs are not directly related with patient care and have minimal care provider interactions, we specifically focus on the Clinical HIT and Augmented Clinical HIT (Augmented HIT hereafter).

Clinical HIT

Clinical HIT systems “primarily deal with collection, testing and processing of patient data for medical purposes or in treating patients” (Sharma et al, 2015, p 28). These are not new to hospitals as “a vast majority of these systems have been present as islands of automation across U.S. hospitals since early 1980s” (Sharma et al, 2015, p 28), while some systems (eg, computed tomography or CT scan) have been in use since the mid-1970s (Filler, 2009). Thus, hospitals have been investing in Clinical HIT for long. As a result, caregivers are generally familiar and comfortable with Clinical HITs and investment in Clinical HIT does not lead to significant disruptions to their work routines. Moreover, studies have shown that Clinical HIT helps hospitals to eliminate inefficiencies in care delivery process (Staggers, 2004; Watcharasriroj and Tang, 2004), improve care coordination (Borzekowski, 2009), which reduces additional rework and errors, ultimately reducing operating cost (Borzekowski, 2009).

Augmented HIT

On the other hand, Augmented HIT systems are comparatively rarer technologies in the HIT. For example, EMR technologies which form a significant part of Augmented HIT only had a 7.6% adoption rate in the year 2008 (Jha et al., 2009). Besides, Augmented HIT systems are expensive and requires substantial investments (Poon et al., 2004, Sharma et al 2015). For example, depending on hospital size, computerized practitioner order entry (CPOE) system can cost anywhere between \$3 million and \$10 million (Poon et al., 2004). According to Kuperman and Gibson (2003), augmented Clinical HIT adoption involves significant cultural transformation which can be extremely expensive, too.
In addition, as Augmented HITs are relatively new technologies, their adoption often faces resistance from the users as many individuals find it difficult to manage the change in the dynamics of the work processes and environments (Cresswell & Sheikh, 2015). For instance, Lapointe and Rivard (2005) found that physicians in major teaching hospitals to be reluctant in using Augmented Clinical HIT systems because of requiring substantial change in their regular work routines. Thus, hospitals are forced to implement mandatory training programs for care providers after adoption of Augmented HIT systems. This results in significant operating expenses. In addition, there is little appreciation that benefits may take a long time to materialize

(Cresswell et al, 2012). Thus, although Augmented HIT may complement Clinical HIT, the return on investment on Augmented HIT is usually low during the early days of adoption.

HITs and hospital performance

The impact of HIT adoption on hospital performance has been widely studied in the medical services literature, and to some extent in the operations management literature. Increased adherence to guidelines, enhanced surveillance, and reduced medication errors have been identified as major benefits of HIT adoption that drive better performance (Wani & Malhotra, 2018; Jones et al, 2014; Chaudhry et al, 2006). Performance has been measured in different dimensions. EMR implementation has been shown to improve efficiency (Ko et al, 2019; Queenan, Angst & Devaraj, 2011, Wang et al, 2015; Roham et al, 2012; Çam, 2016; Xiao et al, 2012; Zhivan & Diana, 2012; Jones et al, 2014). While some studies reported improved care coordination as a result of EMR adoption, others have reported inconclusive results (Bates, 2015; Agha, 2014). Better coordination strategies have been associated with better patient experience in the healthcare quality and services literature (Figueroa et al, 2018; Mohr et al, 2019;) as well as in the operations management literature (Dobrzykowski & Tarafdar, 2015; Cite). Few studies have also examined the relationship between and quality measures and different HIT applications or customized HIT solutions (Feldman et al, 2018). For example, positive association between EMR implementation and patient satisfaction (Kazley et al, 2012; McCullough et al, 2010), computerized physician order entry and clinical quality measures (McCullough et al, 2010). Yet, the literature has not conceptualized HITs as different bundles based on their application and functionality when examining their relationship with different dimensions of quality and operational risks such as data breaches.

THEORETICAL DEVELOPMENT

How hospitals manage investments in different HITs

To gain first-hand insights on hospitals' investment practices and policies around different HIT types, we interviewed a healthcare attorney who graciously shared her experience with us. One of the stories she shared provides useful insights on how hospitals juggle investment priorities around regulatory requirements, budget constraints and revenue generation. She mentioned the incident when one of her client hospitals had to put aside the purchase of robotic *da Vinci Surgical Systems* (which cost ~$2 million each) to make investments into an EHR system as a response to the MU initiative. After successful adoption and implementation of the EHR system, the hospital received the incentive money from CMS, and utilized that money to purchase the *da Vinci Surgical System.* She further elaborated that although hospitals have separate IT budget and capital budget, often hospitals must pull back on their capital budget to fuel IT adoption. Once the hospitals no longer need to invest more on IT, or receive incentive payments tied to IT adoption, they put money on the capital budgeting areas which had to shrink previously because of the IT investments.

This story really points out that hospital administrators look at the two types of HITs as different infrastructural elements. We think it is important to understand how government incentive payments influence hospitals' decisions on these two types of HITs as this helps to generate valuable insights on healthcare organizations' investment strategies and guide future policy development. Additionally, given the different roles these HITs play in hospital operations, it is conceivable that they will have different influence on operational risks such as data breaches, and operational performance such as EQ. Based on this rationale, we adopt the conceptual framework depicted in figure 1 for our research.

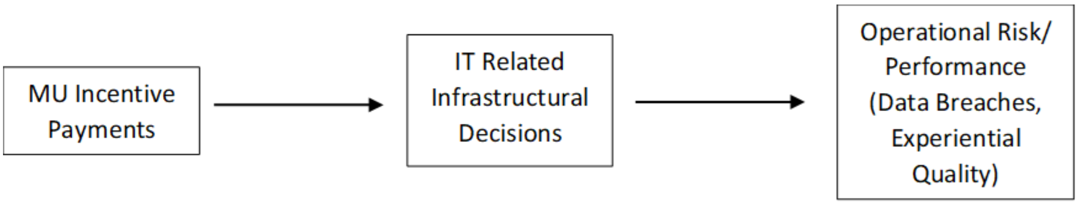

FIGURE 1: Conceptual Framework

Coercive pressure and HIT adoption

We draw on Institutional Theory (DiMaggio & Powell, 1983) and explain this phenomenon with the concept of institutional isomorphism. According to Institutional Theory one form of institutional isomorphism is the *coercive isomorphism* which "results from both formal and informal pressures exerted on organizations by other organizations upon which they are dependent and by cultural expectations in the society within which organizations function. In some circumstances, organizational change is a direct response to government mandate" (DiMaggio & Powell, 1983, p150). Mandated by the MU initiative of CMS, and motivated by the financial incentive payments awarded after successful demonstration of MU criteria, hospitals postpone investments on Clinical HITs and divert those funds towards adopting newer EHR (i.e. Augmented HIT) technologies. When the MU requirements are satisfied, hospitals are rewarded with the incentive payments, and are no longer required to invest in Augmented HIT. With the coercive pressure for newer and expensive Augmented IT adoption no longer in place, hospitals use the available money to fund the more stable and revenue generating options – the Clinical HITs which had been postponed. Based on this rationale, we hypothesize:

H1. Incentive payments will negatively influence Augmented HIT adoption.
H2: Incentive payments will positively influence Clinical HIT adoption.

Complex Adaptive System (CAS)

We draw on the CAS (Choi et al, 2001; Dooley, 1996) framework to examine the different HIT systems and their association with healthcare data breaches. A CAS is defined as a group of heterogeneous, independent agents (or elements) who interact with each other in interdependent ways and make decisions which produce system-wide patterns. Such patterns eventually influence behavior of the agents as well as the outcomes of the system. It is often difficult to predict those outcomes by looking at individual agents or specific interactions between agents. The key characteristics of a CAS are:

a) The system outcome cannot be predicted simply by analyzing agents and/or interactions in isolation
b) The behavior of the system is dynamic and changes with time
c) The agents/elements of a CAS are self-learning, and they change their behavior depending on circumstances and previous experience

Complex Adaptive System (CAS) and HITs

We propose that Augmented HITs are complex adaptive systems as they exhibit all the three characteristics listed above. The purpose of Augmented HIT systems is to integrate and manage information from multiple other HIT systems and to provide decision support as well as reporting capabilities to higher level care providers such as physicians and nurses (Sharma et al, 2015). For example, Clinical Decision Support Systems (CDSS) represent Augmented HIT which help the clinicians in diagnosis by accessing patient's demographic information, medical history, laboratory test results, and combining those with currently available knowledge on medicine, clinical research, and best practices recommendations. This helps care providers in their decision-making in diagnosing and treating patients.

Secondly, an Augmented HIT system is subject to much more human interactions relative to Clinical HITs. For example, the EHR (an Augmented HIT) accesses information from multiple other clinical and augmented HIT systems and combines it with the patient's demographic and medical history. From this point, information from across the organization can be accessed by several providers involved in a patient's care such as the radiologist, the referring physician, nurses, and other allied health professionals. As a result, Augmented HITs are more vulnerable to individual behavior and the outcome of a patient's stay cannot be predicted by analyzing any specific part of the system. As more caregivers interact with the system, they go through self-learning processes and create workarounds, too. This adds to the dynamicity and increases the complexity of the entire system. Therefore, Augmented HITs are indicative of CAS and this makes it much difficult to secure juxtaposed Clinical HITs which are much stable and less complex in nature. As Sharma et al (2015, p 28) rightly observes, "Augmented HIT is substantially more complex than Clinical HIT and is primarily focused on integrating various clinical technologies."

Moreover, multiple points of exposure in the Augmented HITs make them more vulnerable to accidental as well as intentional data breaches. Additionally, integrating multiple technologies improves access to organization wide data (Galbraith, 1973). Thus, from a breach perpetrator's point of view, Augmented HITs are more attractive targets as they integrate information from several systems and thereby provide access to a larger database as compared to Clinical HIT which is limited in this regard. Thus, hospitals that have higher level of Augmented HIT implemented, are likely to suffer more from data breaches. On the other hand, the integrative nature and decision support capability of Augmented HIT will enable providers to deliver better care quality and thus, will lead to enhanced patient experiential quality.

On the other hand, Clinical HITs offer less complexity than Augmented HITs. For example, Clinical HITs such as a computed tomography (CT) scanner machine is a type of diagnostic equipment used to obtain images of internal anatomy (brain, lungs, bones, etc.). A CT scanner machine involves care provider interaction at a lower level (e.g., a technologist that operates a machine) as they generally collect unidimensional data. A trained technologist is the only person who uses the CT machine to obtain images of a patient's internal organs. S/he uploads the images into the CT machine's data storage. This process is generally stable unless there is a need to change the regular established protocols.

Moreover, Clinical HITs are generally independent from each other, have limited integrative functions, and very little to no decision support capabilities. Therefore, Clinical HITs are much stable, less complex in nature, and easier to secure compared to Augmented HITs. As a result, Clinical HIT's association with operational risks such as data breaches will be negative. At the same time, as integral part of providing patient services in terms of diagnostics and data generation, Clinical HITs help improve the quality of care, and thus have a positive association with patient experience. Based on this rationale, we hypothesize:

> **H3a:** Augmented HIT will have a positive association with data breaches.
> **H3b:** Augmented HIT will have a positive association with experiential quality.
> **H4a***:* Clinical HIT will have a negative association with data breaches.
> **H4b***:* Clinical HIT will have a positive association with experiential quality.

METHODS AND DISCUSSION

A unique database was developed from 4 different secondary data sources to test the hypotheses. We employ seemingly unrelated regression to test our hypotheses. Results will be presented and discussed at the conference.

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Available upon request from the first author.

The USA Federal Government heavily incentivizes hospitals to adopt health information technology (HIT) which is costly. Understanding how incentives influence HIT adoption is important because different types of HIT influence operational performance differently and are vulnerable to different levels of operational risks (i.e., data breaches). We adopt a complexity perspective to investigate the influence of incentives on HIT bundles and consequently operational performance/risk by analyzing 141 data breaches transpiring 544 hospital years. Incentive payments lead hospitals to invest heavily in clinical HIT which reduces breach magnitude, but also lowers EQ. However, while augmented HIT increases breach magnitude, it improves EQ.

DECISION SCIENCES INSTITUTE

How Supply Chain Complexity Drives Inventory Record Inaccuracy: Empirical Evidence from Cross-border E-commerce

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ABSTRACT

Retailers in e-commerce face supply chain complexity (SCC) from multiple sources (internal versus external, static versus dynamic, product versus component), making inventory record accuracy increasingly important while greatly challenged. This study explores how SCC affects inventory record inaccuracy (IRI) in a cross-border e-commerce context. With empirical analysis on a proprietary data set comprising inventory, sales, and product-attribute information, we find external complexity affects IRI to a greater extent, notably through demand pressure. External complexity also strengthens the relationship between internal complexity and IRI. Dynamically, IRI is more likely to accumulate during periods with intensive product or component launches than phaseouts.

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Impact of COVID-19 on the Residential Construction Industry in the Tampa Bay Area

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ABSTRACT

The COVID-19 pandemic has globally impacted different industries and construction industry is one of them. Many of the demographic effects of the pandemic have led to an increase in the demand for residential construction and currently, the infrastructure is not capable to meet this demand. In this study, COVID-19 impact on the construction industry in Tampa Bay Area was studied. New construction demand was forecasted by using different forecasting methods such as ARIMA, Holt's Smoothing, and Regression techniques. Forecasted demands and analysis results provided insights into the current state of the Residential Construction industry, specifically on materials supply and distribution chain.

KEYWORDS: COVID-19, Construction Industry, Residential Construction, Supply Chain.

INTRODUCTION

The Construction Industry is a vital part of countries' economies (Weber et al, 2016), and it consists of two different sectors: Residential and Non-Residential (commercial, institutional, industrial, etc.). The COVID-19 pandemic has been the largest global health crisis we have experienced in the last years and decades (Abdullah et al., 2021). The pandemic, aside from all the health implications, has caused an economic slowdown and continues to heavily disrupt supply chains (Ivanov, 2020). The COVID-19 pandemic has forced a significant portion of the workforce to transition into permanently remote job positions (Capponi et al, 2020). To escape from expensive metropolitan or COVID-19 highly restricted areas, many higher-earning working professionals have decided to move to relatively minor cities which have caused a disproportionate increase in demand in those local housing markets (Gera et al., 2021), including the Tampa Bay Area. This mass exodus and unintentional demand, aggravated by the negative effects on the supply chain of the pandemic, led to building materials and supply shortages in the area.

Although the outbreak of COVID-19 has impacted people's lives all over the world, its consequences have been different in every country, state, and area. Simultaneously, the Tampa Bay Area has been growing significantly due to many higher-earning working professionals moving to less expensive housing markets. This growth has led to several supply chain constraints in different industries, particularly in the Residential Construction Industry. In addition to material shortages and delays, construction procurement/supply chain managers have taken additional measures to guarantee project completion. For instance, ordering materials with a lot of anticipation and trying to get the material on time leads to an undesired bump in the current demand for suppliers or leading to material damage if they are sitting on job sites for too long. Additionally, material bulk ordering from different states, having additional expenses for material handling, etc., are translated to less efficiency and higher costs for companies.

So, focusing specifically on the Residential Sector of the Construction Industry, this study aims to answer the following research questions:

- Has COVID-19 impacted the Residential Construction Industry in the Tampa Bay Area?
- Is the Construction Material Supply Chain big enough to meet the rising demand for new residential constructions?
- Do forecasts support the installation of new production plants in the Tampa Bay Area to fulfill the rising future demand?

To answer these questions, we applied a quantitative analysis that involves two parts: First, forecasting the demand for residential construction in the Tampa Bay area and then comparing it with the supply side of the housing in the Tampa Bay area.

Through this study, the community will understand the negative impact of COVID-19 such as soaring prices in the housing market, material supply chain constraints, delays on projects, material price escalation, etc. This study provided insights regarding the positive impacts such as the high inventory turnover ratio of the market and the opportunity for growth and development within the Tampa Bay Area. In addition, forecasted demands and analysis results from this study provided insights into the current state of the Residential Construction industry, specifically on the materials supply and distribution chain. Whether the infrastructure is enough to fulfill the rising demand or not, we believe that this study will represent valuable information, to investors and companies in the industry, for future investments in the construction industry’s supply chain.

Theoretical Framework

In this research, the dependent variable is the Residential Construction Industry. The Residential Construction Industry depends on different factors such as Supply Chain and Distribution, Material Pricing, and Housing Market, which are considered the independent variables in this study. It is extremely important to clarify that in this research the COVID-19 pandemic is considered the moderating variable. Variables are better shown in Figure 1.

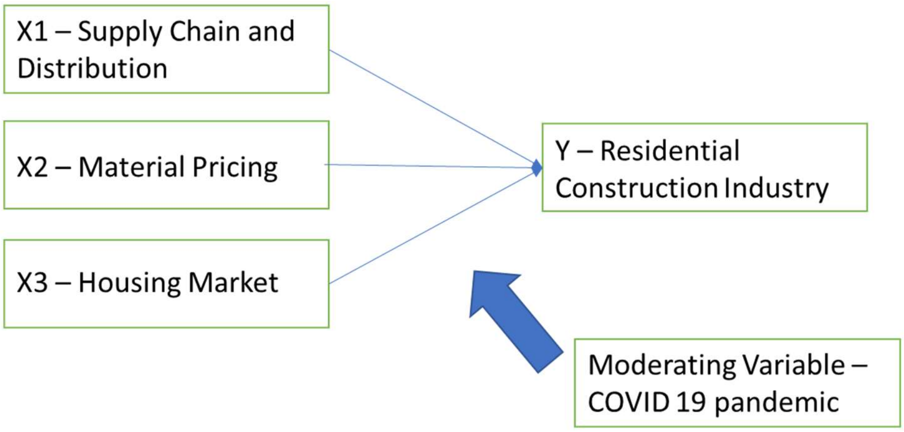


Figure 1 – Variables of the Study

Knowing the equation $Y = X1 + X2 + X3$, it is important to determine how these factors or independent variables affect the dependent variable of the Residential Construction Industry.

Supply Chain and Distribution affect the Residential Construction Industry's performance and efficiencies. Different disruptions or constraints in the supply chain such as problems in production or distribution led to material shortages, translated to project delays, project cancellations, lower performance, etc. Additionally, the Supply Chain & Distribution infrastructure must be big enough or capable of meeting the demand or causing material shortages.

In addition, the variable Material Pricing represents the cost of getting the right material for Residential Construction on time. All construction industries, including the Residential Construction Industry, extremely depend on material pricing fluctuations. Residential Construction Materials such as steel, lumber, or concrete, influence the whole industry and can furthermore manipulate its demand and supply.

Moreover, the variable Housing market plays an important role in the Residential Construction Industry. It is important to mention that the Housing Market is also influenced by migration patterns, the economic situation of the country, development in the area, etc. In this research, the Housing Market conditions the demand and represents the ground where the Residential Construction Industry operates. Within the housing market, there are factors used in this study such as New Private Housing Permits, Median Days on the Market, and Housing Inventory. With New Private Housing Permits, it is desired to measure the change in demand during the pre-pandemic era and COVID years. With Median Days on Market, it is desired to measure and give evidence on how the game has changed in the Residential Construction Industry in the Tampa Bay Area, where the buying force of final products (house) is greater than the sales force. Additionally, with the Housing Inventory, it is desired to measure the current supply of the market, used to give evidence of how this supply has been reacting in the market impacted by the COVID-19 pandemic.

Limitation and Delimitation of the study

It is important to restate that this research aims to fill the gap of previous studies, applied to the whole United States, by narrowing the focus exclusively to the Tampa Bay Area. Although this study is filling the gap by focusing on the construction industry supply chain, it is limited to only Residential Construction. Future studies could be addressed to consider materials for Non-Residential construction such as Industrial Construction, Heavy-Industrial Construction, Commercial Construction, etc., which require different materials than Residential ones and could be experiencing other limitations.

This study will cover COVID-19 effects since it started, however, since the development of the COVID-19 vaccine and the arrival of new and different strains and variants, it is necessary to update and conduct new studies without changing demographics. Additionally, time is considered to be a constraint because the environment that COVID-19 has brought is very changing and unexpected, and it can lose validity in matters of weeks or months.

LITERATURE REVIEW

COVID-19 impacts on the Construction Industry

The COVID-19 pandemic, besides the health crisis, has posed both positive and negative impacts on Architecture, Engineering, and Construction (Ogunnusi et al., 2020). The Construction Industry can be classified as Residential and Non-Residential, which includes commercial, institutional, industrial, etc. (Weber et al, 2016), and both sectors have been affected by COVID-19 since its beginning. The early impacts that the Construction Industry in the United States has experienced are project delays, material shortages, price escalations, and lower productivity (Alsharef et al., 2020). The field and office workforce in the industry have also faced other different challenges related to organizational, economic, and psychological factors (Apurva et al., 2021). Concerning these factors, the situation in the Tampa Bay Area has not been different than in the United States internationally.

Migration Patterns and Housing Market

The COVID-19 pandemic has triggered the option for a significant portion of the workforce to transition to permanently remote job positions. Due to this new possibility, in addition to expensive metropolitans or COVID-19 highly restricted areas, many higher-earning professionals have decided to move to relatively minor cities, causing a disproportionate increase in demand in those local housing markets (Gera et al., 2021), including the Tampa Bay Area. This migration pattern from dense large cities to less-dense smaller cities experienced in 2020 is also known as the Donut Effect (Ramani et al., 2021).
The housing market environment in cities and suburbs, and the increase in demand in now desirable areas do not look to change in the short future facilitated by these remote job opportunities (D'Lima et al., 2021).
In addition to increasing housing demand, these areas have experienced supply chain constraints such as supply shortages, builders and suppliers working at full capacity not knowing if they will be able to meet the demand, increasing material pricing, etc.

Tampa Bay Area

Based on Censusreporter.org data (*Census profile: Tampa-St. Petersburg-Clearwater, FL Metro Area*., 2021), the Tampa Bay Area's population has increased by 15.5% since the previous year, and builders and construction companies are working at full capacity to build houses for this growing demand. However, the material production and supply chain have not been capable to meet this demand, leading to project delays or cancellations, low productivity, material price escalations, etc. Some studies also explain the COVID-19 impact on the global construction industry, however, since they are too broad it is hard to generalize the impact or consequences associated with the U.S. to any other area. It is important to restate that this research aims to fill the gap of previous studies, applied to the whole world or the United States, by narrowing the focus exclusively to the Tampa Bay Area. This study will only focus on the Tampa Bay Area and how COVID-19 has impacted it specifically.

Supply Chain Constraints

The Supply chain is the integration of key business processes from end-user through original suppliers that provides products, services, and information that add value for customers and other stakeholders (Lambert et al., 2000). The global spread of the pandemic has had devastating impacts on the supply chains, affecting their efficiencies and performances, resilience and sustainability, and propagating disruptions across them (Priyabrata et al., 2021). This research wants to provide more information about the residential construction supply chain, and how it has suffered the impacts of the COVID-19 pandemic.

Review of Theories

There are different theories about COVID-19 impact on Construction and Supply chains among all the studies reviewed for this research's purpose. D'Lima and Lopez (2021) established a possible relationship between shutdowns due to COVID-19 and price changes in different-density Housing Markets. For dense locations, shutdowns were followed by a price decrease in the housing market, but for less dense locations, shutdowns were followed by a price increase. Alsharef et.al. (2021) estimated in their research "Early Impacts of the COVID-19 pandemic on the United States Construction Industry" that besides delivery delays, material shortages, etc., it was going to also affect the permitting department of each state/county. On the positive side of their theory, they unveiled that companies are putting more effort into complying with safety measures, from workplace measures to COVID-19 measures such as face coverings, social distancing guidelines, etc.
Additionally, Ogunnusi et. al. (2021) established in their research that despite the challenges and negative implications of the pandemic, there are positive impacts such as overhead cost reduction, lower interest rates, more residential sectors, the now available remote working options, as well as better social implications on the safe side.

Review of methodologies

Different Methodologies were used in the studies reviewed for this study. Ogunnusi et.al. (2021) collected data for their research "Lessons Learned from the Impact of COVID-19 on the Global Industry" with a qualitative methodology and with an online open-ended structured

questionnaire, which data was later analyzed through AI analytical tools. Similarly, Ogunussi et.al. (2020) gathered information about the effects and prospects of the COVID-19 pandemic in the Construction Industry with a questionnaire survey addressed to construction professionals from around 16 countries.
On the other hand, D'Lima and Lopez (2021) used a nationwide sample with more than two million residential transactions in the US in their research determining COVID-19 effects and evidence on the housing market and shutdown orders.

METHODOLOGY

To determine the impacts of COVID-19 on the Residential Construction Industry in the Tampa Bay Area, this study followed a quantitative research methodology approach which includes forecasting the demand for residential construction. Several forecasting techniques were used to forecast the new residential constructions and the COVID-19 impact has been discussed based on the results.

Demand Forecasting of New Residential Constructions

This study evaluated the cause-and-effect relationship between COVID-19 and the demand for new residential construction in the Tampa Bay Area. The study consisted of a time series analysis and a projection or forecast of the demand for residential construction in the Tampa Bay Area for the next two years. In this approach, the following six different demand forecasting techniques have been used for the next two years by using Minitab software and their performances have been compared:

1. Holt's Smoothing Method with COVID-19 years (2020 and 2021).
2. Holt's Smoothing Method without COVID-19 years, considering them as outliers.
3. ARIMA Model, with COVID-19 years.
4. S-Curve Trend Model, with COVID-19 years.
5. Linear Trend Model, with COVID-19 years.
6. Quadratic Trend Model, with COVID-19 years.

These forecasting methods were selected because they are the most conventional models used to forecast time series, and they are commonly used with data that does not have seasonal patterns. Additionally, the idea behind these methods is to assign more weight to recent data than older observations (Holt's Smoothing Method) and to describe the trend, and seasonality in the data, if any (Hyndman & Athanasopoulos, 2018).

With these forecasted demands, the COVID effect on the construction industry was confirmed. Additionally, future studies could use these demands to evaluate whether the current status of the supply chain of construction materials is capable enough to meet the demand by comparing it with the production capacity of major material suppliers in the Tampa Bay Area.

Data Collection

Data were obtained from secondary sources such as Federal Reserve Economic Data, United States Census Bureau, www.realtor.com, historical data from past studies, or reports of the pre-pandemic era (2012-2020) in addition to the pandemic era (2020-present) in the Tampa Bay Area. It is a mixture of the consistent growth that the Tampa Bay area has been experiencing, during the last ten years, and the special effect of COVID-19 on the migration pattern. The variables in this data set are New Housing Permits Issued in the Tampa Bay Area (Dependent Variable) over time (Independent Variable). This data collection methodology was selected because it is necessary to establish the difference between “before” and “during” COVID-19 of the growing housing demand in the Tampa Bay Area, understanding that it is possible to forecast the short future if past growth patterns can be identified (Chambers et al., 2020).

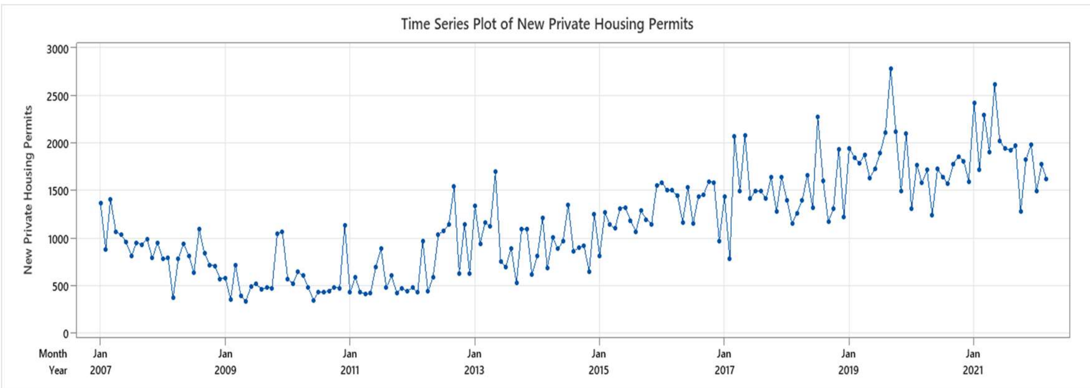
RESULTS

This study aimed to explain and measure many different impacts of COVID-19 in the industry that have not been measured, although, they have a high influence on the experienced shortages and supply chain issues. This study represents a great tool for companies in the industry to understand what the current situation is, and what to expect in the short future. The results are presented in two headings: First is the forecasting results, which show both the historical situation of the demand for new houses and the expected future demand; and second is the market analysis results which include the behavior of the market and the housing inventory.

Forecasting results

In this study, the first data collected from the Federal Reserve Economic Data was “New Private Housing Units Authorized by Building Permits for Tampa-St. Petersburg-Clearwater, FL (MSA)” (FRED, 2022). As shown in Figure 1, we can see the behavior of New Private Housing Units that have been authorized by Building Permits in the Tampa Bay Area, composed of Tampa, St. Petersburg, and Clearwater, in months, over the last years.

Figure 1. Time Series Plot of New Private Housing Permits.



The demand for the next two years was estimated by using forecasting techniques including Holt’s Smoothing Method (Linear Exponential Smoothing), S-Curve, Quadratic, Linear Regression, and ARIMA model based on this data. Additionally, the demand was also estimated with and without COVID years data (from 2020 until now) to see the impact of COVID on the demand.

Figure 2 and Figure 3 show the trends and the forecasting results of the new housing permits with and without COVID years, and both forecasts for new residential construction in the Tampa Bay Area have positive growth patterns with similar slopes. However, with only these two graphs we cannot conclude that the COVID-19 pandemic has had a certain impact on the demand for new residential construction in the Tampa Bay Area, even though it is seen that the greatest point was right before the pandemic (September 2009 with 2782 new permits).

Figure 2. Forecast New Private Housing Permits without COVID years using Holt's Smoothing Method.

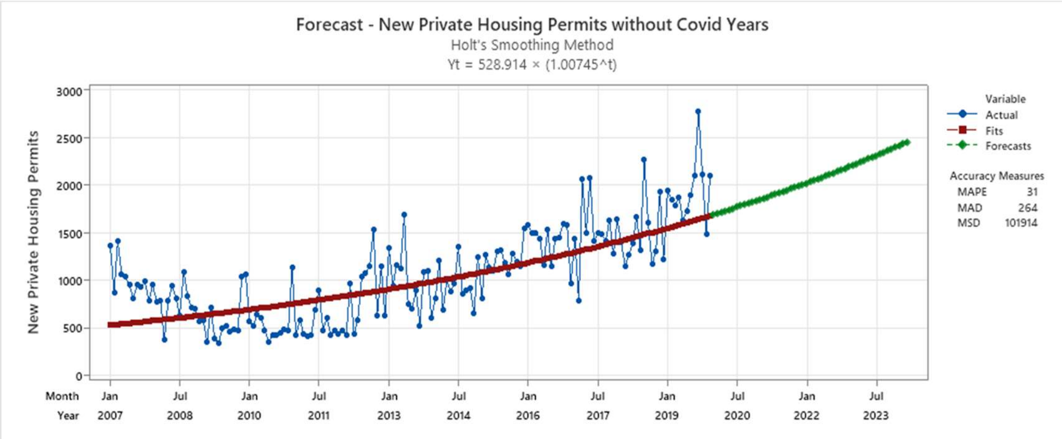
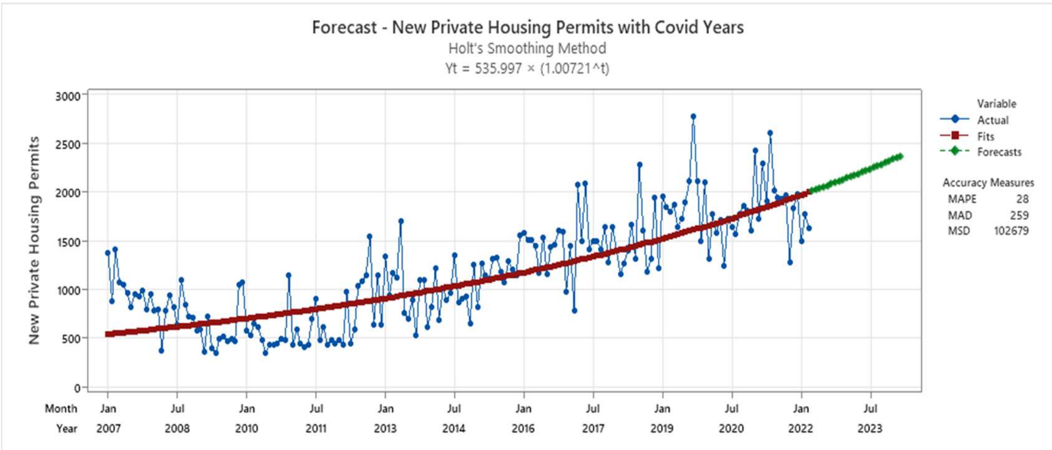


Figure 3. Forecast New Private Housing Permits with COVID years using Holt's Smoothing Method.



In addition, by considering only the real data (with COVID years), the Mean Absolute Percentage Error (MAPE) was estimated for all the different models used to determine which model fits the most accurately, since it is one of the most commonly KPIs used to measure forecast accuracy (Vandeput, 2021). The other forecasting results and the accuracy measures are presented in Figures 4-7

Figure 4. Forecast New Private Housing Permits with COVID years using ARIMA Model.

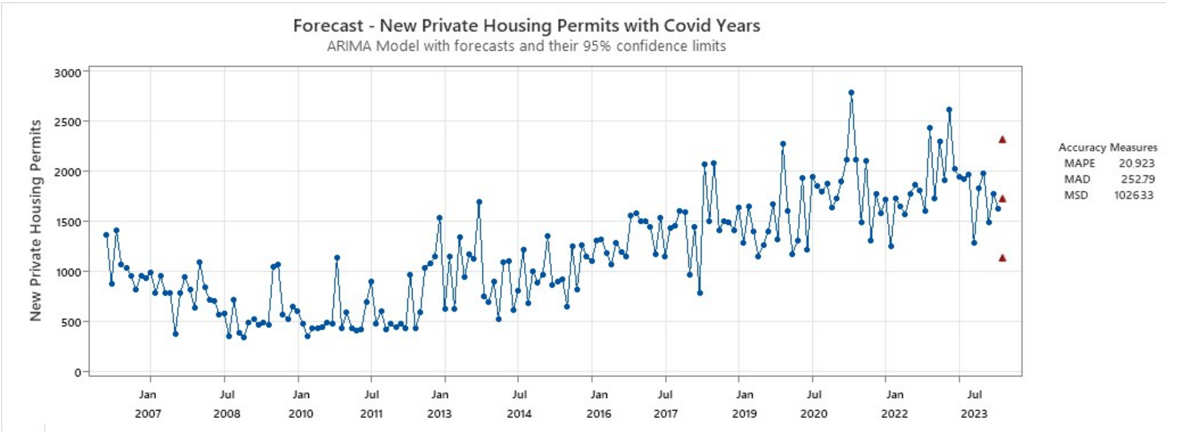


Figure 5. Forecast New Private Housing Permits with COVID years using S-Curve Trend Model

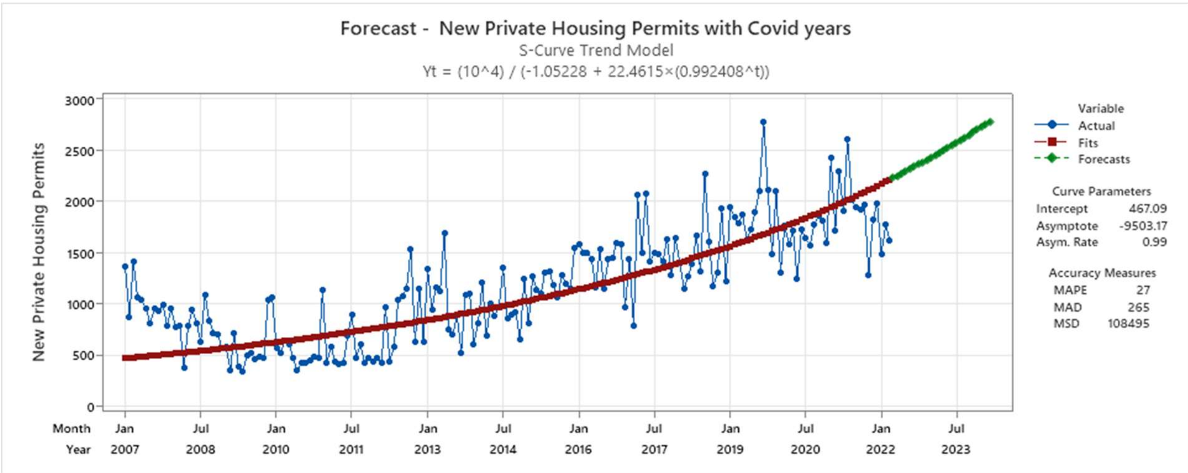


Figure 6. Forecast New Private Housing Permits with COVID years using Linear Trend Model.

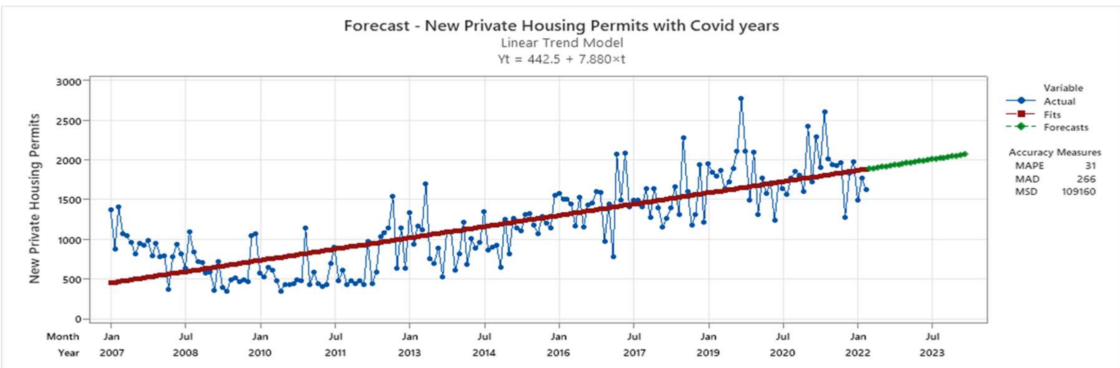


Figure 7. Forecast New Private Housing Permits with COVID years using the Quadratic Trend Model.

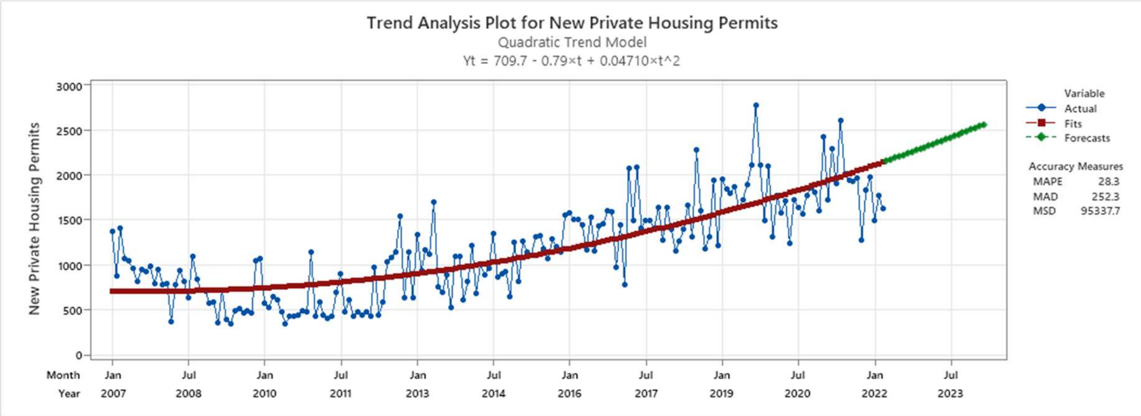


Table 1 also shows the comparison results of these forecasting models in terms of the Mean Absolute Percentage Error (MAPE).

Table 1. Accuracy results of the forecasting techniques.

Accuracy Comparison	
Model	**MAPE**
Holt's Smoothing	28
ARIMA	**20.923**
S-Curve Trend	27
Linear Trend	31
Quadratic Trend	28.3

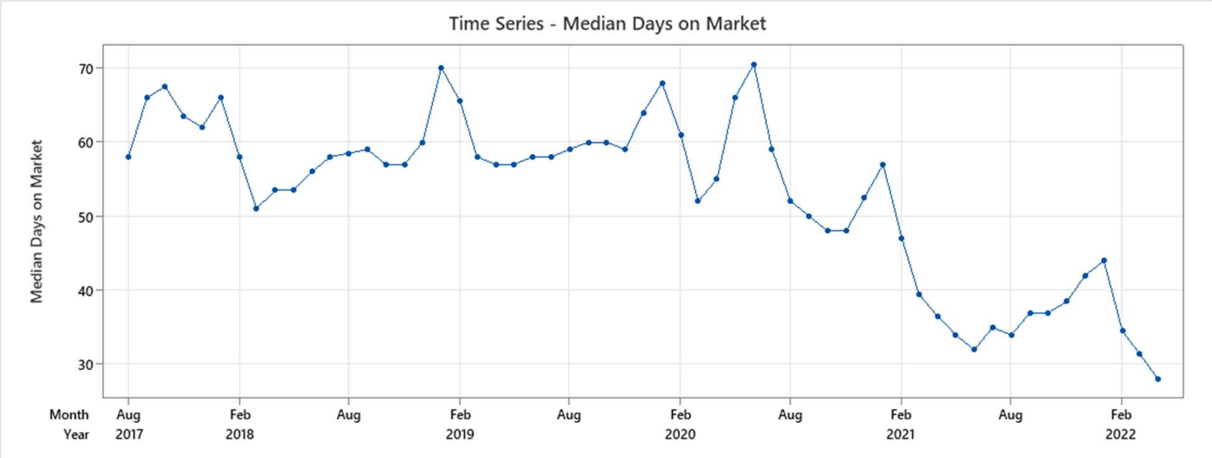
As seen in Table 1, the demand forecast that fits the best for this study is the ARIMA model since it has the lowest MAPE and is the most accurate estimation, within the studied models, of the behavior in the Tampa Bay Area.

Market analysis results

A few more analyses have also been done to see the impact of COVID on the housing demand. To confirm the high demand for new housing, the data from “Market Hotness: Median Days on Market in Tampa-ST. Petersburg-Clearwater, FL (CBSA)” (FRED, 2022) have been used. The “Median Days on Market” variable shows the behavior of the market and the fluctuation during the last year of the variable which is the number of days from the date on which the property is listed for sale on the local brokers’ to the date when the seller has signed a contract for the sale of the property (Greffner, 2019).

As shown in Figure 8, the “Median Days on Market” variable has noticeably decreased over time with a negative growth pattern, meaning that customers are more likely to buy houses (in this case: new or not) in the Tampa Bay Area.

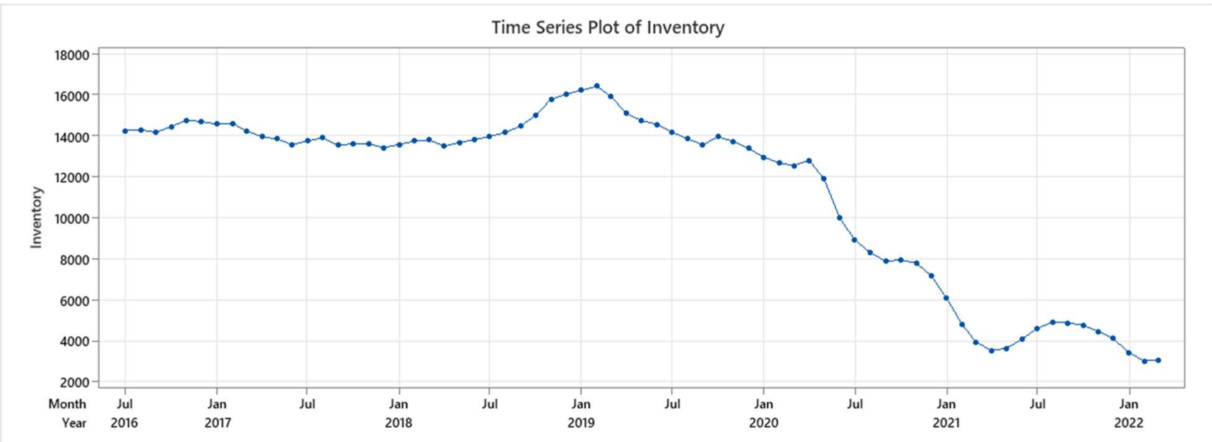
Figure 8. Time Series of Median Days on Market



Additionally, another analysis has been done on the data of "Housing Inventory: Active Listing Count in Tampa-ST. Petersburg-Clearwater, FL (CBSA)" (FRED, 2022) from the Federal Reserve Economic Data. This data shows the behavior of the housing inventory levels in the Tampa Bay Area during the last few years. The variable "Inventory Level" is defined by the National Association of Realtors as the count of the number of active listings and pending sales on the last day of the month.

The analysis of the data shown in Figure 9, reveals a negative trend, which we can use to imply that the housing supply in the market has been slower than the demand, causing a diminution of normal housing inventory levels in the Tampa Bay Area. Builders have not been able to keep up with this rising demand, and it all goes to construction materials and the supply chains that are taking longer than expected to normalize due to short supply and price spikes since the COVID-19 pandemic took hold in 2020 (Lerner, 2021). Material Suppliers have been hauling materials from different estates because their production is not enough to fulfill the current demand while maintaining current conditions.

Figure 9. Time Series Plot of Housing Inventory – Active Listing



With these two patterns discovered, further studies can be done to determine the feasibility and profitability of the installation of new material plants in the Tampa Bay Area such as Concrete material plants, Block Material plants, etc. This study represents an instrument to evaluate these expansions or investments, potentially through vertical or horizontal integration, specifically for concrete and lumber materials, where the price impact and shortages have been more significant.

Discussion and future directions of the study

With this research, different impacts of COVID-19 on the Residential Construction Industry have been proved. However, it is necessary to understand that this pandemic has changed the world drastically, and these new conditions in the industry may change or adapt in the short, medium, and long future.
Even though the difference in Means for New Private Housing Permits in the Tampa Bay Area with and without COVID-19 years (H_A) could not be accepted, it is recommended to run this test again but, in this case, using at least two more years of data that could show a better behavior of the variable New Private Housing Permits in the Tampa Bay Area under the presence of COVID-19 pandemic.

Additionally, in the research two patterns were identified with the variables Housing Inventory and Median Days on the Market. With both variables decreasing over time, evidencing the current incapacity of the supply to meet the current demand, it is recommended to study in further research if builders or construction companies would be able to keep up with the demand in the future. Companies have suffered project cancellations, project delays, lower productivity, etc., due to material shortages, furthermore, it is advised that further studies are done to determine the feasibility and profitability of the installation of new material plants in the Tampa Bay Area such as Concrete material plants, Block Material plants, etc.

This study represents an instrument to evaluate these expansions or investments, potentially through vertical or horizontal integration, specifically for concrete and lumber materials, where the price impact and shortages have been more significant. Additionally, future studies could be addressed to consider materials for Non-Residential construction such as Industrial Construction, Heavy-Industrial Construction, Commercial Construction, etc., which require different materials than Residential ones and could be experiencing other limitations.

CONCLUSION

It is necessary to determine and evaluate the different impacts of COVID-19 on the Residential Construction Industry in the Tampa Bay Area. Additionally, focusing specifically on the Residential Sector of the Construction Industry, it is necessary to forecast demand for new constructions for the upcoming years to determine if the current infrastructure (material production, supply chain, distribution, etc.) can fulfill this rising demand. So, in this study, COVID-19 impact on the construction industry was studied and new constructions were forecasted by using several forecasting techniques.

Readers of this study will understand the impact that COVID-19 has had on the Residential Construction Industry in the Tampa Bay Area. Additionally, readers will now be able to evaluate the behavior of residential housing demand in the Tampa Bay Area and draw their own conclusions about the upcoming future in the industry. Companies within the industry need to have the tools to evaluate expansions or installation of new production plans, specifically for concrete materials, where the impact and shortages have been more significant. So, the key question is if these expansions or investments will create feasible and profitable results in the future. If demonstrated that the current infrastructure is not enough, further studies will determine the feasibility and profitability of the installation of new concrete material plants.

In the construction industry in the Tampa Bay Area, a normal state of production consisted basically of zero to two days of lead time for common-use materials such as block, steel, hardware, concrete, etc. On the other hand, for more complex materials such as lumber, lead times are more controlled, and they averaged about eight weeks, oscillating between four to fourteen weeks (Bashford et al., 2003). However, after COVID because of the supply chain disruption, lead time increased to one to three weeks for common-use materials and sixteen to twenty-four weeks for complex materials.

COVID also helped develop a better relationships and communication between suppliers-customers. Both customers and suppliers have understood how important is to work together and to share information. If customers give more time and share information with suppliers such as estimated monthly demand, upcoming new projects, etc., suppliers will be able to provide a better service and accomplish what is needed. Similarly, if suppliers are proactive and inform customers about material shortages or stops in production before they happen, it will help customers to take preventive actions and avoid supply chain constraints in production.

Additionally, COVID-19 touched on other aspects of the construction process such as the Occupational Safety and Health Administration (OSHA) and workplace safety compliance, project suspensions or reschedules due to uncertainty in the market or price materials, etc. (Chivilo et al., 2020). After COVID, OSHA requirements are more strictly followed in addition to social distancing in work environments forced by COVID-19 regulations by state, local, and municipal governmental agencies. Although there was a balanced labor market pre-COVID, a slowdown in labor has been seen after COVID because of the COVID relief checks and so the demand for labor has increased. In addition, project cancellations have been seen a lot after COVID because of the higher costs and the uncertainty of the market. Table 2 shows clearly how COVID disruption differs from normal state conditions.

Table 2. Comparison COVID-19 disruptions.

	Pre-COVID	Post-COVID
Lead time effect	Zero to two days in common-use materials (block, steel, hardware, concrete). Four to fourteen weeks, averaging 8 weeks for more complex materials such as lumber, windows, etc.	One to three weeks in common-use materials. For more complex materials, sixteen to twenty-four weeks.
Buyer-Supplier Relationships	Underestimated collaboration between parties in the industry.	Stronger collaboration and sense of unity within the Construction Industry.
Workplace Safety and Health Compliance	OSHA requirements	OSHA requirements are more strictly followed in addition to social distancing in work environments forced by COVID-19 regulations by

		state, local, and municipal governmental agencies.
Labor	A balanced labor market, depending on the season of the year.	A slowdown in labor force availability, caused by COVID-19 relief checks and higher demand for workers due to higher work volume
Project Cancellations	Sporadic cancellations due to cost analysis or investment pullbacks.	A wave of project cancellations due to higher costs, the uncertainty of the market and price materials, etc.

It is also important to restate that although this study fills the gap by focusing on the construction industry supply chain in the Tampa Bay area, it is limited to only Residential Construction. So, future studies could address the materials for Non-Residential construction such as Industrial Construction, Heavy-Industrial Construction, Commercial Construction, etc., which require different materials than Residential ones and could be experiencing other limitations. In addition, because of the development of the COVID-19 vaccine, it is necessary to update and conduct new studies without changing demographics.

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DECISION SCIENCES INSTITUTE

Incorporating Lean Practices into Cooperative Product Development to Enhance Competitiveness

(Full Paper Submission)

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ABSTRACT

This article aims to study potential relationship between lean practices (LP) and cooperative product development (CPD). Comparison and analysis of several key factors show high degree of resemblances between the two methods. Several hypotheses regarding similarities between the factors for the two methods were developed and tested. Survey data from a sample of manufacturing organizations strongly supports the hypotheses regarding similarities between the two factors. Statistical results also indicate compared with conventional product development methods, organizations utilizing CPD teams are in a much better competitive position by being able to develop products faster with better quality, lower development cost, higher frequency, and lower manufacturing cost.

KEY WORDS: Cooperative, Product Development, Lean Practices

INTRODUCTION

Innovation and speedy new product development is crucial for companies to gain competitive advantage. Creating new product ideas that are consistent with organizational strategy and moving the ideas through the stages of design, development, testing, and deployment has been the trade mark of successful world class organizations (Jacobs and Chase, 2023; Johansson and Safsten 2015; Ferioli et al. 2010; Roulet et al. 2010). Introducing new products to the market early has several strategic and tactical advantages. (Lofstrand, 2010; Kristav, 2016; Wen et.al. 2020; Cooper and Kleinschmidt, 1994).

Despite its strategic role, for large number of manufacturing organizations innovation, design, and successful management of new product development has often been a major challenge. Long development time, prohibitive development and manufacturing costs, and questionable quality have been the common result for many of these organizations. The primary factor contributing to such unsuccessful result is perhaps the use conventional sequential approach to product development by these organizations (Morgan and Liker, 2006). However, manufacturing literature for the past three decades clearly shows that through their lean pactices, world class organizations such as Toyota have dominated competition not only in the area of manufacturing but also in the area of innovation, design, development, and quick commercialization of new products (Marisa et al. 2008; Heinzen and Hoflinger 2017; Ulrich and Eppinger, 2004; Michael, 2008; Unger and Eppinger 2009). Instead of conventional sequential approach, world class organizations utilized cooperative product development (CPD) method. The aim of this article is to address such contrast between the two types of organizations.

LITERATURE REVIEW

For the past three decades, lean manufacturing (LM) has been a great force in the world of manufacturing. Some of the main benefits of a LM such as lower inventory, quicker delivery, and lower cost have been well documented (Cook and Rogowski, 1996; Hobbs, 1994; Temponi and Pandya, 1995; Deshpande and Golhar, 1995; Billesbach, 1991; Handfield, 1993; Lawrence and Hottenstein, 1995; Golhar, Stamm, and Smith, 1990; McKay, et.al 2011; Moras and Dieck, 1992). In the simplest form, LM requires maximizing value added production activities by removing unnecessary wastes. Identification and elimination of waste and respectful treatment of employee are the two fundamental principles of a LM system (Hobbs, 1994; Womack and Jones, 2003). Elimination of waste is achieved by adopting practices such as continuous quality improvement, setup time reduction, utilizing flexible resources, group technology layout, and pull production system (Gargeya, and Thompson, 1994; Sohal, Ramsay, and Samson, 1993). Respectful treatment of people often means employee empowerment; it includes elements such as team work, fair compensation, employee training and new positive attitude toward suppliers (Sohal, Ramsay, and Samson, 1993). Unfortunately, since its beginning in mid 1980's, often a narrow view of LM has been accepted and utilized by western manufacturers. Application of LM to reduce inventory and increase deliveries is only a small fraction of the full potential benefits of a LM system (Blackburn, 1991; Kristav, 2016). To take advantage of the full benefits of LM, one needs to have a much broader view of LM principles (Blackburn, 1991). Looking at LM as a process of eliminating waste and respectful treatment of employee, its principles can be applied to other areas including service areas such as healthcare, education, government, and new product development, (Womack and Jones (2003). Application of LM principles to new product development has great opportunity to shorten product development time, improve design quality, and reduce product development and manufacturing costs (Anand and Kodali, 2008). The company that originated famous LM system, TPS, also developed Toyota Product Development System (TPDS). TPDS employs LM principles and tools such as value stream mapping, Kanban, 5S system, and continuous improvement to eliminate waste from product development activities and bring quality products to market faster than their leading competition (Morgan and Liker, 2006; Ward, 2007). However, TPDS is a comprehensive strategy that involves various approaches to eliminate waste from new product development activities. The focus of this article is on special case of TPDS with the aim of answering the following questions:

1. Are there relationships between LM and CPD practices?
2. Are product development for companies using CPD more competitive than companies using conventional companies?

The remainder of the article is organized in the following manner: First, an overview of the differences between conventional sequential method and recent CPD is presented. Second, the article compares and analyzes similarities between LM and CPD for a number of critical elements followed by a set of test of hypotheses on similarities between the elements. Third, the article tests product design performance for conventional sequential method and CPD method. Research methodology, results, and conclusion are the final sections of the article.

CONVENTIONAL AND COOPERATIVE PRODUCT DEVELOPMENT

Product development is a sequence of inter-connected activities in which information regarding customer needs is translated into final product design. In a conventional method, PD process typically involves phases such as idea generation and validation, preliminary design, final design and prototyping, and pilot production and ramp-up (Wheelwright and Clark, 1992; Jacobs and Chase, 2020). Traditionally, this design process is managed sequentially by personnel from various functions of the organization. A major drawback of this approach is that the output from one design stage is passed to the next stage with little or no communication. Lack of

communication and feedback among sequential stage causes the process to require too many design changes which causes the process to require longer development time which indeed causes the process to be too slow, too costly, and often of poor quality. The two elements of long delay and design changes during the delay creates a never-ending cycle where time delay causes design change and to accommodate design change it needs more time. The final result is that the designs are often rejected because the design is either outdated due to long development time or it is infeasible in term of manufacturing capability (Yamamoto and Abu Qudeiri, 2010; Blackburn, 1991; Ulrich and Eppinger, 2000).
Unlike conventional approach where functional units work sequentially and downstream functions are not involved until late in the process, CPD requires early involvement of cross functional teams. It requires that designers, manufacturers, marketers, suppliers, and customers work jointly to design product and manufacturing process in parallel. The design team must truly understand the concept of simultaneous engineering in which activities of product and process design are performed in parallel and in a coordinated manner The objective is to integrate product design and process planning into a common activity (Albers and Braun, 2011; Liang, 2009; Anderson, 2008; Donnellon, 1993; Millson, Ranj, and Wilemon, 1992; Shunk, 1992). Application of CPD under various manufacturing environments in order to shorten development time, improve quality, reduce risks, and reduce development cost is reported by these researchers (Anderson, 2008; Skalak, 2002; Kowang and Rasli, 2011; Lofstrand, 2010; Moges, 2009). Due to early cross-functional communication, CPD approach enables an organization to be more innovative in terms of improving design quality, shortening development time, reducing design risks, and reducing development and manufacturing costs (Lynch et.al, 2016; Blackburn, 1991; Ulrich, and Eppinger, 2000; Arora and Mital, 2012; Katzy et.al, 2012; Zirger and Hartley, 1996).

COMPARISON OF LEAN MANUFACTURING AND CPD FACTORS

For the past three decades, there has been an extensive volume of research in the area of LM. As a result, there is a set of generally accepted guidelines that organizations can follow to achieve manufacturing success. However, there has been limited research on the application of LM practices to product development and there is no comparable set of guidelines for successful management of the process. Recently, a number of world class PD companies have attempted to apply the principles of LM to PD activities (De Waal and Knott, 2019). The company that started the most famous LM system, Toyota Production System (TPS) is also started Toyota Product Development System (TPDS). TPDS employs LM principles and enable the company to bring the highest quality products to market faster than their leading competition. Also, a number research on the application of LM principles to PD process has shown that achieving certain manufacturing process improvement such as reducing variation, reducing rework and yield loss, solving process bottlenecks, and managing capacity, can significantly reduce PD times.

Similarities between LM and CPD for a number of critical elements are shown in Table 1, (Goffin et. al, 2019; Spencer and Guide, 1995). Following is a brief comparison and analysis of selected elements in Table 1:

Layout
Layout in LM environment is often in the form of product focus and manufacturing cells. This type of layout is necessary because small lot size production requires that the layout to be compact and efficient to ensure smooth flow of materials and close communication between work stations. Unlike conventional manufacturing, where material is pushed forward, the flow in a LM environment is in two directions; material is pulled forward, but information flows backward to provide feedback on performance and material requirements.

In CPD, overlapping of a large number of activities requires a complete change in layout that facilitates communication and encourages team work. Instead of organizing by sequential functions, CPD emphasizes on cross-functional integration and the formation of a design team. The design team sits together in one location, creating a type of project layout. A project layout creates an environment for frequent, two-way communication between team members, which encourages concurrent development of a product and its associated processes.

Lot Size
In contrast to conventional manufacturing, LM manufacturing requires production of small lot-sizes. Production of small lot-sizes is possible by drastically reducing set-up times. It is well documented that production of small lot-sizes in LM is closely associated with improved quality, reduced inventory, faster delivery, and more responsive to market demands.
Similar to LM, CPD also utilizes small lot-sizes; the only difference is that in LM small lot sizes of goods are processed but CPD requires small lot-sizes of information. That is, continuous two way communication in CPD is similar to early release of small batches of information (Blackburn, 1991; White, 1993). With the early release of small batches of information, downstream constituents can begin working on different phases of the design while final design is evolving. The early release of information reduces uncertainty and encourages early detection of problems, which enables organizations to avoid costly, time-consuming changes.

Employee and Supplier Involvement
In LM environment, management encourages employee involvement and team work. The responsibility for job scheduling and quality are often passed to the teams at the shop floor. Due to small lot size production, delegation of authority to the teams at the shop floor is essential for smooth production flow. Also, in LM suppliers work closely with manufacturing organization to improve quality and shorten delivery time.
Similar to LM, in CPD the responsibility for scheduling of the activities pushed down to product development team at the lowest level. Passing responsibility down to the team is essential to achieve a high level of activity coordination and information sharing among team members. Also, in CPD suppliers work closely with the design team to reduce development costs, shorten development time, and offer ideas toward improving the quality of the design.

Quality
In LM and CPD environments, organizations are often proactive and quality means getting it right the first time. In LM, since batch sizes are small quality at the source and continuous quality improvement are the main foundations. Shop floor workers are empowered to become their own inspectors responsible for the quality of their output. In CPD, because of the teamwork and two-way flow of information between team members, and utilization of quality improvement tool such as six sigma process quality problems are detected earlier and solved before they have a cumulative impact on the rest of the project (Chakravorty and Franza, 2009).

Technology
In a LM system, technology is not viewed as a substitute, or shortcut to process improvement. Rather, technology has been utilized after process analysis and simplification has been performed. The role of technology in CPD is also enormous; it requires that the design team with diverse expertise makes a large number of interrelated decisions regarding the form, fit, function, cost, quality, and other aspects of the design (Karagozoglu and Brown, 1993). This requires supply and processing of relevant information from multiple sources in a coordinated manner. Successful organizations use technology in their PD process similarly to the way they use technology in their LM system. In CPD, the design team utilizes appropriate technologies and tools at various stages of PD process. Effective use of technologies and tools can

dramatically shorten PD time, reduce number of prototypes, cut costs, and improve quality of the design (McKay et al. 2011; Yamamoto and Abu Qudiri 2011; Roulet et.al (2010). The key to the success of technology in CPD is building an effective design team with open cross-functional communication lines.

FACTOR HYPOTHESES

Comparison and analysis of elements in Table 1 show a high degree of similarities between LM and CPD. To study further, a set of twenty five hypotheses (H1-H25) that statistically test similarities between LM and CPD will be presented. The hypotheses are shown in Table 2. Each hypothesis in Table 2 consists of two parts- a and b. In part a, the test is conducted for LM elements and the corresponding test for CPD elements is conducted in part b.

<u>Hypotheses (H1-H20):</u>
There are high degree of similarities between lean manufacturing and CPD factors..

PRDUCT DEVELOPMENT PERFORMANCES

The following dimensions of quality, time, competency, development cost, and manufacturing cost are used to measure the performance of NPD (Ulrich and Eppinger, 2000; Wheelwright and Clark, 1992):

- **Quality**: Quality is ultimately reflected in the price customers are willing to pay, the market share, and the bottom line profit. In PD, quality problems are often the results of incomplete information and miscommunication among various functions. Quality often means a minimal number of redesign or rework. In this article, number of design changes during the development process and early manufacturing phase is used as a measure of design quality.

- **Development time**: Development time is the length of time between initial idea generation until new product is ready for introduction to the market. Shorter development time raises the competitive value of new product in terms of premium price, larger market share, and higher profit margin.

- **Development competency**: Development competency is the ability of the organization to develop future products better, faster, and cheaper. Competent workforce and effective use of technologies are important elements of organizational PD competency. Frequency of new product introduction to the market is used as a measure of development competency.

- **Development cost**: This is the total cost from the early idea generation until the product is ready for manufacturing. For most organizations, development cost is usually a significant portion of the budget and must be considered in light of budget realities and the timing of budget allocations.

- **Manufacturing cost**: Manufacturing cost includes initial investment on equipments and tools as well as the incremental cost of manufacturing the product. There is a close relationship between manufacturing cost and the type of decisions made during the early design stage. Although early design decisions determine about 70 percent of future manufacturing cost, organizations often spend far too little time and resources during this stage (Huthwaite, B. 1991). To save future manufacturing cost, it is prudent for the companies to spend more time and resources during the early design phases of PD process where critical design decisions are made.

PERFORMANCE HYPOTHESES

In the second set of hypotheses (H21-H25), the differences between PD performances for LM companies and conventional companies are tested.

Hypotheses (H21-H25):
H21: By utilizing CPD, LM companies are able to design new products with fewer design changes than conventional companies(better quality).

H22: By utilizing CPD, LM companies are able to design new products faster than conventional companies.

H23: By utilizing CPD, LM companies are able to design new products more often than conventional companies.

H24: By utilizing CPD, LM companies are able to design new products with less development cost than conventional companies.

H25: By utilizing CPD, LM companies are able to design new products with less manufacturing cost than conventional companies.

RESEARCH METHODOLOGY

The target population for this study consisted of manufacturing firms in the states of Illinois, Indiana, Ohio, Michigan, and Wisconsin. A sample of manufacturing firms with more than 50 employees was chosen from manufacturers' directories of those states. The sample covers organizations in variety of industries ranging from fabricated metal, communication, electronics, automotive, toots, chemicals, rubber, and paper products. A comprehensive survey instrument based on examination of the literature and critical elements listed in Table 1 was developed. A panel of practitioners and researchers with experience in LM and NPD was used to validate the survey. Cronbach alpha reliability test was also used to validate the survey. The minimum Alpha value for all factors was 0.72. In addition to general organization and managerial profile items, the survey contained 40 items (20 paired) regarding similarities between LM and CPD factors. The twenty paired questionnaire items are shown in Table 2.
The survey instrument also contained a number of questionnaire items on product development performances for LM companies using CPD and conventional companies. Out of 91 completed surveys received, 84 surveys were usable resulting in a response rate of 17%. Based on a number of questionnaire items on the principles of LM practices, 33 organizations were grouped as LM companies and 51 organizations were categorized as conventional companies.
The survey data indicates that majority of respondents had various high level managerial positions from organization with less than 500 employees. Presidents and vice presidents accounted for 29% and plant managers accounted for 30% of the sample. About 35% of the sample had other managerial positions such as operations/production managers, quality managers, and the remaining 6% were production line supervisors. In terms of manufacturing and PD experience, about 28% of the respondents had between 10 to 20 years and 60% had more than 20 years of manufacturing experience. About 72% of the sample had more than 10 years of LM experience and close to 65% of the sample had more than 10 years of PD experience.

RESEARCH RESULTS

As stated earlier, in the first set of hypotheses the objective was to examine similarities between LM and CPD for a set of paired elements shown in Table 2. For each item, the null hypothesis was that the mean response for LM is equal to the mean response for CPD. The differences between the mean responses for LM and CPD were compared using two independent populations statistical t-test. The respondents were asked to rate each element of Table 2 based on the degree of their agreement on Likert-type scale of 1 to 5 to the questions, where (1=strongly disagree; 2= disagree; 3 = indifferent; 4=agree; and 5=strongly agree). Table 3 shows the result of similarities between LM and CPD.

As shown in Table 3, overall the respondents strongly agreed with the statements regarding similarities between LM and CPD elements. The mean ratings for about 70% of the elements for both LM and CPD are above 3.80. Specifically, out of twenty hypotheses, the respondents agreed that there is a high degree of similarities between LM and CPD for all except three hypotheses H4, H7, and H9.

For H4, the mean ratings for LM and CPD are respectively 4.34 and 3.81. This means although the respondents understood that short set-up and fast transition time are the main requirements of successful LM and CPD, the relationship between short set-up and LM was much stronger. This is a reasonable result because an average manufacturing manager has longer experience with LM than CPD. They clearly understood that successful LM requires small lot-size and small lot-size requires short set-up time. However, due to their shorter experience with CPD and because CPD is primarily an information processing process, the links between small batches of information and fast transition time is not clear. H7 hypothesizes the relationships between small lot-sizes and quality improvement for both LM and CPD. For this test, the mean ratings for LM and CPD are respectively 3.43 and 3.89. This indicates for an average manager it is easier to recognize the relationship between CPD and quality improvement than the relationship between LM and quality improvement. The higher rating for CPD is perhaps due to continuous and two way communication among design team members, which encourages early detection of the design problem. The LM result is also consistent with the literature because although total quality management and quality improvement are fundamental requirements of successful LM, an average manufacturing manager has difficulty to understand this relationship. The relationships between small lot-size and reduced manufacturing cost in LM and the relationship between small batches of information and reduced development cost in CPD are examined in H9. The mean ratings for LM and CPD are respectively 3.58 and 3.94. For the same reasons as H7, this means for an average manager it is easier to understand this relationship in CPD than LM. The LM result is interesting and also consistent with the literature because reduced manufacturing cost in LM is primarily due to elimination of wastes, a fundamental principle of LM, and an average manufacturing manager has difficulty to see this relationship. The overall impact of LM principles on LM and CPD is examined in H20. It is obvious that the data supports the hypothesis as the mean ratings for LM and CPD are respectively 4.56 and 4.29 indicating strong agreement with the statements that the main principles of waste elimination and respectful treatment of people in LM can also be applied in CPD.

The last column of Table 3 shows correlation coefficients between LM and corresponding CPD elements. The correlation coefficients in Table 3 strongly support the above analysis. With the exception of three hypotheses H4, H7, and H9 other coefficients are greater than 0.60 indicating a high degree of linear association between LM and CPD elements.

The performance hypotheses (H26-H30) state that by utilizing CPD approach, LM companies are able to design new products with fewer design changes, faster, more often, with less development cost, and less manufacturing cost than conventional companies.

Table 4 provides useful statistical information regarding PD performances for LM and conventional companies. The average number of design changes for conventional and LM companies are respectively 5.36 and 3.28, a quality improvement of 63%. The average development time for conventional and LM companies are respectively 37.52 and 24.73 months, an improvement of 52%. For development competency, the average time between introduction of new products for conventional companies is 49.46 months and 32.72 months for LM companies, an improvement of 51%. Table IV also indicates that LM organizations enjoy a 45% reduction in PD cost and 36% reduction in manufacturing cost. From the last column of Table 4, it is clear that the hypotheses are strongly supported by the data as the p-value for all five hypotheses is less than 0.005.

CONCLUSION

The focus of this article was to demonstrate possible links between LM practices and CPD. First, comparison and analysis of a number of elements showed remarkable similarities between LM practices and CPD. Second, a set of paired hypotheses was used to test similarities between LM practices and CPD elements. Statistical results clearly support the hypotheses regarding similarities between LM and CPD for majority of elements. Specifically, out of twenty four hypotheses, the respondents agreed that there is a high degree of similarities between LM and CPD for all but three hypotheses. The last pair of hypotheses that examines the overall impact of LM principles is especially important. Statistical results strongly agreed that the main principles of waste elimination and respectful treatment of people in LM is also applicable to CPD. The correlation coefficients between LM and CPD elements also supported the same result. Third, statistical results also indicate that compared with conventional companies, LM companies are able to develop new products with 63% better quality, 52% less development time, 45% less development cost, and 36% less manufacturing cost. Also frequency of new product introduction is 51% faster than conventional companies.

(Tables and references are available from the author upon request)

DECISION SCIENCES INSTITUTE

IT Governance to Comply Control and Compete: A Bibliographic Study

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ABSTRACT

Risks in Information Technology (IT) prompted the development of IT Governance frameworks. IT Managers have looked for guidance from such frameworks in managing enterprise IT. Consequently, this led to a plethora of research under the umbrella term – IT Governance - that examined varied aspects of IT Governance, scholars have synthesized the published research through literature reviews focusing on specific aspects such as IT governance mechanisms, influence of culture, risk assessment, and board-level IT Governance. This study takes a different approach to synthesize past research using a bibliometric technique, specifically co-word analysis, to unravel the latent themes in the research on IT governance. Based on co-word analysis of 746 unique papers from the web of science database, we explore the various themes emanating from IT Governance research. Our analysis revealed eight broad research clusters. Our results provide more integrated insight into the value that IT Governance purports to provide.

KEYWORDS: IT Governance, IT value creation, IT frameworks, IT Capability, Risk Management

DECISION SCIENCES INSTITUTE

IT Procurement in the Public Sector – a Close Look at the IRS Tax Day Failure

Submission to the 2022 DSI Annual Meeting

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ABSTRACT

This paper explores IT procurement issues within a public agency and highlights the need for a greater understanding of its complexity and challenges. The findings add to the public procurement literature and confirm the policy and budget dependency of IT procurement within the public sector. The proposed maturity model provides a framework for public agencies that face IT procurement challenges.

KEYWORDS: Procurement, Information System, Public sector, Maturity model

DECISION SCIENCES INSTITUTE

Let's talk about exit strategy or not? The effect of an intentional exit strategy on investor evaluations and additional funding resources for cleantech ventures

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ABSTRACT

The low-carbon future depends on successful clean technology funding. Due to their role as gatekeepers to technology, it is vital to look at the decision criteria of cleantech venture capitalists. Drawing on signaling theory, we hypothesize that a pre-planned exit has a positive impact on investor evaluation, especially in the cleantech industry where exits are regarded as an investment barrier. We explore this effect in an experiment with 105 VC investors and a real cleantech company. Against our hypothesis, the results indicate that an exit strategy negatively affects investor evaluation.

KEYWORDS: Renewable Energy, Field Experiments, Entrepreneurial Finance, Intentional Exit, and Venture Capital Decision Criteria

INTRODUCTION

Cleantech entrepreneurs may play a critical role in the mitigation of climate change and the development of the green economy (Chapple et al., 2010; Marcus et al., 2013). They address environmental concerns such as energy storage, global warming, or natural resource scarcity while delivering commercial benefits for customers (Caprotti, 2016). New technologies in energy storage, energy transportation, or energy efficiency are not yet proven and will mostly not be able to get debt funding from banks. Cleantech entrepreneurs are therefore looking for venture capital (VC) to commercialize and fund their new technology venture (Ghosh & Nanda, 2012). VC researchers propose that VC is important for bringing sustainable energy technology solutions to the market (Wüstenhagen et al., 2009; Wüstenhagen & Teppo, 2006). Due to its role as a gatekeeper to technology and a disruptor of industries (Marcus et al., 2013), it is vital to look at VC's decision variables for investments in the cleantech sector, as well as how entrepreneurs acquire funding. While the latter question has gained a lot of attention in the past (Cassar, 2004; Drover et al., 2014; Fernandez, 2021; Hor et al., 2021) and substantial research has been conducted on VC decision criteria in the field of biotechnology or information technology (e.g. Baum & Silverman, 2004). In comparison, research in the field of cleantech VC is still scarce (Cumming et al., 2016; Wüstenhagen & Teppo, 2006). When comparing cleantech VC with traditional VC, scholars assess that cleantech investments tend to be riskier, have more capital requirements, are less likely to scale up, and, importantly for this study, are more difficult to exit (Cumming et al., 2016; Ghosh & Nanda, 2012).

While research on cleantech exits is scarce, entrepreneurial exit theory has picked up pace over the last years (Albert & DeTienne, 2016; Hohen & Schweizer, 2021). Exit theory became one of the main research areas in the current decade (Wennberg & DeTienne, 2014). In the past, exit research focused on exit strategies (DeTienne et al., 2015; Isaksson, 2007); the importance of the exit in the entrepreneurial process (DeTienne, 2010); involuntary exit and failure (Muñoz et al., 2020); or differences in exit strategy intention and exit paths (Hohen & Schweizer, 2021). Albert & DeTienne (2016) studied the effect of initial financial resources on the exit strategy. Our research draws on their perspective. However, we take another approach. Based on signaling theory (Bhattacharya, 1979; Connelly et al., 2011), we hypothesize that a pre-planned exit strategy has a positive impact on investor evaluation and additional financial resources. Hereby, we try to answer the question if an entrepreneur should include an intentional exit strategy in their pitch to increase investor evaluations when searching for funds. We assume this effect is particularly visible in the cleantech industry where exits are regarded as a barrier to investing (Ghosh & Nanda, 2012; Marcus et al., 2013; Wüstenhagen & Teppo, 2006) and entrepreneurs are more prone to end up in the “valley of the death”, the stage where entrepreneurs do not find enough capital to commercials the prototype (Cumming et al., 2016).

To disentangle the relationship between investor evaluation and pre-planned exit strategy, we test our assumption in a 1x3 experiment, based on a real-life case in the cleantech sector, which was looking for capital at that time. We explore the effect of a pre-planned exit strategy on the decision criteria of cleantech investors. We then measure if the pre-planned exit strategy leads to more favorable evaluations by investors (idea attractiveness, investment quality, and investment amount).

We position our study at the intersection of VC evaluation, cleantech, and entrepreneurial exit research. In this way, we answer the call by Cumming et al., 2016 for more research on cleantech exits and by Wüstenhagen & Teppo, (2006) for increased understanding of VC’s decision criteria in energy investments. Lastly, we make the research more relevant for practitioners by drawing the data from an experiment (Shi & Lai, 2013; Williams et al., 2019). Therefore, answering the call by Williams et al., (2019) for more experimental research design in entrepreneurship. Our practical contribution is manifested in our belief that a low carbon future can only be solved by the advancement in technology (Marcus et al., 2013). Through our paper, we hope to expand the understanding of investor evaluations in the cleantech industry with a focus on an intentional exit strategy as well as contribute to the knowledge of entrepreneurs acquiring much-needed capital in the segment (Masini & Menichetti, 2013). The rapid funding of clean technology for a low-carbon world is of utmost importance for the future of our society (Cumming et al., 2016; Marcus et al., 2013; Mazzucato & Semieniuk, 2018).

The paper is structured as follows. The second chapter provides the conceptual background and hypothesis development for the study. In the third one, we present and explain our research design. The results are shown in the fourth section. The fifth part discusses the results, we critically reflect on our paper, indicate limitations, propose future research, and conclude our study.

CONCEPTUAL BACKGROUND & HYPOTHESIS

Capital Acquisition for Cleantech Entrepreneurs

Since (Cassar, 2004) there has been vast research on the topic of how new ventures attract capital. Academics in the field of entrepreneurial finance studied various aspects of the capital acquisition process. A recent study by Shepherd et al., (2018) focused on the different

dependent variables in entrepreneurship research. Focusing on VC they included studies that looked at the evaluation of the founder or the stage of investment. Interestingly there has not been research focusing on the exit strategy as a decision variable for capital acquisition yet. Looking at the VC process, it is a multilayered model generally including the following five steps. The identification of potential investments, the first screening of the investment, the assessment of the potential, the structuring and negotiation of the deal, and lastly, the post-investment management (Tyebjee & Bruno, 1984). While cleantech investments do not differ from the general model, the industry has certain characteristics that make it challenging for a traditional VC to invest in. We follow the definition of clean energy by Marcus et al. (2013, p. 32), it is defined as “solar and wind energy; biofuels; energy efficiency; alternative modes of transportation like hybrid, electric, and fuel cell vehicles; and supportive technologies such as storage and smart grid”. Some scholars believe that clean innovation and clean energy are necessary to drive the net-zero transmission (Stern & Valero, 2021). The role of entrepreneurs in creating sustainable solutions for society and in particular cleantech has been gaining attention in academia in the last decade (e.g. Cumming et al., 2016; Ghosh & Nanda, 2012; Hockerts & Wüstenhagen, 2010; Sadorsky, 2011; Stern & Valero, 2021).
In comparison to the vast research on internet or biotechnology VC decision process, cleantech VC research is limited (Cumming et al., 2016; Ghosh & Nanda, 2012). Cleantech investments tend to be riskier and more capital intensive but they have more social benefits than other investments (Cumming et al., 2016). Additionally, they differ from the time horizon of the investment. A cleantech investment needs more time to unfold its potential and does not normally fit into the typical 5-8 years hold and sell period of a VC (Marcus et al., 2013).
For entrepreneurs, the increased investment time horizon rises challenges, especially, when they are at the stage of first commercialization of the product. Through the in comparison to other industries' increased capital requirements for the commercializing of the product, many cleantech entrepreneurs are not able to raise sufficient funds. While an internet venture needs capital to increase the quality of the software or recruit personnel, a cleantech venture needs to build a demonstration plant which is way more expensive. This increased capital risk and the inability to raise funds is known as the “valley of death” (Nanda et al., 2015). Through the characteristics of their innovation or ventures, cleantech entrepreneurs have a higher probability to fall into it. Another big challenge for cleantech entrepreneurs is the weak exit mechanism in the industry (Cumming et al., 2016; Ghosh & Nanda, 2012). When compared with example the biotech sector, large corporates will buy young innovative startups. They see these innovative firms as complementary and as an asset, not a substitute. This is not the case in the energy or utility industry. In comparison to other industries, incumbent firms have not been active in acquiring young growth startups. This weak exit mechanism may discourage VCs to invest in cleantech (Cumming et al., 2016).
The importance of the sector for the future and especially for fighting climate change (Stern & Valero, 2021), the characteristics of the industry, and lastly, the weak exit mechanism, makes the cleantech industry an ideal setting for our study.

Entrepreneurial Exit Theory and Intentional Exit Strategy

Entrepreneurial exit theory has picked up pace over the last years accelerated by the research from DeTienne (Albert & DeTienne, 2016; Hohen & Schweizer, 2021). The theory tends to become one of the main research areas in the current decade (Wennberg & DeTienne, 2014). In the past, exit theory research focused for example on exit strategies (DeTienne et al., 2015; Isaksson, 2007); the importance of exit in the entrepreneurial process (DeTienne, 2010); involuntary exit and failure (Muñoz et al., 2020); changes in exit strategy intention (Hohen & Schweizer, 2021); the role of gender involuntary exits (Justo et al., 2015); or the perceived exit performance on the individual level of the entrepreneur (Strese et al., 2018). Entrepreneurial exit theory established three main exit routes apart from involuntary exit through bankruptcy; 1) financial harvesting e.g. through a trade sale to another company or an Initial Public Offering (IPO); 2) stewardship e.g. through succession or management buyout; 3) voluntary cessation through liquidation of the company by the entrepreneur (DeTienne, 2010). Scholars agree now that exit is regarded as a “critical and strategic outcome for the firm and has a significant effect not only on the founder(s) but also on firms, industries, and economies” (Albert & DeTienne, 2016 p. 827). Whereas entrepreneurial exit research has been increasing and entrepreneurial exit has been finally acknowledged as an important topic of the entrepreneurial journey, research with a focus on pre-planned or intentional exit strategies is still limited. Especially, when combining a pre-planned exit strategy with attracting additional funding resources. Looking at the research on intentional exit strategies, we identified three streams, the investor perspective, the entrepreneur perspective, and the firm-level perspective. The first stream looks from the investor's perspective. Cumming & Johan, (2008) researched the relationship between a pre-planned exit strategy and control rights as well as the used financial instrument. Sørheim et al., (2018) looked into the relationship between value-adding activities and pre-planned exit strategies. They identified the “Tailor and the Architect” as two investor groups. The first one already has a pre-planned exit strategy in mind and all value-adding actions from the investor are directed towards the intentional exit strategy. The latter does not have a specific exit strategy in mind, since the investor sees building a good company as the best exit strategy (Sørheim et al., 2018). Both papers looked from an investor perspective and acknowledge the importance of an exit strategy. However, even though they are taking the viewpoint of the investor they never assess how important the exit strategy of the investee for the investor is. The other stream of pre-planned exit strategy takes the viewpoint of the entrepreneur. DeTienne & Cardon, (2012) researched the relationship between founders’ experience on exit intentions. They found that different experiences and demographics affect the intended exit strategies of the entrepreneur, an old entrepreneur, for example, would rather go for a family succession strategy than a financial harvesting strategy (DeTienne & Cardon, 2012). While the research is looking on solely at the individual exit of the entrepreneur, the entrepreneur is influenced by many variables that affect the intended exit strategy. Hohen & Schweizer, (2021) researched the final exit path of the intended exit strategy of the entrepreneur. They were able to identify two different entrepreneurs. The first one financed the business through equity investors. The intended exit strategy of the first group was financial harvesting and the entrepreneur also settled with it. The second group of entrepreneurs intended for a stewardship strategy and financed the business only with their equity. This group was not able to pursue its intended exit strategy, e.g. family succession was rejected by the children (Hohen & Schweizer, 2021). For our research, the first group of entrepreneurs is more interesting, since they are looking for external capital while focusing on a financial harvesting strategy and also going through with it. The last stream of pre-planned exit looks at the level of the firm. Brush et al., (2008) researched the effect of the aspirations as well as the initial location of the firm on resource allocation and first firm sale. Grounded in a resources-based view they found that higher aspirations are correlated with more resources, but could not find a clear link to financial resources. In 2016, Albert & DeTienne applied imprinting theory, which suggests companies are shaped by resources and early decisions, to examine if the initial resources of the venture lead to an existing exit strategy. They base their perspective on the initial resources, theorizing that “strategic financial, human, and technological resources will imprint the firm in a way that will lead to a well-developed exit sale strategy” (Albert & DeTienne, 2016, p. 829). The results suggested that an existing exit strategy was correlated with technological resources. Although, they were not able to identify a strong positive relationship between initial financial resources and the exit strategy of a venture. Brush et al., (2008) and Albert & DeTienne (2016) were already trying to research the relationships between initial financial resources and intentional exit strategy. We build on their research. However, we differentiate ourselves by focusing on the relationship between additional financial resources and the intentional exit strategy on a firm-level basis while applying signaling theory.

Signaling Theory

Acquiring external funding from VC investors is crucial for cleantech entrepreneurs. However, when they are in the stage of commercializing the product they often fail to receive external funding. One reason for this failure could be the fundamental information asymmetry between possible investors and entrepreneurs (Amit et al., 1990). One possibility to overcome the information asymmetry and convince VC investors of their investment is the use of a signal (Colombo, 2021; Connelly et al., 2011).
Signaling theory is applied to overcome information asymmetries, reduce uncertainty for a given investment, and to communicate the quality of a given investment to the investor (Bhattacharya, 1979). The theory is mainly used to derive which attributes the signaler has to send to convince the receiver, that the proposal has high legitimacy and low uncertainty (Colombo, 2021). A signal can be positive or negative, in the capital acquisition process for new venture financing, signaling theory is skewed towards positive signals to attract capital (Colombo, 2021; Connelly et al., 2011). In signaling theory, the communicated signal can be used as a predictor for the actions of the receiver. In our case, the intentional exit strategy is turned into a signal to convince the investor that the entrepreneurs set exit strategy is possible and reduce the information asymmetry via signaling theory (Bhattacharya, 1979; Connelly et al., 2011). Through the inherent characteristics of the industry, e.g. the weak exit mechanism, the intentional exit strategy should be a positive signal to increase the perceived quality of the investment. The entrepreneur needs to signal that the chosen exit strategy is feasible, specific, and can be executed in a timely matter. Through the intentional exit strategy, the entrepreneur signals to the investor, that he is aware of the weak exit mechanism in the cleantech industry and already found a possible solution or in that case, a possible acquirer for the venture. Therefore, reducing the information asymmetry between the potential investor and the entrepreneur.

Hypothesis: Exit Strategy as a Signal for Investor Evaluation and Capital Acquisition

Based on the theory mentioned before and the characteristics of VC in cleantech, we can assume that an intentional exit strategy will be positively affecting an investor’s evaluation. We divide the investor evaluations into three parts, the idea attractiveness, the investment quality, and the investment amount. The idea of attractiveness is focusing on how the investor perceives the idea of the investment and his willingness to find out more about the investment proposal. The investment quality shows how the investor rate the investability of the venture, and lastly the investment amount, shows how much capital they would invest.
An investment decision is regarded as a multi-stage process (Clarke et al., 2019). Research suggests that pitches are an important part of this process and the pitch plays a major role in the materialization of the investment decision (Clarke et al., 2019). Before investors agree to invest, they evaluate the general attractiveness of the idea. At this stage, the investor decides to collect more information about the entrepreneur or the venture's environment (Falchetti et al., 2022). Through the intentional exit strategy, the investor should be persuaded to find out more about the venture, therefore we conclude:

H_1a: An intentional exit strategy will be positively correlated with the idea attractiveness of the venture

To measure the investment quality, we draw on the investment readiness (IR) framework. VCs often explain their high proposal rejection rates by referring to missing IR (Mason & Kwok, 2010; Zana & Barnard, 2019). IR focuses on three dimensions, investability, presentational failings, and equity aversion. We exclude the last dimension since the venture is looking for capital in exchange for equity and is not in the idea phase of the venture cycle. The intentional exit strategy should convince the investor, that the team knows the environment and plan ahead. Hence:

H_1b: An intentional exit strategy will be positively correlated with the investment quality of the venture

Lastly, through the intentional exit strategy, the investor should be persuaded, that the proposal has a lower uncertainty and higher legitimacy (Bhattacharya, 1979). A lower uncertainty and higher legitimacy should lead to a higher investment amount. Therefore, we hypothesize:

H_1c: An intentional exit strategy will be positively correlated with the investment amount for the venture

RESEARCH DESIGN

To test these hypotheses, we conducted a field experiment. We researched how VC investors would react to a pitch deck with a preplanned exit strategy and if it would lead to more favorable evaluations by investors (idea attractiveness, investment quality, and investment amount). We invited 105 VC investment employees to have a look at the pitch deck of Poligy, a cleantech company looking for 1 million euros (Poligy, 2022). Poligy is in the product commercializing stage. The participants were randomly assigned to a pitch deck of the venture. We prepared three variations of the pitch deck. The first group received the normal pitch and the second one the preplanned exit strategy pitch. To increase robustness and exclude time spent as a confounding variable (Platt et al., 2009), we added an extra information slide instead of an exit strategy slide in the pitch deck of the third group.

Experimental Study

To test our hypothesis, we conducted one experiment with three groups of VC employees associated with investment analysis. The groups were asked to analyze the pitch deck of a real cleantech venture. They were randomly assigned to three conditions. The first received the standard pitch deck. The second got the pitch deck with an exit strategy slide. The third received the pitch deck with an additional product slide.

Participants

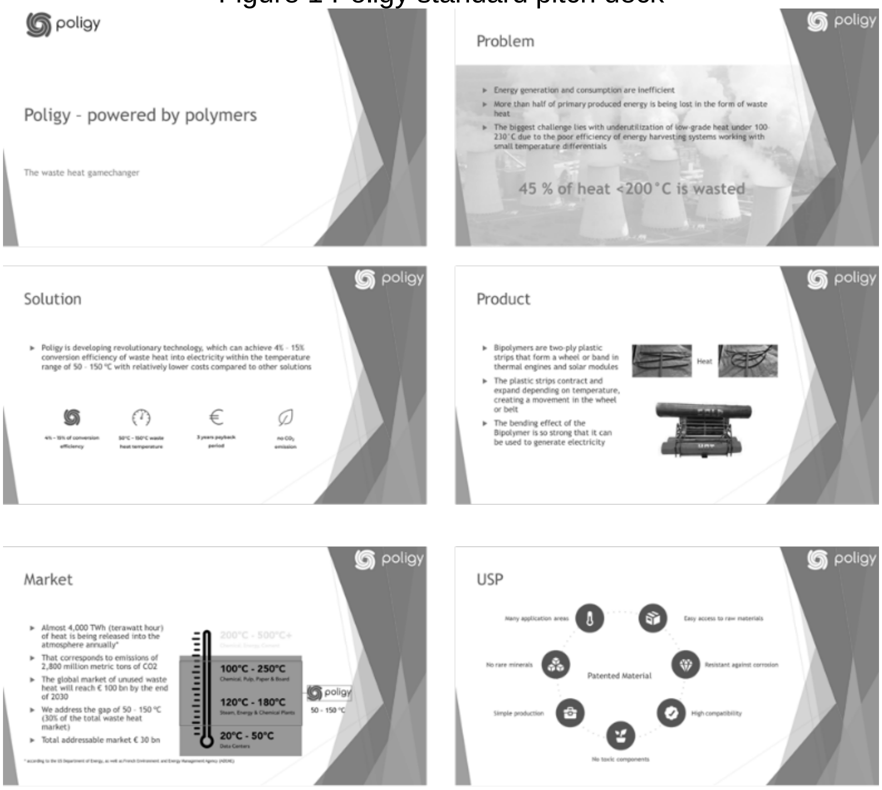
For the study we recruited investment analysts or managers working in a VC or CVC via LinkedIn and through the network of our researchers in Europe. Since our case was a real venture looking for capital, we persuade the participants to analyze the pitch deck and answer our questions afterward. Additionally, we added a catch question to detect inattention (Meyvis & Van Osselaer, 2017; Oppenheimer et al., 2009) [Please indicate in which industry is the venture

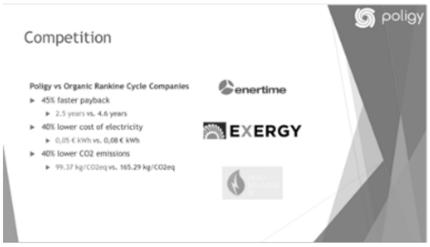
active? Pharma or Energy]. The participants were randomly assigned to one of the three conditions.
The final sample consists of 105 VC investment employees. 23.5% of them were female and 76.5% were male. The average age was 31.7. Regarding the educational background, 1.96% had a high school degree or equivalent, 23.53 % had a bachelor's degree or equivalent, 57.84% had a master's degree or equivalent, and 16.67% had a Ph.D. or equivalent. The sample consists of 54.9% Investment Analysts or equivalent, 18.63% Investment Managers or equivalent, 14.71 % of Investment directors or equivalent, and 11.76% others. The average experience in the investment sector was 2.56 years and the average experience in the cleantech sector was 2.26 years. The final sample of 105 was divided into three groups, standard (n=35), product (n=36), and exit (n=34). Regarding demographic variables the samples between conditions were homogenous.

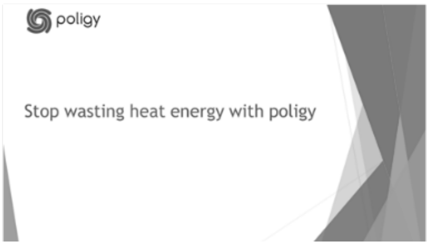
Material & Procedure

We used the pitch of the venture Poligy. Poligy is a cleantech venture that develops electricity through unused waste heat (Poligy, 2022). The venture was looking for real capital, therefore we reflected mundane and psychological realism (Berkowitz & Donnerstein, 1982; Colquitt, 2008). In the experiment, participants were randomly assigned to one of the three conditions, standard deck, exit strategy slide, and additional information slide in a between-subject experiment (Allen, 2017). We invited the participants to look at the pitch deck through an online survey tool. After looking at the pitch deck participants were able to complete the questionnaire. To ensure realism the participants were able to download the pitch deck through the survey tool. The pitch deck of venture Poligy is visible in Figure 1.

Figure 1 Poligy standard pitch deck





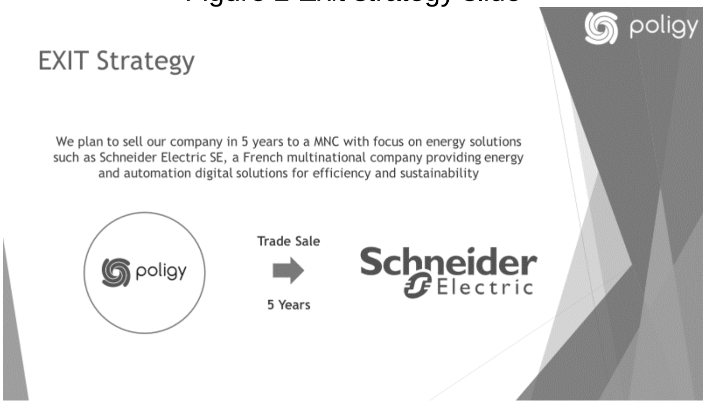


The original pitch consists of 11 slides, the intro, the problem, the solution, the product, the market, the unique selling proposition (USP), the competitors, the team, the proof of concept, the ask slide, and the outro (Poligy, 2022). The pitch deck was the basis for both conditions. For our data manipulation, we added an exit strategy slide after the proof of concept slide and an additional product information slide after the USP slide. Since the venture was looking for real capital we explained our data manipulation after the questionnaire and the manipulation check questions were completed.

Data Manipulation of The Independent Variable: Exit Strategy

We manipulated the content of the pitch deck by adding one exit strategy slide to the deck. The exit strategy is a trade sales strategy since IPOs are less common in the cleantech VC industry (Amit et al., 1998; Isaksson, 2007; Wüstenhagen & Teppo, 2006). The slide can be seen in Figure 2. The slide was constructed by the Poligy team.

Figure 2 Exit strategy slide



Data Manipulation of the Independent Variable: Additional Product Information slide

To ensure the effect on our dependent variables is not from more time spent on the evaluation (Platt et al., 2009), we included an additional product information slide, see Figure 3. The slide was constructed by the Poligy team.

Figure 3 Additional product information slide

Measures

Dependent Variables Idea Attractiveness

Adapting our items from Clarke et al., (2019) and Falchetti et al., (2022), we asked the participants if they liked the idea (1 = not at all, 7 = extremely) and the probability to search for more data about the venture. The probability to search for more information consisted of, do further research into the management team (1= definitely, 7= not at all), and do more research on the venture (1= definitely, 7 = not at all). Following Falchetti et al., (2022) we took the average of the two items to calculate a single score for probability to look for more data. Subsequently, we checked if the two items were correlated to support the operationalization. The results show that they are highly positively correlated (r=0.8, P-value=0.00), hence supporting the operationalization. Afterward we computed a summative indicator by combining the single score with the measure of liking the idea.

Dependent Variable Investment Quality

To measure the investment quality, we draw on the investment readiness (IR) framework. VCs often explain their high proposal rejection rates by referring to missing IR (Mason & Kwok, 2010; Zana & Barnard, 2019). IR focuses on three-dimension, investability, presentational failings, and equity aversion. We exclude the last dimension since the venture is looking for capital in exchange for equity. We measured the investment quality by asking the participants, if they think that the team has realistic expectations (1=not at all, 7= extremely) and if the venture provided enough information in the pitch deck (1= not at all, 7= extremely). Additionally, we asked if the venture has the potential for investment (1= not at all, 7= extremely). Afterward, we computed a single score for investment quality by averaging the three answers.

Dependent Variable: Investment Amount

To measure how much capital investors were willing to invest, we asked: “You received € 100,000 from your fund to invest in cleantech companies, how much would invest in the venture?” Participants indicated the amount via a sliding scale from € 0 to € 100,000. Even though Poligy was asking for € 1 million in funding we used a € 100,000 scale to reduce the standard deviation. The sliding scale as a measurement for investor evaluation is frequently used in this kind of research (e.g.: Falchetti et al., 2022; Huang & Pearce, 2015).

Manipulation Check: In-Experiment Exit Strategy

To determine if our data manipulation was appropriate, we did an in-experiment manipulation check (Hoewe, 2017). To ensure that the participants were not manipulated by the manipulation check questions (Kühnen, 2010), we positioned the questions at the end of our survey. The participants were asked to answer the questions on a 1 – 7 Likert scale (1= not at all, 7= extremely). The questions were: “I am sure what the company's plan is for the next 5-7 years” and “I know exactly how the company wants to exit”.
To determine if our manipulation was successful we compared the results of the treatment group with the control group. The one-way ANOVA for the question “I am sure what the company's plan is for the next 5-7 years” showed a difference between the two groups (F 21.65, F crit 3.98, P-value 0.00). Participants in the standard condition were not so sure about what Poligy`s plan for the next 5 years is (A=1.85, SD 1.33), whereas participants who received the exit strategy were more confident in their answers (A=3.85, SD 2.14). The results for the second question “I know exactly how Poligy wants to exit” were the same. The one-way ANOVA illustrated that there are differences between the groups (F 111.69, F crit 3.98, P-value 0.00). The standard group did not know how Poligy wants to exit (A=1.8, SD=1.47), while the exit strategy group was confident in their answers (A= 5.74, SD=1.62).
Therefore, we concluded that our data manipulation was successful.

RESULTS

Excluding Time as Confounding Variable: Additional Product Slide

To exclude time as a confounding variable and mediator, we added one additional product slide in one group of participants. First, we compared the total duration of the survey and the time spent on the pitch deck between the standard and additional product groups. The one-way ANOVA for the survey duration showed no differences between the two groups (F 0.3, F crit 3.97, P-value 0.57). Afterward, we checked if the participants spent more time on the pitch deck.

Here the one-way ANOVA also showed no differences in the groups (F 2.41, F crit 3.97, P-value 0.12).
Additionally, we compared the results of the additional product slide group with the results of the standard pitch deck group.

Idea Attractiveness

The one-way ANOVA for the indicator idea attractiveness should no differences between the standard (A=4.96, SD=0.82) and the product (A=4.83, SD=0.98) group (F 0.37, F crit 3.97, P-value 0.54).

Investment Quality

For the investment quality indicator, the one-way ANOVA illustrated no distinction, (F 0.3, F crit 3.97, P-value 0.58) between the standard (A=4, SD=0.82) and product group (A=4.1, SD=0.82).

Investment Amount

We compared the average invested amount between the standard pitch deck group and the additional product slide group. Even though there are small differences between the average invested amount from the groups, standard (A= € 23,099, SD=16,375) and product (A=€ 21,438, SD=18,107), the one-way ANOVA illustrated that these differences were not significant (F 0.16, F crit 3.97, P-value 0.68).
Due to the fact, that there are no statically significant differences between the results and the one-way ANOVA of the time spent on the pitch deck, the survey duration, the idea attractiveness, the investment quality and, the investment amount showed no significant differences in the groups. We excluded time as a confounding variable in our experiment. Additionally, we concluded that the additional product slide did not affect the investor evaluation.

Exit Strategy Slide

Since we could exclude time as a confounding variable, we were able to continue our analysis of the group with the exit strategy slide and the standard pitch deck group.

Idea Attractiveness

In the idea attractiveness dimension, the participants in the standard pitch (A=4.96, SD=0.82) liked the idea more by 3% than the exit group (A 4.84, SD=1.21).

However, the one-way ANOVA showed that there was no real difference between the groups (F1, F crit, 3.98, P-value 0.61).
Based on the results mentioned above, they are inconclusive with our hypothesis H_1a.

H_1a: An intentional exit strategy will be positively correlated with the idea attractiveness of the venture

Investment Quality

In the investment quality indicator, the standard group found the venture more qualitative than the exit group. The standard group (A=4, SD=0.83) reported 3% higher values than the exit group (A=3.89, SD=1).

Yet, the one-way ANOVA for investment quality indicated no distinction between the two groups (F1, F crit, 3.98, P-value 0.62).

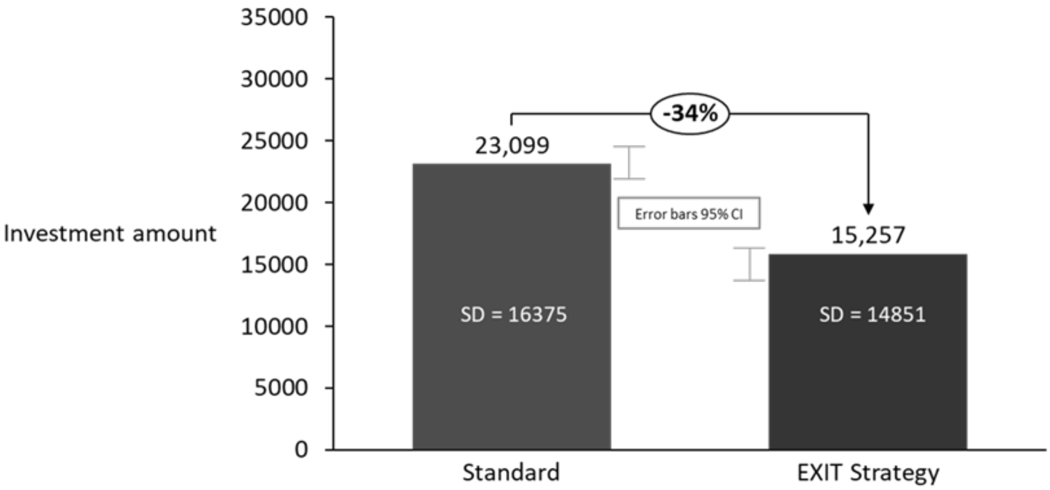
Due to the results of the investment quality group we cannot find evidence for the hypothesis H_1b.

H_1b: An intentional exit strategy will be positively correlated with the investment quality of the venture

<u>Investment Amount</u>

The standard group reported a 34% higher investment amount (A=€ 23,099, SD= 16,375) than the exit group (A= € 15,257, SD=14,851).

Figure 4 Investment amount Standard vs Exit



The one-way indicated that the differences between the two groups are statistically significant at a 95% confidence interval (F:4.33, F crit 3.98).

The results of the investment amount are rejecting our hypothesis H_1c.

H_1c: An intentional exit strategy will be positively correlated with the investment amount for the venture

Since the results for H_1a and H_1b are inconclusive and H_1c is rejected we can reject our hypothesis that an intentional exit strategy will be positively correlated with the investor's evaluation.
Instead, we find that an intentional exit strategy is negatively affecting investor evaluation.

DISCUSSION

Sustainable entrepreneurship may play an important role to deal with climate change (Chapple et al., 2010; Marcus et al., 2013). However, cleantech entrepreneurs are depending on VC funding (Ghosh & Nanda, 2012), to bring their technology onto the market. While general VC investor decision criteria are widely researched, research in the field of cleantech VC is still scarce (Cumming et al., 2016; Wüstenhagen & Teppo, 2006). When comparing cleantech ventures with other ventures, cleantech companies are riskier, have more capital requirements, are less likely to scale up, and are more difficult to exit (Cumming et al., 2016; Ghosh & Nanda, 2012). Based on the generally positive effects associated with a pre-planned or intentional exit strategy in theory (e.g. Brush et al., 2008 or Albert & DeTienne, 2016). We hypothesized through signaling theory (Bhattacharya, 1979; Connelly et al., 2011), that a pre-planned exit strategy has a positive impact on investors' evaluation and additional financial resources. Hereby, we tried to answer the question if an entrepreneur should include an exit strategy slide in the pitch deck to increase investor evaluations and therefore the invested amount. We assumed that this effect is particularly visible in the cleantech industry where exits are regarded as a barrier to investment (Ghosh & Nanda, 2012; Marcus et al., 2013; Wüstenhagen & Teppo, 2006). Grounding our research on a real investment case, we tried to disentangle the relationship between investor evaluation and pre-planned exit strategy. We tested our hypothesis in a 1x3 experiment with 105 VC investment associated employees. We explored the effect of a pre-planned exit strategy on the decision criteria of investors by varying only one slide, the exit strategy in a pitch deck presentation of a cleantech venture. We then measured if the pre-planned exit strategy leads to more favorable evaluations by investors (idea attractiveness, investment quality, and investment amount).

However, our results indicate a negative effect on investor evaluation. While we could not find any significantly different results between the two factors idea attractiveness or investment quality, we found a strong negative relationship between the investment amount. VCs provided 34% less capital to the venture when the pitch deck included an exit strategy.

The results of the study contradict the generally positive impact associated with an initial exit strategy on the venture (e.g. Brush et al., 2008 or Albert & DeTienne, 2016). However, we need to remark, that past studies did not focus on the cleantech industry, which has a weak exit mechanism (Cumming et al., 2016; Ghosh & Nanda, 2012), and were not focusing on additional resource acquisition. To our knowledge, we are the first study that researches investor evaluation and additional financing resources concerning initial exit strategy. Additionally, we draw our data from a field experiment.

Still, while the preplanned exit strategy has positive effects in other industries, it seems that in the cleantech industry this effect is not visible. We identified two reasons that could be the explanation for the negative effect, the weak exit mechanism in the industry or the focus on sustainable value and role in the industry.

Weak Exit Mechanism

One explanation could be that investors are aware of the challenges in the cleantech industry. They know about the weak exit mechanism in the sector (Cumming et al., 2016; Ghosh & Nanda, 2012). They recognize that for example in the biotech sector, large corporates will buy young innovative startups. In the cleantech industry or in general, in the energy and utility industry, large corporates see innovative firms as a substitute, not as complementary or as an asset. Since incumbent firms have not been active in acquiring young growth startups (Cumming et al., 2016), they do not see the exit strategy as feasible. Therefore, instead of sending a positive signal, the exit strategy is sending a negative signal to the investors.

Focus on Sustainable Value and Role in the Industry

Another explanation for the results of this study could be the motivation of the sector to create sustainable value for society and the role of cleantech entrepreneurs in driving the net-zero transmission (Stern & Valero, 2021). Even though the intentional exit strategy, could mean, that the proposal has a lower uncertainty and higher legitimacy (Bhattacharya, 1979). Following our theory, the emphasis on financial benefits through the exit strategy leads to unfavorable evaluation due to the missing focus on creating sustainable value, establishing social benefits for the society (e.g. Cumming et al., 2016; Ghosh & Nanda, 2012;), and the driving the net-zero transmission (Stern & Valero, 2021).

IMPLICATIONS FOR THEORY & PRACTICE

Implication for Theory

Our experiment provides new insights into the relationship between intentional exit theory, investor decision criteria, and cleantech. This study's main contribution is to the discussion of intentional exit theory and funding resources. Earlier research applied imprinting theory or goal theory to research initial funding resources and intentional exit theory. Our research extends this domain by introducing additional capital and investor evaluations to the intentional exit theory. To the best of our knowledge, we are the first experimental study that researches investor evaluation and additional financing resources in relation to the initial exit strategy. While previous studies find a positive impact associated with an initial exit strategy on the venture (e.g. Brush et al., 2008 or Albert & DeTienne, 2016). Our study shows that this may not hold for industries with weak exit mechanisms or industries with a focus on social and sustainable value. This is opening avenues for research focusing on an exit strategy in industries with these characteristics. This study further advances our knowledge of cleantech VCs decision criteria by drawing the data from a real-life experiment based on a real cleantech venture in a funding round. Researcher suggests that VCs also plays a role in the commercialization of clean energy solutions (Wüstenhagen et al., 2009). In comparison to the vast research on internet or biotechnology VC decision process, cleantech VC research is still limited (Cumming et al., 2016; Ghosh & Nanda, 2012). We contribute to the knowledge by focusing on an exit strategy as a decision criterion for investors. Lastly, we contribute to the signaling theory by identifying exit strategy as a negative signal in the cleantech industry. Our results encourage further research into the relation between intentional exit theory and cleantech VCs decision criteria.

Implication for Practice

From a practical perspective, research on investor decision criteria supports aspiring and existing cleantech entrepreneurs with the knowledge to increase the efficiency of capital acquisition. Through our paper, we hope to expand the understanding of investor evaluations in the cleantech industry with a focus on an intentional exit strategy as well as contribute to the knowledge of entrepreneurs acquiring much-needed capital in the segment (Masini & Menichetti, 2013). Acquiring additional capital is a major challenge for cleantech entrepreneurs since they are more likely to fall into the “valley of death” (Nanda et al., 2015). Especially, in the rapidly changing environment of entrepreneurial finance (Connelly et al., 2011), gaining knowledge over positive and negative signals, or in other words, which slides to include in a pitch deck, to attract capital is very important. Our research yields a strong contribution for aspiring and existing cleantech entrepreneurs. While in other industries intentional exit strategy seems to have a positive impact on the venture. In the cleantech sector, it indicates a negative signal. Hence, a cleantech entrepreneur should think twice to include an exit strategy slide in a pitch deck. This negative effect may hold as well in non-financially driven industries or other sectors with weak exit mechanisms.

LIMITATIONS AND FUTURE RESEARCH

There are several limitations to this study. First, we collected our data from European VCs, even though we are confident that the relationship between intentional exit strategy and investor evaluation in the cleantech industry will hold for other investment cultures as well. We believe that a replication of our study in a different investment context such as in America or emerging markets would yield a contribution to theory and practice. Second, our study draws on a sample with 105 responses. While the sample size of our experiment is rather small, the population of cleantech VC firms in Europe is also limited. Additionally, we establish good evidence that issues regarding our sampling size are unjustified. Still, stability challenges may exist. Furthermore, due to the small sample, we could not delve into differences between the demographics of the investors or their experience within the industry.
Lastly, we are aware that there are differences between investment behavior in different industries and venture stages. There is evidence of the negative effect of the intentional exit strategy on investor decision criteria and additional funding resources in cleantech in the pre-commercialization stage. Also, we believe that this holds for non-purely financially driven industries and industries without proper exit mechanisms as well. However, we cannot generalize the results to other industries. A replication of the study focusing on intentional exit strategy and funding resources for example in the pharma industry or other impact industries could increase our understanding of the relationship between intentional exit strategy and additional funding resources even more. Additionally, a study focusing on the later stages of a venture and intentional exit strategy might discover unknown aspects of the intentional exit theory.
In summarizing we believe that the relationship between intentional exit theory and investor decision criteria in this study opens new avenues for research. Especially, we are certain that further research on the importance of exit in industries without a proper exit market or in non-financially focusing industries, the relationship between intentional exit and additional funding resources, intentional exit concerning investment stage, and cleantech investor decision criteria will profit scholars, investors, policymakers, and entrepreneurs.

CONCLUSION

Let`s talk about exit in cleantech or not? While exits in the cleantech market still need more research and we should talk about it. As a cleantech entrepreneur, however, pitching your idea to investors, you should rather not.

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Managerial Decisions in Your Firm

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Location Analytics Strategies: A Case Study Analysis

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ABSTRACT

Location analytics is increasingly applied in business. Its importance calls for development of mid- to long-range strategies. Hence, Geographic Information Systems (GIS) management needs strategic plans with prioritized objectives. There is lack of a theoretical framework and few empirical studies of GIS strategy. Case study analysis is conducted to answer three research questions: what is of high priority in GIS strategy, extent that competitive features are included; how is GIS strategy positioned relative to business strategy and IS strategy. The answers are explored for three businesses, based on semi-structured interviews. Findings are informative on strategic priorities, competitive force, and alignment.

KEYWORDS: Geographic information systems, Location analytics, Strategy, Case study

INTRODUCTION

Spatial strategy of a business can serve as a guide towards reaching long-term goals of bringing Geographic Information Systems (GIS) to fruition in a firm. In doing so, the leadership of the GIS department or team needs to have a major role in creating the plan. At the same time, GIS must be balanced against other goals the organization may have (Tomlinson, 2013). The GIS leaders formulating the strategic plan need to ask about the where, how, why, and what for GIS in the firm and then seek to understand how GIS contributes to the overall firm strategy. Since GIS is a rapidly advancing technology, the strategic plan must look forward and include new and growing features of location analytics that will impact the firm over the next five or ten years (Pick, 2008).

A Geographic information system integrates geographic locations with associated attribute data and has features for input, analytics, and output of maps and digital imagery. Location analytics refers to analytics that are enhanced by incorporating locations and mapping for description, prediction, and prescription. Spatial strategy refers to organizational strategy that recognizes and enhances its strategic steps and goals by incorporating spatial information and knowledge (Lewin, 2020).

The present research study has the objective to examine, in an exploratory way, how companies, small and large, can formulate major strategic goals, how a strategic plan can include competitiveness, and determine what the arrangement is of the GIS strategy in relation to the company's strategy. This area has been little studied, as evidenced by the paucity of articles or books that have investigated GIS strategy. This scarcity creates a gap that the present paper seeks to shed light on in an exploratory way.

The gap means that many companies that seek to start up locational analytics or broaden the intensity and scope of existing location analytics are guessing too much on how to set strategic goals incorporating location and implement the goals. The firm could fall back on conventional IS strategy (Peppard & Ward, 2020; Papp, 2001), but that will neglect or miss out entirely on incorporating the locational and geospatial aspects of strategy. What is needed is for management to identify what, if any, mapping and spatial tools and skilled spatial workforce are available. Further, how can these capabilities be added or enhanced in order to supplement IS strategy with complementary location analytics/GIS strategy. The present study recognizes this gap and utilizes authors' reasoning and induction and modified conceptual frameworks, including spatial variations of strategic alignment theory and competitive forces theory, to seek to improve managers' cognition and readiness to add spatial strategy alongside IS strategy, or alternatively combine the two together.

The study's importance is further justified, because GIS is growing in size and importance in the business sector. For instance, for year 2020, GIS has been expanding for the geospatial industry at an estimated at 13.8 percent growth rate, and the geospatial industry is valued at $429.8 billion (est.) (Geospatial Media and Communications, 2019). Moreover, it is competitively important for a company with evolving location analytics to learn about the experiences of other firms in developing and putting in place GIS strategy, in order for the company to accomplish its GIS strategy.

LITERATURE REVIEW

There has been limited study of GIS strategy. Our extensive review of the literature has yielded only a few studies that constitute a base to build on. These studies are grouped in the areas of theorizing and cases on spatial strategy, competitiveness as part of GIS strategy, and alignment of GIS strategy with the corporate and IT strategies.

Theorizing and Cases on Spatial Strategy

Early studies of GIS strategy were put forward in an era of GIS that was mostly local-server-based with minimal online access (Hendriks, 1998; Somers, 1998). However, their strategic frameworks have bearing today. GIS strategy can draw on the better-known framework of IS strategy, having the sequential stages of strategic analysis, formulation, implementation, and evaluation (Hendriks, 1998). The stages were further focused for GIS strategy development into the three steps to (1) identify the challenge, (2) position GIS, and (3) position the organization. The step of positioning GIS relative to the organization consists of determining the places in the firm for which GIS can help strengthen the firm's relationship with its environment (Hendriks, 1998). Although this refers to an earlier technological setting, the uncovering of spatial opportunities in strategic GIS planning informs today's planning. The relevance of GIS in the supply chain, supported by administrative departments and R&D was emphasized as a way to organize spatial strategy (Hendriks, 1998). Although the GIS supply chain model might be useful for a manufacturer, it is less relevant for many industries having less prominent supply chains.

An early organizational model that includes GIS roles constitutes another basis for GIS strategy development (Somers, 1998). Somers' suggested roles include GIS as a component of an enterprise system, a source of data, a support service, and/or a business tool. For strategizing, it is recommended to establish a GIS model for the enterprise, i.e., similar to a business model but focused on GIS (Somers, 1998). Somers further recommended to provide a vision for GIS keyed to user needs and to assess the risk in proposed GIS initiatives. This implies a thorough and intensive GIS strategy formulation, which however, may be limited by the small size of the GIS team. Even today, the team in one of the largest global pharmacy firms has a GIS staff of only five, which is tiny compared to the larger IT department. Another organizational approach emphasizes convincing executive leadership of the value of GIS (Lewin, 2020) and for amenable organizations, proceeding with five spatially-informed practical steps of mapping business needs, defining the meaning of spatial strategic success keyed to an individual organization, prioritizing choices of spatial "building blocks," testing for feasibility and viability of the strategy, and iteratively executing the strategy (Lewin, 2022).

An investigation of 20 case studies of GIS strategies in business posited an "evolutionary framework" for GIS strategy based on three dimensions: extent spatial is customer-facing, extent of geography in the business, and extent of spatially-enabled web integration platform (Pick, 2008). The cases were retrospectively categorized by the dimensions. For instance, Motion-based Technologies (pseudonym) was high in all three dimensions, while Bay State Health was low on all dimensions. In today's environment, the dimensions would need to be updated, since for instance GIS on the web platform is commonplace in today's leading spatial software products. The study also summarized the dominant goals of each firm's spatial strategy. For instance, for the Southern Company, a large US utility, GIS strategy emphasized collaboration with several leading generic GIS and utility-specific spatial software vendors to achieve successful enterprise spatial system (Pick, 2008).

Other prior literature emphasizes in-depth case study analysis of strategic GIS in firms (Zhao & Lu, 2006; Rice, Ostrander, & Tiwari, 2016). A case study analysis of strategic planning at software-consulting-firm MDI Pty Ltd, considers its deployment of GIS strategy, with reference to the models of Value Innovation, and sustainable business development (Zhao & Liu, 2006). For MDI, strategic planning involved researching the set of applications where GIS services are needed, performing a SWOT analysis on each area to build the strategic GIS plan, and adjusting the detailed strategic GIS activities referring to MDI's IT spatial value chain model. The process developed by MDI was made available to the firm's auto industry clients, which could in turn formulate the strategic goals, critical success factors, specific strategic activities and action plans (Zhao & Lu, 2006).

A case study analysis of Wal-Mart's spatial strategy sought to explain the geographic change in the firm's network of stores and distribution network (Rice, Ostrander, & Tiwari, 2016). The study evaluated the changes in the geographic flows in the firm's networks by accessing a comprehensive database of its store locations and distribution centers from 1963 to 2006. It sought to confirm whether in its build-up, Wal-Mart targeted geographic areas with specific demographic profiles. The research informed the giant retailer's patterns of change though retrospective analytics, gaining insight into Wal-Mart's locational expansion strategies through this indirect approach (Rice, Ostrander, & Tiwari, 2006). This method was necessary, because the key managers and executives had retired or declined to be interviewed.

Several studies have applied varied spatial methods to support strategies of locating stores and planning branch offices (Baviera-Puig, 2016; Maximenko & Maximenko, 2021). For supermarket locations, a geomarketing model was built to inform location strategies using a mixed approach of objective and subjective variables that relate to a supermarket company and its trade area (Baviera-Puig et al., 2016) The strategy was implemented by applying GIS tools for location analytics at high spatial resolution, including a multiplicative competitive interaction model based on the location theory of retail enterprises. A study in Moscow, Russia, sought to support a bank's GIS strategy to locate a branch network by analyzing accessibility zones that overlap with agribusiness clusters. It was designed to fulfill the strategic goal to extend banking services to agricultural territories that have had underserved banking services (Maximenko & Maximenko, 2021). The geospatial methods applied were drive times and GIS-based cluster analysis of micro-data on agribusinesses. These studies focused more on the methods that underpin GIS strategy, rather than on the strategic focus, competitiveness, and alignment examined in the present research.

Competitiveness in GIS strategy: The Competitive Forces Model

Since competition is essential for profit-making firms and across industries, GIS and location analytics can help strengthen competitiveness, reducing the cost of goods and services, better differentiating products and services, and encouraging a business to specialize in a market niche (Porter, 2008). For instance, Walgreens has implemented an enterprise system for GIS that integrates the crucial functions of site location, competitor locations, demographic and economic profiles of communities, and other spatial characteristics to achieve integrated planning by location, which makes it more competitive again its major competitor. In another example, a small firm, GIS Consulting Inc.(pseudonym), established a strong niche in high-end location analytics software for sophisticated federal government agencies that deploy GIS applications in real-time, spatially dynamic environments, including design of a standardized spatial surveillance system for government vehicles and personnel that provided support to a US Presidential inauguration (Pick, 2008).

These advantages are evident by applying the “Porter 5-Forces Model” (Porter, 2008). At the center of this model is a company, referred to hear as Firm X, that competes with other companies to seek to realize a sizeable portion of the market benefit (profit). This first force is *direct competition*. The firm can utilize GIS in a variety of ways to strengthen its positioning against direct competition. For instance, it might optimize the location of company assets, analyze vehicular patterns around retail locations, track the location of originating, developing, producing and distributing and selling products and services in the supply chain.

The relationships in the model of *new market entrants, substitute products, firm-supplier relationships*, and *firm-customer relationships* (Porter, 2008) likewise can be strengthened by GIS, leading to strategic advantage.

Substitute products or services can remove the benefits of an existing product or service of a company by providing alternate product/service that outcompetes the existing one. In the sharing economy, Airbnb can track the characteristics of customers who utilize spatial locations of certain types of properties.

The *customer relationship* between Firm X and its customers is important competitively, since the customers can significantly influence Firm X’s costs and competitive position, based on the intensity of demand as well as government regulations (Porter, 2008). GIS technologies and location analytics can affect the firm-customer relationship in manner that depends on the industry. GIS improves customer relationships across industries through such diverse features.

The last competitive force, the *firm-supplier relationship*, depends on the positioning of the supplier in the market. If the supplier holds costing clout over the market, firm X may benefit by deploying GIS applications to improve its relationship with the supplier.

Given the prevalence of GIS roles in the five forces model, GIS can be a dynamic tool that can reduce a company’s costs or differentiate its products and services (Zhao & Lu, 2006).

Analyzing competitive forces related to spatial enhancements represents a way that a firm can analyze market factors to determine the competitive position of a firm in a particular industry (Zhao & Lu, 2006). The model can be utilized in conjunction with other models to support and strengthen GIS strategies.

Business-GIS-IT Strategic Alignment Model

Another approach to GIS strategy emphasizes the need to align the GIS strategy with the firm's corporate and IT strategies. A spatial strategic alignment means that business, IT, and GIS strategic plans are in tandem and progress towards complementary goals. Achieving alignment reduces conflicts, redundancies, and divisive cultural differences, boosting the firm's competitive strength (Luftman, 2001). On the other hand, misalignment can lead to cultural tensions and problems (Peppard & Ward, 2016).

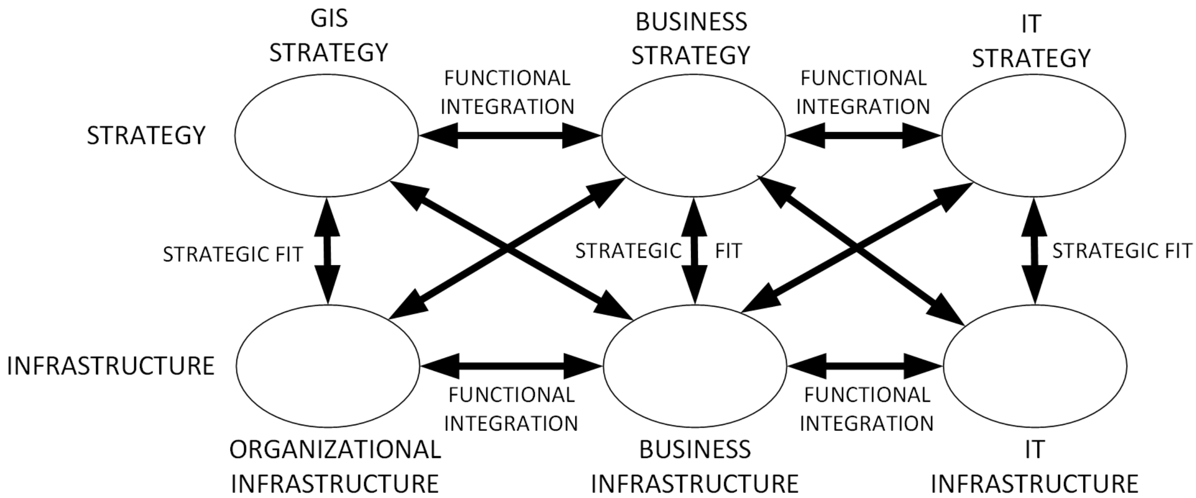
For GIS, there are challenges in achieving alignment. As regards to business strategy, it has long been known that the human/behavioral competency in management needs to be matched to the underlying organizational infrastructure (Henderson & Venkatraman, 1993; Papp, 2001; Luftman, 2001; Peppard & Ward, 2016). For example, for a Big Property/Casualty Insurance Inc. (Pick, 2008), there is strong organizational structure and workflows, which are a good fit for its mature enterprise-level business strategy.

If IT and GIS strategy are developed together to achieve alignment, the softer side of strategy, i.e. competencies in technology, IT governance, and scope, needs to be matched with the underlying technical side, consisting of IT architecture and infrastructure processes (Disera, 2015), and the same for the softer and technical sides of GIS. Tensions may arise due to communications and collaboration issues (Disera, 2015). Integration and smooth teamwork can be achieved by having the chief information officer (CIO) and GIS manager be actively involved in IT/GIS strategy development, and vice versa (Disera, 2015).

Another relationship is that between GIS strategy and the business strategy (Tomlinson, 2013; Hitt, 2017). A GIS strategy must ultimately be in concordance with the firm's strategy (Tomlinson, 2013). This can be assisted by the GIS manager or management team spending the time and effort to become acquainted with the job tasks of a variety of employees at different levels and functions in the enterprise. Moreover, the GIS manager should spend time visiting a worker in a part of the firm with potential for GIS and observing what the worker is doing, with the manager asking questions and clarifying just how work is accomplished (Tomlinson, 2013). By garnering grounded knowledge about the whole company, the GIS leader can adopt a strategic plan that conforms to the business strategy, in fact not just in words (Tomlinson, 2013). The GIS manager needs to understand the mission of the organization and develop the GIS plan with business mission in mind (Hitt, 2017; Lewin, 2020).

This set of relationships can be summarized in a diagram showing business strategy in the left column, with strategy at the top and infrastructure at the bottom, and IT strategy similarly in the right column. The three strategies need alignment, namely business, GIS, and IT. As seen in Figure 1, there are many more relationships between strategy (at the top) and infrastructure (at the bottom). Additionally, a third set of cross flows, between business strategy and information strategy, are not shown on the figure but are similar to the cross flows portrayed (Pick, 2008).

Figure 1. Alignment of Business, GIS, and IT Strategies



(modified from Pick, 2008)

The six strategic cells have cross flows with each other (Papp, 2001). The cross flows represent that each one of the 6 quadrants informs every other quadrant both on strategy and functional integration. This diagram demonstrates that even achieving alignment between two of the three strategies is complex and may need adjusting, negotiation, and compromise to reach a balance that allows multiple strategies to work well together.

Given the complexity of aligning three strategies, the GIS group is challenged to find the time to create its strategy, and even more so if the group has few employees, which is common even in global firms. For instance, Kentucky Fried Chicken has a 3-person GIS unit and Walgreens has a 5-person unit. The sheer workload involved implies that the GIS strategy may need to be simplified.

The organizational framework in Figure 1 can be helpful to GIS strategic planners to think through and prioritize the relationships that potentially need to be researched. Once a strategic plan is underway, further steps are recommended to help build, strengthen, and maintain the alignment relationships (Luftman, 2001; Disera, 2015; Papp, 2001; Peppard & Ward, 2016). These steps should be guided by the following cultural and behavioral principles.

- *Effective communication*. All along the way, alignment is assisted by communication across the organization.
- *Organizational culture*. Sharing a common culture between the GIS unit and its collaborating units can stimulate free flow of ideas, based on similar values, procedures, and processes that enable productive outcomes.
- *Motivation to and from the C-Suite*. If the C-Suite, i.e., the executive managers in an enterprise, is not being proactive, it falls on GIS leadership to reach out to it.
- *Governance maturity*. There needs to be synchrony in governance between various partners.

- *Partnership*. “How each organization perceives the contribution of the other, the trust that develops, and the sharing of risks and rewards are the contributors to mature alignment.” (Luftman, 2001).

In summary, strategic alignment is a major challenge and opportunity for the spatial unit and its leaders to leverage what is often a small, semi-silo’ d GIS group into vibrant, sharing role across levels and functions in an organization, and to stride forward in partnering with the business and IT functions.

RESEARCH QUESTIONS AND JUSTIFICATION

Based on the literature review and recognizing the gap in research literature on GIS strategy, we posit the following research questions, each followed by the justification imputed from the literature or authors’ reasoning.

Research Question 1. What is/are the principal GIS strategy focus(es) in the organization?

Organizations have rarely formalized their GIS strategy, as seen by its paucity of examples in the literature including the authors’ research (Pick, 2008). Given the limited number of in-depth case studies on development of GIS strategy (Rice, Ostrander, & Tiwari, 2016), analysis of the organization, the placement of the GIS team in the enterprise, its competitive spatial position, and other factors can give insights on what are the principal GIS strategic focus or focuses for the firm.

Research Question 2. Does GIS strategy recognize and include the relationships in the Five Competitive Forces model?

Since an important part of a firm’s GIS strategy is how GIS can contribute to competitiveness, it is appropriate to test a competitiveness model that can include GIS. As suggested in a study of GIS strategy (Zhao & Lu, 2006), the competitive forces model (Porter, 2008) is appropriate to determine if models of the five forces are recognized by GIS managers, even if the formal model is not known to them. It is important to see if these forces actually are used in developing GIS strategy, or if they are not utilized. The answer may depend partly on the characteristics of the industry, in addition to how competitive is the firm and how it develops GIS strategy.

Research Question 3. How is GIS strategy aligned in the company in relation to its business strategy and IS strategy?

This question seeks to know how aligned the business, IT, and GIS strategies are (Disera, 2015; Pick, 2008). It seeks to determine the positioning of the three strategies and why they are aligned in a particular way. Alignment is measured by whether or not GIS is a part of the firm’s strategic plan, and whether or not GIS is included as part of the firm’s IT plan.

METHODOLOGY

The present research conducts in-depth case studies directed at answering the three research questions (Yin, 2018). The research questions are imputed from prior literature and from the reasoning of the authors, which is appropriate for an exploratory study of a new area of knowledge (Stebbins, 2001).

Within-case analysis is conducted to answer the research questions. Subsequently a limited cross-case analysis is done to determine if there are similarities across the cases. The data comes partly from the transcription of interviews (by a paid online transcription service) of the top leader of GIS in each company. The transcripts were reviewed by the two investigators and research assistants for accuracy. The key findings for the research questions were based on relevant questions in the interview transcripts, supplemented by documents and web-based materials that were collected and analyzed for each firm. Since the sample is very small at only three exploratory cases, numerical metrics were not applied to address the research questions, but rather consensus of the team members on facts or processes described in the transcripts.

The case selection was determined by selecting firms of differing sizes (small, medium, medium-large), industries (grocery marketing consultant firm, regional electric utility firm, and international convenience store chain), and uses of GIS. Within these parameters, we requested known practitioners to recommend enterprises for the study. The choice of the three firms was a convenience sample.

The respondents were managers or executives with corporation responsibility for GIS. The firm BCI Media Group in Australia acquired the former Planned Grocery firm, now an independent division of BCI in January, 2021. The interviewee is the executive and former partner of Planned Grocery in charge of GIS strategy. The firm CoServ is a utility for electric and natural gas that serves the seven Texas counties north of Dallas, that has rural areas. CoServ functions as a nonprofit rural cooperative. The interviewee is the GIS manager of CoServ which has 24,000 members for electricity and utilizes GIS primarily for utility network development, operations and maintenance. Finally, Oxxo, a part of the larger Femsa Group, is the operator of 18,000 convenience stores in Mexico, as well as thousands of stores in Chile, Columbia, and Peru, utilizing location analytics to locate its expanding network of stores as well as locations of its competitors, enriched with GIS layers of socio-economic and competitor data. The interviewee is the Manager of the Expansion Process, which oversees the expansion of stores in Mexico and overseas and is the principal manager of GIS for the corporation.

The study data were collected through semi-structured interviews, documents, and web content. An interview protocol was designed based on the themes in the literature that were associated with the research questions. The research protocol was tested by student researchers and staff, who gave feedback on the questions. The research protocol ended up with 30 open-ended questions, encompassing introductory background, spatial business solutions, pluses and minuses of spatial business, and spatial strategies and competitiveness, the latter consisting of seven questions. The protocol appears in Appendix 1. Sections A-C consists of questions on the background of the firm, how spatial applications add value, and what the advantages and disadvantages are of GIS for the firm. Section D has seven questions specially seeking information on spatial strategies and competitiveness including questions about alignment of business, IT, and spatial strategies, about the components of Porter’s competitive forces model, innovation, leadership, and future vision of spatial mapping and analysis in the company. The research questions and sections that follow are particularly supported by questions 24, 25, 26, 28, and 30.

For instance, questions 24 and 26 ask about “spatial imagery as a competitive force,” as well as how it influences “customer relationships, supplier relationships, new products, and ease of entry.” These are the components of Porter’s five forces model which Research Question 2 asks about and which sections of each cases write-up summarizes for that firm.

The choice of the three firms is based on convenience as well as the need for contrasting industry, uses of GIS, and firm size. One of the firms, Planned Grocery, was chosen because the investigators were familiar with the company, having met one of the founders at a leading GIS industry conference. The other two case firms were selected through the investigators' interaction with the company, Oxxo, at a corporate training workshop which both investigators presented at. Finally, CoServ was selected by request of the investigators for referral of interview prospects from utility companies that utilize GIS extensively. The use of a convenience sample is justified because firms using GIS competitively are often reluctant to be interviewed.

The choice of cross-case analysis on three dimensions: type of GIS strategy, relevance of Porter's competitive forces model, and strategic alignment of GIS with IT and business strategy, was based on an early classic methodology study (Eisenhardt, 1989) which suggested to look for within-group similarities coupled with intergroup differences." There was not prior research to select these dimensions, so we chose the three dimensions described above as suggested in the classic paper (Eisenhardt, 1989). We explained these dimensions for each firm, and then follow with a short section that discusses the similarities and differences.

The study was approved at the authors' university by its Institutional Review Board. The interviews averaged 77 minutes, with a range from 75 to 80 minutes. Transcriptions of the interviews, combined with the interviewers' notes and a limited set of case documents provided by the company including annual reports, information from intensive internet search, were used to develop a narrative write-up of each case. The case write-ups were checked for accuracy by student research assistants who participated in the interviews.

CASE FINDINGS AND WITHIN-CASE THEORETICAL IMPLICATIONS

Case study of Planned Grocery/BCI Media Group

Company Description

This firm was founded as a small business in 2014 and officially opened in 2016. The company has the goal to provide US nationwide information on the actual and planned locations of grocery outlets, along with additional spatially-referenced information such as demographics, geo-demographics, and social media content related to real estate in the grocery sector. The firm has two founders, one who is an expert on displaying the location of properties stemming from prior work at a commercial real estate developer, and the second one who is highly skilled in programming and developing robust online platforms. Additionally at the start and subsequently, there is a data manager who is skilled at consolidating grocery retail data from multiple sources including major grocery chains, newspapers, aerial photos of commercial real estate development projects, and social media. An example of a display page from Planned Grocery shows the planned and existing locations of groceries in an urban setting.

This firm's strategic business goal is to spatially track planned grocery store locations nationwide (Beitz, 2018). There is no need to align GIS, since spatial is embedded endogenously in the purpose of the firm. IT at the firm emphasizes compiling a database of planned grocery locations in the US, using web programming tools to create a robust cloud-based interface that can run in Esri's ArcGIS Online and in several retail-specific software platforms.

The GIS planning process at Planned Grocery is informal and ad hoc. Since mapping is integral to the business strategy of the company, the business and GIS plans are one and the same. Likewise, the second founder supports the combined GIS and IT infrastructure that underpins their functional integration.

Porter's Model as It Relates to Planned Grocery

Although the leadership is not aware of Porter's Five Forces model, it is unknowingly manifesting many of the Porter model features. Planned Grocery represents a new market entrant in the market of mapping tools for national grocery siting. The firm's innovation includes an interactive national mapping interface keyed to unique grocery location data.

Planned Grocery has continued to achieve and maintain this competitive position through its emphasis on customer and supplier relationships, which have strong spatial components. It strives to have nationwide customers, using mapping as a marketing tool to find new customers and maintain relationships with hundreds of continuing ones. The strength of its GIS tools and platform is integral to its customer relationships and it cultivates customers by adding new technical features through listening to customer suggestions. It also has strong relationships with suppliers that emphasize inherently spatial aspects. Through its data suppliers, the firm offers national, comprehensive coverage of grocery properties that are officially advertised on the real estate market, provided by client firms, or only apparent from posted news announcements of property purchases. For some of its data, Planned Grocery relies on its major grocery customers who are willing to share their property locations. This unique relationship helps to protect Planned Grocery from substitute products. Planned Grocery relies partly on its major grocery customers who are willing to share their property locations.

After Planned Grocery's acquisition by BCI Media Group, it continues to operate under its original name in the US, utilizing extensive data sources on to map and analyze current and planned locations of groceries in the US. The division has contributed to other parts of BCI Media Group, in particular to Geospex, which utilizes GIS to access planned real estate development data to offer knowledge about the real estate market's geographic growth opportunities and potential risks (BCI, 2022).

GIS Strategy at Planned Grocery

Planned Grocery's spatial strategy has been intimately integrated with the firm's strategy, since the original four employees originated and grew a company in which the major business strategy was to "specifically track planned grocery store locations nationwide." (Beitz, 2018). GIS is endogenous to the business strategy of showing subscribers the grocery store expansion and contraction across the nation, a service previously unavailable in the market. The founder interviewee indicated that the firm's "spatial strategy is to provide the commercial real estate sector [and grocery chains] with best-in-class data and mapping platform solutions." (Interview with David Beitz, October 30, 2018, brackets added based on the interview transcript). Regarding the firm's use of the competitive forces model, the main part of the model emphasized at Planned Grocery's was the firm-buyer relationship. The firm has focused time and effort to work with clients quickly and maintain a user-friendly experience. It also emphasized the model's firm-supplier relationship by establishing partnerships with web providers inside and outside the Esri user community who can link to Planned Grocery's platform, as well as improving the streaming of its services to Esri clients.

Another factor in GIS strategy is that the two founding partners represent a high-level bridge between the firm's business strategy, an alignment originating from the founder interviewed. GIS and IT strategy have also been aligned from the company's start by the tech-laden founder, who guides the company's choice and configuration of software as well as custom programming. In short, there is no alignment problem because at the highest level of the firm, IT, business, and GIS strategies are united.

In summary, Planned Grocery demonstrates the concepts of a strong GIS strategy for a small business, but so far based on ad-hoc tactical planning that averted formal use of the detailed and powerful planning models and concepts that are available.

GIS at Planned Grocery: The Future.

As it grows, Planned Grocery should consider formalizing its business-GIS strategic plan. With a larger workforce and market base, Planned Grocery could formally link its strategic plan to performance goals and highlight the competitive aspects of its strategy based on the Porter Model or other means. Additionally, if IT and GIS were to become separate departments, then the alignment of GIS and IT would need to be inter-departmentally planned.

Case Study of CoServ

Company Description

CoServ is an 85-year-old electric and natural gas distribution company that provides services to prosperities having over 250,000 electric meters in seven counties north of Dallas, Texas. Since 1998, CoServ Gas has grown to serve 130,000 gas meters in Denton, Collin, and Kaufman counties (CoServ, 2020). The firm also supplies electricity from solar renewable energy. The company began as a group of rural residents who formed the non-profit cooperative to supply themselves with energy. CoServ grew to the north and northeast of Dallas on former farmland being converted through investments into corporate headquarters and other facilities. CoServ's western area still serves farms in the sense of a rural cooperative, although the lands are beginning to experience the corporate pull as well.

CoServ commenced its GIS originally to upgrade small orange map books of its electrical systems, which had previously been manually copied for use in the field. Today CoServ has an enterprise GIS system, web mapping in its business units, and real-time connection to field workers, who can access the enterprise GIS on their mobile devices. The enterprise GIS supports business-unit GIS teams in electric utilities, gas utilities, and engineering. For location analytics professionals, central GIS staff configures their desktop systems and stores copies of data-sets for professional uses.

The GIS manager of over a decade, who was interviewed, has developed workforce, set project goals, established working relationships with the business divisions, collaborated on a workable structure for an integrated IT/GIS department, established strong relationships with vendors and outsourcers, and developed visibility for GIS across the company, including with senior corporate leadership.

The small GIS group within the IT department works well with the rest of IT because of the understanding that professionals in the IT department are in charge of configuring systems and servers, building and maintaining data-bases, and operating the networks. On the other hand, the GIS group is responsible to gather and populate the spatial data-bases, manage the GIS software and portal, and supervise the spatial administrative accounts. Both units work in their specialty areas, without the tense and often siloed standoffs reported for GIS in some other organizations.

GIS management has also worked out a productive relationship with the spatial teams in CoServ's engineering, electric, and gas units. Engineering, for example, has specialized utility design, mapping, and operations software, for which the GIS department stepped back to serve only as a consultant if needed. This makes sense since engineering understands much better its own data, specialized processes, and techniques. Gas and electric GIS groups are involved with SCADA software to monitor transmission and pipeline flows, for which central GIS likewise installs spatial software and platforms and then steps back as a support unit.

If an application exceeds his GIS team's overall capabilities, the GIS manager will outsource outside of CoServ, often in liaison with several team members. Examples were in deploying some web maps from the map portal and working on complex integration of enterprise GIS with other company systems.

The most intensive spatial project has been to design and develop the enterprise GIS. The GIS team, led by its manager, realized this would take many months, not just of technical effort but also coordinating end users, scoping the steps of the project, going through iterations of testing, changing time-worn processes, and training users. User resistance was encountered at times but resolved. Having a champion in the CIO has helped. The system first succeeded with electric utilities and is in process with gas. The web portal for mapping, constructed on top of the enterprise base, has been popular with end-users since they can customize spatial applications within hours or days, rather than waiting weeks.

The GIS manager indicates that the firm's senior leadership has been "very interested and engaged" during over a decade as GIS manager and especially during the enterprise project. A large challenge has been communicating what GIS is to non-GIS users who sometimes struggle to learn and appreciate GIS. He regards communications with users as essential. Projects not vetted are prone to falter or fail. His view is that "success is understanding that when the failures come, it is not the end -- weave it together and it will work."

Porter's Model as it Relates to CoServ

Regarding the role of competitive forces in CoServ's GIS strategy, for the buyer relationship in the model, GIS is considered as more of an ancillary feature. This reflects that GIS at CoServ is much more internally than externally focused. By contrast, there is strength in the firm-supplier relationship, since information on the network and engineering software and its architecture are transferred back and forth between the GIS team and Esri technical support experts. The prospect of new products or services entering is reduced, since CoServ's GIS team relies heavily on Esri to keep up with new products/services. This reliance on rapid updating from the vendor reduces the possibility of coupling Esri software with that of other providers.

GIS Strategy at CoServ

Regarding CoServ's GIS strategy, the GIS manager pointed to two primary goals for GIS strategy – safety and reliability. Achieving these goals depends on GIS. The business strategy has changed over time. CoServ's business strategy was to make certain that members of the cooperative receive electricity according to their specifications. Hence it is clear that the GIS and business goals area aligned. IT strategy is to reflect CoServ's core values in engaging with communities, and to provide services that customers want to have. The internal aspect of customer-centricity also aligns with the GIS strategy.

Regarding the order of importance at the company, the business strategy comes first, followed by IT strategy and then GIS strategy. The point that GIS strategy must stay focused strategically with the company, lending support to research question 3.

The relationship between GIS and IT is smooth because they have clearly differentiated their responsibilities in that IT supports the GIS team with hardware, networks, servers and databases, while the GIS team builds out the software that is compatible with IT's platform, as well as provides support to administer the spatial software. Ultimately, top leadership of the firm is responsible for setting strategy of any type.

The CoServ story exemplifies long range strategic long-range planning (shown here by the enterprise system as a long-term goal), based partly on coordinating the interaction and communications of the GIS team with key internal users.

GIS at CoServ: The Future

As CoServ evolves in the future, the strategic success with the enterprise system is expected to undergo continuing enhancements. According to the CoServ GIS manager, the firm would benefit from increased effectiveness of the enterprise GIS software tools, by adoption of continuing version upgrades of the Esri software suite, and from improvements in the utility network through transition to a software-driven network, where software features increasingly replace hardware-driven functions. Another future thrust could be towards a higher level of location analytics, enhanced mapping, and better data collection, with the caveat that the improvements must be useful to field personnel who need them. Field personnel can also benefit by being able to manage utility outages without having to consult with the central office

Case Study of Oxxo

Company Description

Oxxo, Mexico's leading convenience store chain, is one of the four main companies of FEMSA, a leader in the global beverage industry through Coca-Cola FEMSA, Mexico's largest Coca-Cola bottling franchise. Oxxo's 18,000 stores (2018) in Mexico and Latin America are part of FEMSA Comercio, which accounted for 63% of FEMSA's total annual revenue for 2018 of 469,744 million pesos (approximately USD 19,236 million). Oxxo's network of stores and gasoline outlets had 120 million customers in Mexico with 225,000 people. An OXXO store has about 3,200 different products including milk, cookies, ice-cream, soda, beer, coffee, tea, cell phone cards, and cigarettes (FEMSA, 2018).

Expansion, Competition, and Customers

The early 2000's was a period when Mexicans increasingly shopped at convenience marts on their way to and from work, due to increase in two-income households as well as increasing vehicular traffic in densely, populated urban areas. As consumers increasingly became time-poor, they demanded convenience and flexibility in their shopping experiences and were drawn to bright aisles, longer hours, and varied product selections in convenience marts compared to mom-and-pop corner stores or street concessions.

The first OXXO store opened in Monterrey, Mexico in 1978, and had almost 1,500 stores in Mexico by the year 2000. By the mid-2000's, senior leadership estimated that the Mexican market could accommodate 15,000 convenience stores. Around that same time, Oxxo's main competitors included Extra, 7-Eleven, Super City, Circle K, and local mom-and-pop convenience stores. In this period, competition was especially stiff from Extra, a rival convenience chain.

By 2012, Oxxo's store footprint increased to 10,600 including expansion into Colombia. By 2018, Oxxo operated 18,000 stores in Mexico as well as Peru, Chile, and Colombia, making it Mexico's largest retailer. In 2018 alone, Oxxo opened 1,422 new stores including its first store in Peru. On average, pre-Covid-19 pandemic, a new Oxxo store opened every six hours, and the company plans to responsibly expand its retail footprint by opening approximately 1,300 new stores per year and have 30,000 stores by 2025. Each Oxxo store is part of a geographic and strategic unit called a Plaza. In 2020, there were 52 such Plazas, each with a management team responsible for the performance of stores in its "service area."

Oxxo's sustained growth has been marked by an intimate understanding of the Mexican convenience retail landscape and customers' wants and needs. From the beginning, proximity, accessibility, and customer service have been hallmarks of Oxxo's value proposition. To remain flexible and adapt to local customer needs, Oxxo's department of expansion and infrastructure prioritized store location over store shape and size. To provide accessibility, an expansive geographic footprint of stores is matched by extended store hours. In addition, Oxxo's steady growth has been as a result of its differentiated retail approach, characterized by a focus on creating value for its customers. Senior leaders and business strategists at Oxxo realized that as much as customers visit Oxxo's stores to take advantage of one-stop convenience, example. to purchase a quick drink, grab a prepared meal, or purchase a household product, they would value additional services. In accordance, Oxxo introduced services such as diverse banking by partnering with ten banking institutions, cash remittances, in-store bill payment of phone and electric bills, purchasing pre-paid gift cards for streaming online services, and replenishment of calling cards. By 2016, 70% of daily cash at Oxxo stores came from financial and payment services while the rest came from sale of merchandise (FEMSA, 2018).

In addition, Oxxo has provided a solution to Mexican consumers for whom there are significant barriers to online shopping. Customers can visit their nearest Oxxo store to make purchases from online merchants and pay for the products when they are delivered to the store. Since 2015, Oxxo entered into a "click and collect" partnership with Amazon which allows customers to securely pickup their Amazon packages for their local Oxxo store (FEMSA, 2018). As a result of proximity and accessibility to customers and a sustained commitment to convenience, Oxxo enjoys strong brand recognition among its customers. This has fueled remarkable growth despite strong competition over the past two decades.

Location Analytics at Oxxo: The Present

Location analytics has been at the core of Oxxo's expansion. Spatial thinking at Oxxo stems from the need to continue to enhance its value proposition – provide proximity, accessibility, and convenience to its customers. This drives the company's use of location intelligence — to seek authoritative data about its stores and customers, combine it with external data received from hundreds of fieldworkers, in order to derive insights about local needs and business conditions.

These insights are subsequently shared with right people in the organization at the right time, facilitate modeling of sales, and ultimately manage external disruption and stay ahead of competition.

Specifically, Oxxo deploys GIS to maximize market potential, improve sales forecasts, avoid cannibalization, identify market opportunities, and drive faster decisions. GIS helps Oxxo's location intelligence team to conduct demographic and psychographic analysis of its markets to better understand its customers and drive decisions on the type of store to open in its trade areas. Store segmentation is therefore an important strategic function of GIS-based location intelligence at Oxxo. For example, Oxxo uses GIS to map population densities, income, traffic patterns, the rate of local car ownership, and shifts in demographics in the new markets (Elliott, 2019).

In addition, GIS analysis provides Oxxo's real estate and expansion team with location intelligence on sites previously deemed unprofitable, for example, niche stores in small spaces at airports, train stations, and other locations (Sandino, Cavazos, & Lobb, 2017). Store segmentation and sales potential analysis are key functions of Oxxo's GIS use. As GIS drives store segmentation depending on market conditions, product placement in stores is optimized and appropriate SKUs are introduced depending on local consumer preferences.

Fieldwork remains an important activity in Oxxo's expansion strategy. As part of its workforce, Oxxo employs "brokers," who collect information on potential sites for stores using mobile data collection apps such as Esri's ArcGIS Collector. This information is uploaded to form additional layers in Oxxo's GIS and ultimately used at the operational level at Oxxo's Plazas, each of which has an expansion team of 5 – 6 people, led by an expansion manager.

Porter's Model as it Relates to Oxxo

Oxxo's GIS team is involved with all five forces in the competitive model and its relationships, although the firm does not formally recognize the model. Competitiveness has been present ever since Oxxo started its nationwide expansion of stores. The is seen by the keen competition of Oxxo in the mid 2002s with Extra, 7-Eleven, Super City, and Circle K and the competition today with Circle K and 7-Eleven in the Mexican market, with Tostao and Tiendas D1 in Colombian market, and with Tambo Mas in the Peruvian market. Oxxo has partially competed well because of the accuracy of its spatial data and the power of its GIS platform.

In Mexico, Oxxo is the dominant player and serves to repel new competitors for entering. Since it stocks a very large and varied inventory in each store, substitution by competing physically stores is difficult. The challenge may be greater with virtual competitors, although that is not yet reduced Oxxo's dominance. Since Oxxo is large, dominant, and growing geographically supported by GIS, it attracts suppliers. The role of GIS in helping to optimally locate Oxxo stores in cities demonstrates the spatial influence on positive buyer-firm relationships. In a nutshell, Oxxo is making efficient competitive use of all five forces and the firm is significantly strengthened by having strong GIS.

GIS Strategy at Oxxo

The company's expansion manager interviewed emphasized that GIS is considered a strategic competitive element at Oxxo. The benefits of GIS are enormous inside the company. GIS is a main emphasis of corporate strategy, providing the firm with information and spatial solutions for its expanding network. The solutions are guarded carefully since other competitors could obtain GIS capability and be more competitive with the firm.

Furthermore, the manager pointed out that Oxxo's business strategy and IT strategy are very closely connected. In fact, the firm has a separate department, the Office of Projects, that manages and organizes all communications to strengthen the business-IT strategy relationship. GIS strategy is not fully connected to the other two yet but is in process of being controlled by the Office of Projects, so GIS strategy will become tightly connected with business and IT strategies. The CEO of Oxxo is very involved in having the tight connections, through the formal efforts of the Projects Office.

Overall, GIS plays an important strategic and operational role at Oxxo. GIS adoption and use internally at Oxxo started with a strong focus on branch expansion and real estate management and is not enterprise-wide yet at the present time. Yet, as customer behavior and consumer preferences continue to change, Oxxo is positioning GIS to support management of Oxxo's digital transformation and enhance its value proposition to customers by providing proximity, accessibility, convenience, and superior service.

GIS at Oxxo: The Future

GIS at Oxxo is currently situated in the real estate and expansion department, primarily as a driver for site selection of its stores. Consumers of GIS at Oxxo are expansion teams at Oxxo Plazas, which examine operational aspects of existing or potential store location using GIS. Senior leaders of Oxxo are strategic consumers of GIS, who are drivers of Oxxo's continued expansion within Mexico as well growth in Latin America. In Mexico, GIS provides location intelligence to identify "mirror stores" (stores similar to successful stores in profitable markets) as a pathway for expansion (Elliott, 2019). However, for continued international expansion in growing Latin American markets in Peru, Chile, and Colombia, GIS offers a more nuanced and integrated approach to develop intelligence on site locations. For broader adoption of GIS at the senior executive levels of the enterprise, Oxxo's GIS team is developing dashboards that provide an integrated view of existing stores, complementary and generator businesses, and intelligent spatial insights on local market conditions. Oxxo also aspires to diffuse GIS adoption and usage more broadly across the enterprise in departments such as supply chain for better, integrated management of a vast network of suppliers. With a vast, expansive network of stores, it is essential for Oxxo to deploy adequate security infrastructure and manpower at its stores to ascertain local crime patterns, police station locations, and local socioeconomic conditions.

CROSS CASE SIMILARITIES AND DIFFERENCES

The three cases were chosen to serve as replicated cases of organizations that are posited to demonstrate successful use of GIS strategically (Yin, 2018). This section considers three dimensions of this success, backed by the three research questions. The dimensions are (1) principal GIS strategy focus(es), (2) correspondence to the Five Competitive Forces model, and (3) extent of alignment of the GIS strategy with the business strategy and the IS strategy.

This multiple-case analysis is based on posited replication of successful strategic GIS, as seen by the three dimensions (Yin, 2018). The cases are holistic, rather than embedded i.e., analyzing an overall case and cases of its embedded units (Yin, 2018). Furthermore, the analysis has the expectation that there will be similarities on the three dimensions, but it will also make note of differences (Eisenhardt, 1989; Yin, 2018). Since the study is exploratory regarding spatial strategies, the cross-case analysis is expected not to lead to theoretical propositions, but rather to suggest pathways of future research that could result in substantial theory building. For this study, the benefit of the replicated cases is to determine if the dimensions of spatial strategy are similar, which can inform further study.

Although the cases were chosen to demonstrate successful strategic GIS, the replication does not apply to size of organization, industry, and corporate culture. As seen in Table 1, the three cases have different sizes measured by revenues and workforce size, and come from different industries – business consulting, utilities, and convenience stores. Corporate culture is entrepreneurial and customer-centric for Planned Grocery, carefully managed and regulated for CoServ, and very competitive, expansion-focused for Oxxo. These differences can potentially strengthen the findings further, since the three strategy dimensions may be similar across varied company types and sizes.

Table 1: Description of the Case Study Companies

COMPANY OR SUBSIDIARY THAT COMPRISES THE CASE STUDY	PARENT FIRM	INDUSTRY	NO. OF EMPLOYEES IN CASE STUDY PARENT FIRM OR SUBSIDIARY	REVENUE OF CASE STUDY FIRM OR SUBSIDIARY	PRINCIPAL GIS APPLICATIONS
Planned Grocery	BCI Media Group	Business consulting	76 (1)	26 million USD (3)	Mapping and analyzing grocery properties
CoServ		Utility	451	636 million USD (4)	Enterprise GIS with mobile devices in field, applied to network management & operations.
OXXO	FEMSA	Convenience stores	129000 (2)	9,272 million USD (5)	Location analytics for siting of new stores
Notes : (1) no. of employees in BCI Media Group in 2020					
(2) no. of employees in OXXO in 2020					
(3) revenue of BCI Media Group in 2020					
(4) revenue of CoServ in 2019					
(5) revenue of OXXO in 2020					

(Sources: CoServ, 2021; D&B, 2022; FEMSA, 2021)

Referring to Table 2, there is largely similarity on the three dimensions. For dimension 1, the principal GIS strategic focus is systems across the enterprise, although specific GIS objects of analysis differ. For dimension 2, the competitive five-forces model applies especially strongly for

Planned Grocery and Oxxo, and less so for CoServ, which can largely be ascribed to the lowered competition in a regulated utility. Finally, for the third dimension, the extent of alignment of GIS and business strategies is very strong, and alignment of GIS and IT strategies is strong except for CoServ, for which GIS and IT strategies and complementary rather than aligned. In a nutshell, the cross-case analysis generally confirms strong similarities in the dimensions of GIS strategy, with some exceptions.

Table 2: Cross-case Comparisons

	PLANNED GROCERY	COSERV	OXXO	MULTI-CASE SIMILARITIES AND DIFFERENCES
Dimension 1				
Principal GIS strategic focus(s)	GIS serves strategically across the enterprise and as the primary output platform that the user accesses to run location analytics and see the mapped results.	Enterprise GIS serves CoServ strategically to strengthen utility network modeling and operations for its internal customers	GIS serves Oxxo applies location analytics enterprise-wide to guide the geographic decisions on its vast, multi-year expansion while tracking competitors' locations and informing on store inventories relative to location.	The principal GIS strategic focus is on the enterprise. The particular objects of the mapping and spatial analysis are distinctive by industry and company.
Dimension 2				
Correspondence to 5 forces model	Planned Grocery has strengthened its direct competitive position, firm-buyer relationship, and firm-supplier relations through GIS. New entrant and substitution have limited role due to Planned Grocery's niche dominance.	GIS contributions to the internal enterprise system strengthens CoServ's already dominant position in its geographic area. GIS strengthens the relationship with internal clients and external suppliers. Strong GIS helps to repel new entrants and substitutes. Overall, competitiveness is low, because of utility regulation.	GIS contributes to the forces of direct competition and GIS-buyer GIS-supplier relationships by understanding local behavior patterns of buyers and the spatial proximities of suppliers. GIS helps to repel new physical entrants of services/products and substitutes, both through monitoring the geography locations of new entrants and its marginal contribution to strong barriers to entry.	The 5-forces model applies for all three case companies, It is very strong for Planned Grocery and Oxxo, although for each a different set of forces is strongest. For CoServ, competition itself is limited by utility regulation. There are strong forces for the GIS relationship with internal customers and GIS prospectively serves to reduce the forces of new entrants and substitutes.
Dimension 3				
Extent of alignment of the GIS strategy with the business	GIS strategy was endogenous to both the business strategy and IT strategy at the start	GIS and business strategies are strongly aligned, with GIS included as part of the business strategy. GIS	The business strategy dominates at the company. Currently, the Office of Projects uses the business strategy to align the IT	There is strong alignment of the GIS strategy with the business strategy, although the alignment is more informal presently with Oxxo. The

strategy and the IS strategy.	and very strong alignments have continues. The unity stemmed from the two founders who based the company strategy on GIS and the technical founder who integrated GIS into IT from the start	strategy complements the IT strategy, since the two departments consciously separated their activities so there is clear boundaries between their areas, obviating conflicts or mis-alignments.	strategy. GIS strategy has the least attention currently and will be aligned and prioritized behind business and IT strategies, once the Office of Projects becomes responsible for it.	alignment of GIS and IT strategy is very strong for Planned Grocery and Oxxo. For CoServ, GIS and IT strategies are pre-planned to be complementary with clear-cut boundaries, which is not alignment but avoidance of alignment tensions through complementarity.

DISCUSSION, OUTCOMES TO RESEARCH QUESTIONS

Based on this exploratory study, the research questions are mostly answered as follows.

Research Question 1. The cases showed substantial variation in the primary focus of GIS strategy. Planned Grocery emphasized serving the real estate and grocery customers, while CoServ adhered to the current business strategy for members of the cooperative receive electricity according to their specifications and particularly emphasizing reliability and safety. For Oxxo, the primary goal in GIS strategy is to support the corporate strategy of expanding its store network intelligently including spatial knowledge.

Research Question 2. The results differ. Regarding the five competitive forces, Planned Grocery is mainly focused on direct competition based on GIS and on the firm-buyer relationship, which involves GIS. This stems from its currently paucity of competitors. For CoServ, the part of the competitive forces model relevant to its GIS strategy is its relationship with internal clients and external suppliers. As a utility cooperative, there is little direct competition. Consequently, the threats of new spatially-driven entrants and substitution of products/services is minimal. For Oxxo, the relevance of the competitive forces model is profound, including GIS for direct competition, firm-buyer relationship and firm-supplier relationship, and reducing new market entrants. The threat of substitute physical products and services is small, with the caveat the online providers may grow to become a serious threat.

Research Question 3. All three cases indicate a close alignment between GIS strategy, IT strategy, and corporate strategy. The only moderate weakness is that GIS at Oxxo is somewhat excluded from the tight relationship of business and IT strategies, although GIS is expected to join that tight relationship soon.

CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

This research has studied GIS strategy based on imputed research questions from the literature and investigators' reasoning. The study is instantiated by case study analysis of three diverse companies in size, industry, and GIS focus. The three research questions are addressed based on findings from semi-structured interviews based on a common protocol and from company reports and web-based materials. Findings show that principal focus of GIS strategies varies greatly and is attuned to corporate strategy of each firm. The competitive aspects of GIS strategy, examined based on Porter's competitive forces model, reveal relevance of the five forces competitive model but with unique strengths of GIS across the forces, depending on the company, its deployment of GIS, and the characteristics of its principal market.

For Oxxo, the strategies are aligned by a corporate office, in which GIS strategy is given the lowest priority, as an accompaniment to the higher-priority business and IT strategies. The cross-case analysis on the three dimensions, summarized in Table 2, reveals for dimension 1, there is generally tight integration of business, IT, and GIS strategies for the three firms, and GIS strategy consistently adheres to corporate strategy. Although there are some differences regarding dimension 2, the five-forces model, the cases in general show adherence to it. For dimension 3, the cases all have close alignment of the business and GIS strategies, and mostly the GIS strategy aligns with IT strategy, although through an organization mechanism in each case.

This study has a number of limitations. As a pilot study, it examined three in-depth cases. This limits the possibility to generalize findings. Future research could be performed on a dozen or more cases, leading to formulation of propositions and a framework to understand the extent to which GIS strategy applies more generally. Furthermore, a large sample survey could be administered to hundreds of firms, leading to empirical findings that could be quantitatively analyzed.

Another limitation is the lack of a comprehensive theoretical model or framework to gain broader insight into the structure and function of GIS strategy. Finally, there is the risk of bias in the interviews and interpretations, although every effort was made in the present small-scale case-based research to avoid bias.

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APPENDIX 1. RESEARCH PROTOCOL

A. Introductory Background

1. What is your position at the firm? How long have you been at the firm?
2. What is the industry position, size, and organizational structure of the firm?
3. What are the major products and services of the firm?
4. What is the recent history of the firm, relative to the industry, competitors, and the economy?
5. What are the regulatory constraints on the firm?
6. What is the relationship between the spatial imagery team and the IT department?
7. How mature in the firm in its spatial imagery? Explain.

B. Spatial Business Solutions

8. Describe the key spatial imagery solutions
9. Were these solutions developed in-house, purchased, or outsourced?
10. How do customers interact with the solutions? Any issues or problems?
11. Discuss the company's most important spatial imagery solution, including the original problem, development process to solve it, implementation, training, resistance to it if present, and user/customer response to it.
12. How are company operations made more efficient and productive by spatial imagery?
13. At which points in the supply chain do spatial imagery and location analytics add value?
14. Is there an enterprise spatial imagery? If so, describe its full extent?
15. How do spatial imagery and location analytics support decision-making?
16. How is the firm's analytics spatially enabled?

C. Advantages and Disadvantages of Spatial Business

17. How and where are spatial analysis and spatial imagery applied in the firm?
18. Who are the users of spatial imagery/Spatial in the firm?
19. What are the technology platforms which support spatial imagery in the firm? What hardware, software, telecom, and data storage are used?
20. What are the costs and benefits of spatial imagery in the firm?
21. What do you consider the key successes of spatial imagery/Spatial in the firm?
22. What have been the challenges, barriers, and disappointments with spatial imagery/Spatial in the firm?
23. Can you describe instances of spatial imagery failure at the firm?

D. Spatial Strategies and Competitiveness

24. How much do you consider spatial imagery a competitive force at the company?
25. What is the spatial strategy of the firm? Is it in synch company's business strategy? With its IT strategy?
26. How does spatial imagery influence customer relationships, supplier relationships, new products, and ease of entry?
27. How much is spatial imagery a collaborative force?
28. What innovative, cutting edge spatial technologies are presently being applied, and which ones will be applied in the future?

29. Describe the past and present importance of the company's leadership in spatial imagery and spatial analysis.
30. What is the future vision for spatial imagery and spatial analysis at the company?

Are there any additional comments you would like to share regarding your company or the industry?

DECISION SCIENCES INSTITUTE
Manufacturer's Optimal Price and Supply Chain's Information Provision Policy: Considering Consumer Returns under Product Fit Uncertainty

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ABSTRACT

Faced with product fit uncertainty, online shoppers may return the product upon receipt and their purchase decisions are influenced by both online product reviews and the hassle cost of product return. Anticipating such consumer behaviors, we establish the profit function of a manufacturer and an online retailer under five identified scenarios and derive the manufacturer's optimal price as a piecewise function. We then analyze how more informative information affects the optimal price, returns/demand, and the two members' optimal profit under each scenario. Finally, we derive the two members' information provision policy for the product with different degrees of dispersion.

KEYWORDS: Product fit uncertainty, Online product reviews, Consumer returns, Online purchase behavior, Pricing

INTRODUCTION

Many online retailers, who we also refer to as online platforms in this paper, try to get potential shoppers to browse their product information and buy their product by offering various product categories, rich product information and convenient shopping experiences. A financial report indicates that the number of annual active users at the end of 2020 reached 779 million on Alibaba, 471.9 million on Jingdong, and 788.4 million on Pinduoduo. Offering a sales channel, online retailers match potential buyers and sellers, and become appealing to manufactures who can take advantage of the platforms' established reputation and brand awareness. In this paper, we study the decisions of a manufacturer who produces and sells a product on an online platform. According to Alibaba's financial report in 2020, on Tmall, the sales of 2200 brands reached 100 million yuan per brand, and the sales of 7 brands even reached 10 billion yuan per brand. In establishing partnerships, the online retailer and the manufacturer typically sign a revenue sharing contract, where the retailer takes a commission for every product sale (e.g., the commission rate ranges from 5% to 8% on Jingdong).

Despite the proliferation of online markets, manufacturers and online retailers still face a lot of challenges arising from the inevitable product fit uncertainty (PFU) experienced by consumers. PFU is defined as the degree to which a consumer cannot evaluate whether a product's attributes match his/her preference (Hong & Pavlou, 2014). Moreover, PFU, which either leads to wrong purchase decision or becomes barriers to making the initial purchase, brings two severe problems to both the manufacturer and the online retailer.

Firstly, PFU may lead to product returns when consumers overestimate their willingness to pay. According to results from Return Magic who surveyed 1,000 businesses in multiple industries and over 800,000 Shopify customers, consumer preference-based returns (e.g., size, fit, style, etc.) drive around 72% of all returns (Dopson, 2021). Given that online shoppers cannot physically inspect the product, the return rate of online sellers reach more than 30%, while that of traditional stores is only 8.89% (Saleh, 2021). Product returns incur return handling cost to the manufacturer, and operations cost (such as labor cost and information technology cost required during the return process) to the online retailer.

Secondly, consumers who would buy the product in a physical store may choose not to buy on an online platform when they underestimate their willingness to pay due to PFU. This would lead to reduced sales for the online retailer. According to a survey of 30000 customers worldwide, 51% of the customers expressed that the biggest flaw of online shopping is that they are not able to touch, feel, and try a product (BrizFeel, 2021). In this regard, PFU causes frictions in consumers' purchase process, and brings potential demand loss to firms involved. Given that product returns erode profit margins and even threaten online businesses (Hong & Pavlou, 2014), while potential demand loss reduces firms' revenue, both the manufacturer and the retailer are incentivized to offer consumers with product fit information, aiming to induce more informed purchases. Specifically, manufacturers can display product description information (e.g., the color, size, material and style of clothes) to provide horizontal information to consumers. By contrast, online retailers can provide the detailed text of consumer reviews to deliver fit information. It was shown that those reviews which are deemed as more helpful by consumers are of higher quality and provide information of higher precision (Sahoo, Dellarocas, & Srinivasan, 2018). The precision of information is illustrated by previous analytical work like (Chen & Xie, 2008) as a parameter called review informativeness, which refers to the probability that a buyer receives a private signal which reveals his/her true valuation; our study follows this definition. Moreover, both the manufacturer and the online retailer are able to control the degree of review informativeness. For example, manufacturers can provide more informative information by exhibiting more detailed description information, such as offering clearer text and picture, while retailers can do so by encouraging or rewarding shoppers to publish more detailed and more helpful product reviews.

Some research questions arise naturally. First, through reducing product fit uncertainty, does a higher degree of review informativeness help to reduce returns? (Sahoo et al., 2018) empirically show that more reviews and more helpful reviews indeed lead to fewer returns. Based on data from an online retailer, (Minnema, Bijmolt, Gensler, & Wiesel, 2016) discover that overly positive review valence generates more purchases, but also more returns. However, these empirical studies have not analyzed how more informative information affects the manufacturer's optimal price, and how the changed optimal price influences the number of returns in a vertical supply chain. Second, how does a higher degree of review informativeness affect demand? Although this question has been examined by previous studies, like (Liu, Feng, & Liao, 2017), it has not been analyzed in the situation where consumers' purchase decisions are affected by not only online reviews, but also the hassle cost of returning.

To fill the research gaps, this paper builds an analytical model in a vertical supply chain with a manufacturer and an online retailer. Three research questions are addressed. (1) When product returns occur, how does more informative information affect the manufacturer's optimal price and the number of returns? (2) When product returns do not occur, how does more informative information affect the optimal price and market demand? (3) For the product with a certain degree of PFU, how does the two members' optimal profit change as the degree of informativeness grows, and what's each member's optimal information provision policy? Through addressing these three research questions, we help firms in online markets make wiser pricing and information decisions.

The rest of our study is deployed as follows. In Section 2, we review the relevant literature. We lay out the model in Section 3. In Section 4, with the identified five different scenarios, we establish the manufacturer's profit function and derive the optimal price under each scenario. Then we explore how a higher degree of informativeness affects the optimal price, equilibrium demand/returns and the two members' optimal profit under each scenario. Based on these results, the two members' information provision policy for different product types is derived. Section 5 concludes the paper.

LITERATURE REVIEW

Table 1: Summary of Literature Review

YEAR	REFERENCES	JOURNAL	RESEARCH FOCUS
2009	Su	Manufacturing & Service Operations Management	The impact of full/partial return policies under valuation uncertainty
2013	Akçay et al.	Production and Operations Management	The impact of the opportunity to resell the returned products
2016	Altug & Aydinliyim	Manufacturing & Service Operations Management	How strategic purchase deferrals affect return policy decisions
2014	Huang et al.	Omega	How a secondary market salvaging the returns affects supply chain coordination
2019	Hao &Tan	Information Systems Research	How supply chain contracts interact with information disclosure
2014	Kwark et al.	Information Systems Research	How quality information/fit information affects upstream competition
	This work		How more informative information affects the optimal price, the number of returns/demand, and the optimal profit

In a vertical supply chain where a manufacturer sells one product through an online retailer, this work explores the two members' information provision policy under product fit uncertainty. Hence, this work builds on two streams of literature: consumers' purchase and return behavior under PFU and product information provision policy. Below, we provide a synthesis of the research in each stream as it relates to our research questions. Table 1 provides a summary.

Consumers' Purchase and Return Behavior under PFU

When purchasing from online sellers, consumers face PFU, i.e., consumers are uncertain whether the product's attributes fit their preferences, since they cannot actually try the product but merely obtain product information partially through the web (Hong & Pavlou, 2014).

Existing theoretical models on consumer returns adopts three approaches to model PFU (Abdulla, Ketzenberg, & Abbey, 2019). One stream of literature assumes that consumers' product valuation v follows a Bernoulli distribution, that is, $v = \bar{v}$ with probability p and $v = 0$ with probability $1 - p$. (Ofek, Katona, & Sarvary, 2011) demonstrate that if differentiation between competing retailers is not high enough, opening an online arm decreases retailers' profits by increasing in-store assistance levels. Another literature stream assumes that v follows a general distribution (e.g., a uniform distribution) which is independent of the fit probability. Assuming that there are both consumer valuation uncertainty and aggregate demand uncertainty, (Su, 2009) examines how full and partial returns policies affect supply chain performance. The third literature stream assumes that v follows a uniform distribution if the product fits consumers' preferences with probability p, while it is zero if misfit occurs with probability $1-p$. When high quality means a low return probability, (McWilliams, 2012) proves that offering MBGs benefits the low-quality retailer but hurts the high-quality retailer under continuous demand, while it improves both retailers' profits under lumpy demand which makes each retailer behave monopolistically.

Product Information Provision Policy

This study also contributes to the ever-increasing literature on product information provision/disclosure. The overall product uncertainty has two components, the quality uncertainty and fit uncertainty (Sahoo et al., 2018). Information provision aims to mitigate customers' quality uncertainty or fit uncertainty.

Since product quality influences consumers' purchase behavior, firms need to decide whether to communicate quality information to consumers. (Kuksov & Lin, 2010) observe that although the firm with high quality always offers information mitigating quality uncertainty, in certain conditions the firm with low quality is more incentivized to provide information.
For the fit dimension, (Lewis & Sappington, 1994) show that improved consumer information enables the seller to better segment the market and charge a higher price from high valuation consumers. While (Lewis & Sappington, 1994) only consider seller-created attribute information, (Chen & Xie, 2008) additionally incorporate buyer-created review information and identify when these two information types are complements or substitutes. (Sun, 2011) finds that when product quality is common knowledge, the monopoly firm of higher quality is less incentivized to disclose the horizontal attribute.

Other researchers analyze firms' incentive to facilitate fit-revealing strategies when supply chain contracts interact with product information disclosure. In a vertical distribution channel, (Hao & Tan, 2018) explore the supplier's and retailer's incentive to disclose fit information under the agency pricing contract and the wholesale pricing contract.

Review Comments

In response to the frictions PFU generates in online shoppers' buying process (i.e., their reluctance to purchase and returns of products after purchase), recent studies have explored how online sellers' fit information provision through Internet-based tools that help resolve PFU affects sales and returns of the product. (Sahoo et al., 2018) show that the access of more reviews and more helpful reviews reduce the number of returns, with some context-related factors controlled.

This study addresses whether more informative review information can reduce the number of returns by mitigating PFU, in a vertical supply chain where a manufacturer sells one product to a column of heterogenous customers through an online retailer. Our model complements and extends the above empirical studies in three major ways. First, through formulating consumers' utility of buying and that of returning the product, five scenarios are identified regarding whether returns occur or not and whether the market is fully or partially covered. Second, based on the derived optimal price, this study analyzes not only how more informative information affects the manufacturer's returns when returns occur, but also how it influences the market demand when no returns occur. Finally, synergizing the results of how more informative information affects the optimal profit under different scenarios, the two members' optimal information provision policy for products with different levels of PFU is identified.

MODEL

We consider a manufacturer (or he) produces one product characterized by fit uncertainty, and sells this product through an online retailer (or it) to a mass of consumers (or she). The manufacturer determines the product's retail price p^A, and shares with the retailer a commission equal to s fraction of the price on each sale, given the revenue sharing contract adopted by the two members.

Each consumer decides whether to purchase the product, after reading online reviews, observing the product price, learning her hassle cost of returning and the degree of fit uncertainty.

Upon product receipt, each consumer learns her idiosyncratic true valuation and decides whether to return or keep the product.

Based on consumers' purchase and return behavior, we identify five different scenarios. Then, under each scenario, we establish the profit function of the manufacturer and retailer, and analyze the manufacturer's optimal price.

DISCUSSION AND CONCLUSIONS

In this paper's market environment, a manufacturer produces one product characterized by fit uncertainty and sells it on an online platform with revenue sharing contract, and both channel members are able to control the degree of informativeness. Considering consumers' purchase decisions under partially informative information and their possible return behavior upon product receipt, we establish the manufacturer's profit function under five identified scenarios and derive his optimal price as a piecewise function, and formulate the retailer's profit under each scenario accordingly. We then examine how more informative information affects the manufacturer's optimal price, the number of returns/market demand, and the two members' optimal profit. Finally, synthesizing the results under different scenarios, the two members' information provision policy is revealed. Several managerial insights are derived.

For the product with different degrees of dispersion, the two members' information provision policies can be either consistent or conflicting. For a product with very low dispersion, only scenario NR(F) appears and both members adopt a no disclosure policy. For a product with lower dispersion, the manufacturer adopts a mediocre disclosure policy, while the retailer adopts either a no disclosure policy or provides a lower degree of informativeness. For a product with very high dispersion, both members adopt a full disclosure policy.

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Mapping Food Supply Chains for UK Disadvantaged Communities: A focus on Plymouth

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ABSTRACT

Regardless of many efforts by the government and people of the United Kingdom to address food insecurity and poverty, food inequalities in the country continue to worsen. Having identified the limited research on the role logistics and supply chain management could play in addressing this challenge, this study coproduces a food product for disadvantaged communities using Plymouth as a case study and maps the supply chain for it to identify the processes and key challenges therein. Accessibility is not a major challenge in Plymouth, but limited demand, affordability and inconvenience are.

KEYWORDS: Fish supply chain; Disadvantaged communities; supply chain mapping; UK food redistribution; Distribution Logistics.

INTRODUCTION

Food is of absolute importance for the survival of humans on the planet as it is fundamental to good health and well-being. It is one of the pillars upon which society is built (M. Bourlakis & Weightman, 2004); so that, tampering with food supplies or food sources could instigate serious political instabilities and even wars. Many conflicts have resulted over lands that were deemed arable for food production (Telesetsky, 2011). Not surprisingly, the distribution and sale of agricultural and horticultural products have been going on for centuries (Walley & Custance, 2010). Logistics and supply chain management play a crucial role in this as it is food supply chains that facilitate the provision of safe, healthy, and nutritious food, right from farm to fork (Burlingame & Pineiro, 2007; Septiani et al., 2016).

In recent times, the volatility and vulnerability of supply chains have been increasingly recognised (Ali et al., 2017; Christopher & Holweg, 2011; Sawyerr & Harrison, 2020; Vlajic et al., 2012). Food supply chains face the same challenges, in addition to unique vulnerabilities due to the types of products using these supply chains (Stone & Rahimifard, 2018; Vlajic et al., 2013). As the incidence of extreme weather conditions is rising, it may be anticipated that these challenges will get more pronounced (Allison et al., 2009). Additionally, issues around inadequacies in food safety and quality pose significant risks to food integrity, particularly considering the perishability of some of the products in food supply chains (Fox et al., 2018; Septiani et al., 2016). With increased globalisation, the distances between the points of food production and places of consumption have also increased, thereby impairing traceability and exponentially heightening food integrity risks and food losses and waste (M. Bourlakis et al., 2014; Dania et al., 2018; Facchini et al., 2018).

All of these have resulted in increasing concerns by governments about resilience in food supply chains, food security and the long-term sustainability of the food industry (Accorsi et al., 2018; Leat & Revoredo-Giha, 2013). The United Kingdom (UK) government is insisting on the high resilience of its food supply chain and the country has a food industry that is experienced in dealing with food supply disruptions and firms which try to establish alternative supply routes and suppliers, among other measures, to help minimise disruptions (The Environment Food and Rural Affairs Committee, 2020). Food losses and waste are, by the government's admission, a problem that needs addressing, while many citizens in the country live in food poverty or are food insecure.

This paper discusses food inequalities in developed countries, focusing on the UK's southwestern port city, Plymouth. Even though it is located in a rich and diverse agricultural hinterland with direct access to seafood, the city, like many others in the UK, has an increasing population of persons suffering from food poverty and poor diet-related health. The city thus presents a representative case for which the findings can be generalisable not only across the UK, but in other developed countries as well. The paper begins by providing a literature review of food poverty in the UK and then in Plymouth. It then discusses the utility of supply chain mapping in helping to understand the processes and challenges in food supply chains after which the methodology section presents how data from 40 total interviewees (both national and local) and 4 focus groups in Plymouth were used to map the national supply chain map that serves disadvantaged communities in the UK, identify fish as an aspirational food product that consumption could increase among these groups in Plymouth and map the fish supply chain map in Plymouth. The findings and discussions are presented, and the paper concludes by highlighting opportunities for practical and research interventions.

LITERATURE REVIEW

Food Poverty in the UK

Global food insecurity continues to worsen. Many developed countries – including the UK – have reported increased reliance among their populations on emergency redistributed food offers. In the UK, there is increasing pressure on the government to incorporate "the right to food" into the nation's law (May et al., 2018). As food poverty levels continue to escalate, exemplified by increasing numbers of citizens reliant on food banks (Greener, 2019; May et al., 2018), the insistence on ratifying the right to food into law has been amplified (Westwater, 2021). The Food Foundation (2019) reports that the poorest 10% of UK households need to spend about 74% of their disposable income on food to meet the costs of the Eatwell guide. Additionally, about 80% of adults and 95% of children eat fewer than 3.5 portions of vegetables a day and around 16% of adults skip meals for financial reasons. Indeed, a quarter of the UK's population thinks healthy and nutritious food is unaffordable (Corfe, 2018). Children living in households where a healthy diet is unaffordable are identified to have a higher likelihood of suffering adverse consequences on their education (Adolphus et al., 2013, 2016; Gooseman et al., 2020). The most vulnerable households to such food poverty and insecurity include single-parent households, those living in temporary accommodation, poorer families, households with no recourse to public funds and families where at least one member suffers physical, dietary or mental health conditions (Lovell & Eatwell-Roberts, 2019; May et al., 2018). Other vulnerable groups include adults who live alone, homeless people, individuals without a car or public transport monies, and some pensioners. As they are usually socially and economically disadvantaged, persons within these groups tend to make poor choices on food due to a variety of complex and imposing conditions (Pettinger et al., 2017). The acute rise in food poverty and insecurity in the UK in recent years is corroborated by the 284% (pre-COVID) increase in reliance on food banks since 2012 (Lovell & Eatwell-Roberts, 2019). The Coronavirus pandemic worsened the plight of the most vulnerable, especially as nationally imposed lockdowns disrupted agri-food chains (Dimbleby, 2021). As this research presents the peculiarities of food insecurity and poverty in Plymouth, the next section discusses the food system in the city.

The Food System in Plymouth

Plymouth has high levels of deprivation which is evidenced by the existence of food deserts, where access to fresh and affordable food is restricted (Lewis et al., 2014; PCC, 2020; Pettinger & Bonney, 2016; Williamson et al., 2017). A strong correlation between class, affluence, location within the city and access to fresh food has been identified. This has provided an insight into the diet-related health patterns as observed in these parameters within the city (Lewis et al., 2014) where the lowest income households disproportionately suffer from poor nutrition and related health issues (Kinra et al., 2000; Pettinger et al., 2017; Pettinger & Ellwood, 2019).

The city is favourably located in the rich agricultural hinterland of the south-western English coast with access to rich marine resources. Notwithstanding, not much of the locally consumed food is sourced from the surrounding areas or city's ports where some of the biggest fish-landings are made in the UK (Lewis et al., 2014). This has been attributed to a departure from the city's conventional dependence on outlets that retail locally produced food to shopping from supermarkets that usually source nationally and internationally (Miller, 2013) – a situation that is common in many developed countries. Over time, the capacity to meet the demand for locally produced food has become inadequate and unsustainable despite lingering significant demand (Lewis et al., 2014).

Food inequalities, inadequate food production capacity and easy access to unhealthy foods increase the exposure of the city's residents, especially children to obesogenic food environments. This aggravates the already dire health conditions of children living in food poverty. Seeking to explore the provision of healthier and sustainable food product options for the disadvantaged, this study maps the supply chain for locally landed fish to identify the challenges and opportunities to increase local consumption.

Supply Chain Mapping

There are a variety of risks (for food businesses and consumers alike) within food supply chains that require mitigation. Supply chain mapping is useful for improving visibility in food chains. It, therefore, provides a useful means, not only for risk mitigation but also for resilience, efficiency and sustainability (Donaldson et al., 2020; Mubarik et al., 2021; Sawyerr & Harrison, 2020; Thompson, 2015). This became significantly evident across the globe with the COVID-19 pandemic as about 70% of organisations did not have a clear sense of the parts of their supplier networks that were adversely affected (Choi et al., 2020). The organisations that had mapped out their supply chains at a multi-tier supplier level on the other hand were able to pre-emptively protect their supply by analysing their maps and identifying alternate sources to mitigate the supply lines that were disrupted (Vakil, 2021).

Supply chain mapping involves the process of documenting information across companies, suppliers and individuals who are involved in the company's supply chain, to create a global map of their supply network. The resulting map is "*a representation of the linkages and members of a supply chain along with some information about the overall nature of the entire map*" (Gardner & Cooper, 2003, p. 46). Supply chain maps represent the supply network relationships, flows and dynamics in a simplified yet realistic manner by capturing the essence of the environment in which the supply chain operates. This thereby allows for the visualisation of the upstream and downstream of their supply networks to allow for the identification of problematic areas and to support process decisions (Anastasiadis et al., 2020; Mubarik et al., 2021). It provides supply chain managers with insights to understand the areas of cost savings and offers companies much flexibility because it facilitates the identification of opportunities, monitoring of threats and risks, and avoidance or mitigation of the possible effects in case of disruption (Fragapane et al., 2020; Mubarik et al., 2021). Primarily, a supply chain map may cover all facets of the supply chain structure, showing the firms, facilities, processes and materials, information and financial flows (Craighead et al., 2007; Mubarik et al., 2021). A supply chain map that is useful for strategy execution should typically include the focal firm, its suppliers, the technologies used in the supply chain process and also the capabilities, such as Just-In-Time deliveries (Lambert & Cooper, 2000; Mubarik et al., 2021; Soto-viruet et al., 2013; Suarez-Barraza et al., 2016).

A variety of methods have been employed in mapping food supply chains. In the UK, the food value chain analysis (FCVA) method has been one of the utilised methods. Multiple authors (including Donaldson et al., 2020; Francis et al., 2008; Simons et al., 2003, 2005; Taylor, 2005, 2006) have used the method or a variation of it in different agri-food sectors. One of such modified versions is Kumar et al.'s (2013) relationship-based method where a basic map is developed using data from literature and secondary documentary sources. Data collected from semi-structured interviews with actors in the basic map are analysed and used to understand the processes within the chain, linkages between interfaces, the nature of relationships between actors and the potential opportunities for integration. A similar methodological approach is adopted for mapping the supply chains in this study.

METHODOLOGY

First, a national supply chain mapping for food supply chains that support disadvantaged communities was conducted. After this, an exemplar product was selected through coproduction activities with the local community for which mapping was to be done. Additional data was then collected through interviews to map out this supply chain in Plymouth to identify its challenges and the opportunities to increase local consumption, especially among the communities vulnerable to food insecurity and poverty. The questionnaire for collecting data for the local fish supply chain is provided in the appendix.

For the national mapping of the food supply chain that serves disadvantaged communities, a relationship-based supply chain mapping approach was adopted (Kumar et al., 2013). Having examined the relevant literature and government documents, the "basic" map showing the structure of the UK's commercial food supply chain was developed. With this map, 32 participants consisting of primary producers, manufacturers, retailers, wholesalers and logistics companies were interviewed. In addition, some experienced academic professionals, industry experts, government officials and food charities were also interviewed. The collected data were analysed using an abductive thematic analysis method to map out the infrastructure, and processes involved at the various stages of the supply chain to supply food to disadvantaged communities in the UK. This map was then the template for which the local data collection was going to be done for the food product identified within the Plymouth community.

Based on the national statistics from Kantar, Living Costs and Food Survey (LCFS) and Family Food dataset (FFD), data on spend as a percentage of shopping basket were used to identify the food products consumed by the lowest socioeconomic status (SES) groups within the UK. A variety of the eligible food products identified from the national data were verified through 4 different focus groups, each consisting of 6 individuals from the disadvantaged groups in Plymouth both to ascertain correspondence at the local level, as well as to identify the aspirational food products that would be healthy, sustainable and affordable for them. Fish was identified as one such food product that could be consumed more.

Having identified the product, 8 additional interviews were conducted using the schematic derived from the national supply chain mapping and the data was analyzed and used to map out the fish supply chain. The results of the data collected and analyzed are presented below.

FINDINGS AND DISCUSSION

From the data collected nationally, our findings indicate that the supply chain that serves disadvantaged communities is a merger between the commercial food supply chain (which consists of primary producers, manufacturers, wholesalers, retailers, the hospitality and catering industry and logistics companies) and the food aid supply chain (FASC). Actors in the commercial food supply chain serve as the suppliers (donors) of food (usually considered surplus) to food redistributors from whom the disadvantaged access supplementary food to what they afford through the commercial chains. Food redistributors are either food aid wholesale distributors or food aid service organisations. The former collect food (either surplus or planned donations) in high volumes from the large actors within the commercial food supply chains and supplies these to the latter from which the disadvantaged directly access the food. The findings from the data collected locally were as follows.

Processes within the local fish supply chain

There are well over 50 different species of fish caught in Plymouth including herring, whiting, pollock, haddock, ling, sardine, mackerel, pouting, John Dory, monkfish, wrangler fish, octopus and shellfish (scallops, crabs, lobsters etc.). Most fish landed at the Plymouth ports by fishermen are auctioned by the Plymouth Trawler Agents to buyers through a hybrid system where purchases may either be made online or in person. Buyers include local fish mongers, local wholesalers, wholesalers from other parts of England (such as London) and international wholesalers. A few wholesalers work with small-scale fishermen to purchase their fish directly and sell them off to retailers and the hospitality and catering industry. For most fishermen, selling through the trawling agency provides them better prices, along with convenience, as it helps them avoid any legal and regulatory requirements for selling directly to consumers. It also relieves them of any additional burden of having to market their fish and manage sales. An interviewed fisherman explained: "*it's too much fish and too much variety of fish to be able to sell directly to anybody. It's too large an amount*…*obviously they connect me with 200 buyers, so I get the top price for my fish*".

Local fish consumers therefore primarily access local fresh fish through fish mongers, the local hospitality and catering organisations and sometimes directly from the local wholesalers. They may also get access to fish products from supermarkets but the fish that goes through this route tends to be bought and shipped to the distribution centers of the major retailers from fish products from other parts of England, as well as international imports are assembled and redistributed across the country. It thus becomes relatively difficult to trace fish landed in Plymouth through the supermarket supply chain back to the city. Figure 1 below provides a schematic overview of the fish supply chain in Plymouth.

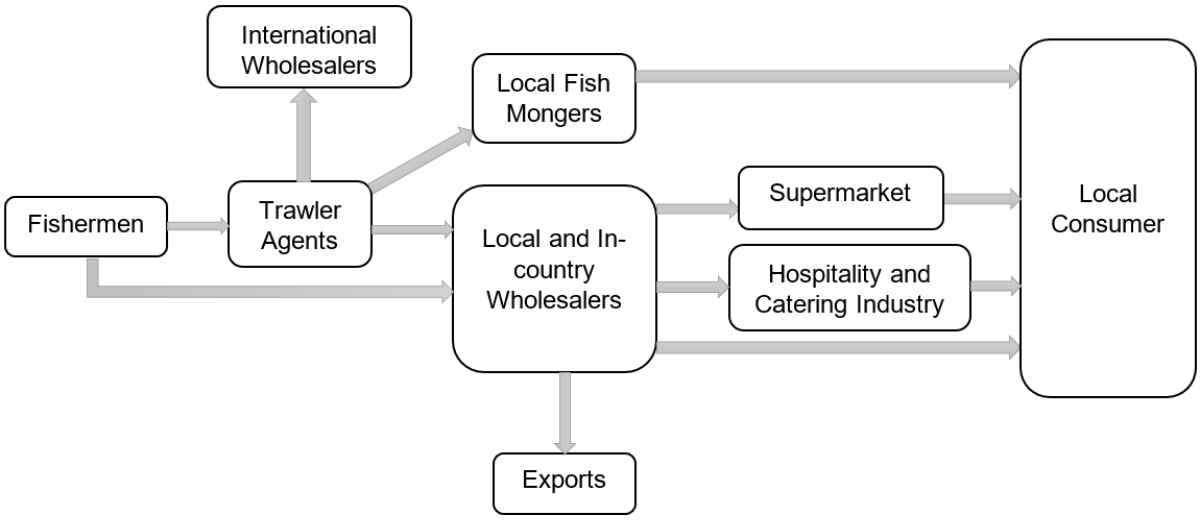

Figure 1 Fish Supply Chain in Plymouth

As is inferable from Figure 1, local fish mongers compete with large local and in-country wholesalers, as well as international merchants for the fish that is landed. As it is an auction, larger players are able to make higher bids which thus means that most of the fish caught in the city's waters get shipped outside of it. Nevertheless, accessibility to fresh fish landed in Plymouth ports is not a problem within the city even though the fishmonger tends to be the primary source for consumers.

Challenges

Even though accessibility is not a major challenge, affordability is. Unlike the supply chains that provide food aid through the redistribution of surplus food, there is very little to no waste in the fish supply chain in Plymouth. Most of the landed fish are sold, those which are not sold in good time get frozen while the remaining are then used locally or exported as bait. This therefore makes it very difficult to have any surplus fish available for redistribution like is done for some ambient food products or even fresh fruits and vegetables. This is consistent with what is observed in the rest of Europe since most of the waste in the fish supply chain occurs at the processing and manufacturing stage of the supply chain involving inedible parts (Caldeira et al., 2019) which are, thus, not surplus and are not available for redistribution. Additionally, local demand for locally landed fish in the UK is relatively low. Compared to Norway, the leading exporter of fish in Europe (Eurostat, 2022) where 57.27% of its landed fish are consumed within country (The Directorate of Health, 2022), most of the UK's landed fish (such as mackerel and herring) are exported, while most of its domestically consumed fish (such as tuna, haddock, cod, shrimps and prawns) are imported (DEFRA, 2021). Consequently, the few stocks of preferred locally landed fish that are sold locally tend to be pricy and less likely to be redistributed.

Limited skill in fish processing (descaling, filleting, skinning, gutting, etc.) was identified as a hindrance for donating or subsiding fish for food charities. One of the interviewed local wholesalers pointed out concerning some of the fish they used to give out, that:
"*They were brought in, as a gift, everything but cut and they would say "But it's still got the skin on it". Fish comes with skin. That's just the way it is. So, in the end, the amount of time that it would have taken me to get it all prepared the way they wanted it, I was losing money by not working to do my actual job.*"
Thus, even when the organisations within the fish supply chain were willing to donate to food charities, there was very little incentive to do it because of the difficulties in handling and processing the fish for the charities.

The lack of skill was also identified as a major hindrance to the consumption of local fish. Convenience was highlighted as high-ranking on consumers requirements of the fish products. A local fish monger said, "…*if you come in and you have a look, most of the products on our counter are actually whole fish. So they (customers) come in and have a look at it,…they're not sure whether they're expected just to pick it up and walk away with it, and do it themselves…. They come in not just for convenience food, but convenience shopping as well.*" Because many people are not adequately skilled to process, prepare and cook the fish (Neale et al., 2012), there was relatively little desire to buy fish directly from fishermen, even if it were at a cheaper price (Carlucci et al., 2015). Fishermen and wholesalers pointed out the need to come to the fish landing sites and the smell of freshly caught fish were also deterrents. Consequently, owing to the declined demand for locally landed fish within the city over time, there were very few fish mongers remaining in the city.

Another challenge towards local consumption, particularly among the disadvantaged, was the cost. Interviewees highlighted facts such as fuel prices, low local demand, government-assigned quotas and the high level of consolidation in the corporations that manage fishing boats and quotas as contributing factors to the prices at which fish gets sold. The processing required to get fish in the state that customers were comfortable with, along with other convenience requirements also pushed the price of fish in the city up.

Opportunities for affordable local fish

Limited data on the fish consumption in Plymouth is a challenge that opens up opportunities to explore solutions. There is an opportunity for the Plymouth City Council to collect data on the consumption of fish food products and compare them with available extant data on the city's fish landings to help facilitate the exploring of viable local solutions. The scarcity of relevant data makes most propositions speculative and difficult to justify implementation. Arguments have been made for the potential of using locally landed sardines and other small-sized fishes in the production of fish pies, fish tacos, canned fish products, among others, to drive up local consumption in line with dietary recommendations on fish (SACN, 2004).

There is optimism with the production of products like fish pies and tacos as they do not require high levels of industrial machinery for processing. Concerns were raised on canned or tinned fish due to the capital and operational expenditure that may be required to operate factories that would produce these products. Worries were expressed about these things causing prices to be high compared to the relatively low-quality tinned fish products that are imported into the UK.

CONCLUSION

Increasing food inequalities in the UK has highlighted the urgent need to deliver affordable, healthy and sustainable food options for the various disadvantaged groups in the country who struggle to get these. As the role of logistics and supply chain management has scantly been explored in addressing these concerns (Wang, 2017), this research sought to investigate the nature of the fish supply chain in Plymouth, compare it to the generic supply chains through which disadvantaged communities access food and identify the challenges to accessibility and affordability of fish in the city. A schematic map of the local fish supply chain is presented.

Our findings indicate that, unlike food products such as fresh fruits and vegetables where surplus from commercial supply chains is redistributed through food aid supply chains to supplement the quantities accessed by disadvantaged communities via traditional routes (Spring et al., 2019), there is little to no surplus in the fish supply chain for redistribution. Thus, despite the variety and quantities of fish landed in Plymouth, there is little overall consumption in the city, and this becomes worse among the disadvantaged. Accessibility was not a challenge but affordability and convenience (in terms of the fish being in a state that was easy to consume) were identified as major obstacles. Unlike Weymes and Davies (2018) who suggested that the reason for the low quantities of fish (and meat) redistributed was due to food safety concerns around the handling of raw materials, our findings show that in Plymouth, the limited redistribution of fresh fish is mainly due to the limited quantities of surplus fish and the inconvenience of processing it. Indeed, some organisations in the fish supply chain which were donating to food charities discontinued their provision of fish due to an extra requirement for processing the fish – an additional cost the donors deemed too high to concede.

Considering the uniqueness and complexity of the challenges identified in the fish supply chain in Plymouth, there are opportunities for interventions through practice and research. This paper has highlighted the need for more data to understand the nature of local fish provisioning and consumption in order to allow for good, sustainable solutions to be developed. It has highlighted how unlike other types of fresh food, fish requires innovative and sustainable solutions. Thus, there are opportunities for further research into making such food products more accessible and affordable for disadvantaged consumers. With food redistribution not being a viable short to medium-term solution to inadequate consumption of fish by disenfranchised groups (Garthwaite et al., 2015; Papargyropoulou et al., 2022; Spring et al., 2019; Vlaholias et al., 2015), researchers and policy makers alike have to seek out long-term solutions that address the demand, affordability and convenience challenges that plague fish supply chains in the UK.

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APPENDIX

Participant Details

Name:
Role:
Experience:
Organisation:

Interview Questions

1. Kindly elaborate on what you (and your organisation) do.

2. Kindly give an overview of the fish supply chain in Plymouth. How much of the fish would you estimate are sold locally in Plymouth?

3. Is fish popular among people who struggle to access food in this community? Why do you think so?

4. Do actors in the supply chain ever end up with fish that does not get sold? If yes, what do they do with those?

    a. Are any of these sent to any local charities (such as food banks)? Who are they? If not, who do they give them to?

    b. What equipment (e.g., freezers, chilled vans) and processes are used to preserve, handle and transport any extra fish within the supply chain and within the community?

    c. Why are the fish sent to these organisations? What resources or capabilities do you think they have that are complementary to each other to help deliver to consumers?

    d. Do you think these organisations learn anything from their work with each other based on what information or knowledge they share with each other? How? Do you think the learning is mutual?

    e. Are you aware of processes, methods or personnel for the redistributing of surplus fish? What processes are these? What is the title of their role and how do they work?

5. What are the key internal barriers within companies that are faced in supplying surplus fish to the charities? What are the external barriers, in terms of the law, regulation, other persons or organisations (fish mongers, other wholesalers, manufacturers) they work with?

    a. Are you aware of any areas within the city that do not have access to fish? What are the causes of these or what hinders accessibility in these areas?

    b. What about the delivery of fish to local communities that may not be able to afford or access food?

6. What plans, if any, do you think organisations could have in addressing these internal and external barriers that you have identified?

7. What are the enablers within companies (internally) that encourages or facilitates the supply of fish to consumers (especially those with limited affordability or access) in the city? What are the external enablers?

8. How do you think that the City Council, along with the other stakeholders in the community can address the supply of fish to everyone, including those with limited affordability or access in the city?

9. Any final thoughts or issues that we have not discussed but you deem relevant?

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Maximizing Demand Fulfillment Probability under Pareto-Distributed Demand

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ABSTRACT

Motivated by the growing empirical evidence of heavy-tailed demand distributions in the inventory management literature, we study a multi-item, multi-period budget-constrained inventory optimization problem under Pareto-distributed demand. We first characterize the joint demand fulfillment probability analytically under Pareto-distributed demand, and then investigate the impact of the available budget and the shape parameter on the optimal inventory targets and the optimal demand fulfillment probability. We further compare the inventory targets and associated demand fulfillment probabilities obtained under the assumption of normally distributed demand to those obtained under the assumption of Pareto distributed demand.

KEYWORDS: multi-item inventory, Pareto distribution, heavy-tailed demand, and inventory optimization

INTRODUCTION

Most of the literature on inventory management assumes that product demands are normally distributed. While this assumption holds for several products and leads to mathematically convenient results, growing empirical evidence in the literature shows demand with heavier tails than the normal distribution. Therefore, it is critical to develop inventory models that can capture demand characteristics accurately. In fact, the demand distribution may have a big impact on inventory decisions (Syntetos et al., 2012; Turrini & Meissner, 2019).

We study a multi-item budget-constrained inventory optimization problem where the objective is to maximize demand fulfillment probability, subject to a budget constraint on the total inventory investment. Our main deviation from previous work is that we assume total periodic demand received for an item follows a *heavy-tailed* distribution. Examples of heavy-tailed demand distributions are the lognormal distribution, the Pareto distribution (or power-law distribution), and the family of stable distributions. We assume that demand follows a Pareto distribution mainly due to the empirical evidence from the literature (Gaffeo et al., 2008; Bimpikis & Markasis, 2016; Natarajan et al., 2018).

For Pareto-distributed demand random variable X, the tail of the distribution satisfies

$$\Pr(X > x) = \left(\frac{x_m}{x}\right)^{\alpha}, \alpha > 0, x \geq x_m > 0 \tag{1}$$

α is referred to as the shape parameter, and x_m is the minimum value of the distribution, which is usually taken as 1. The tail of the Pareto distribution decays polynomially as $x^{-\alpha}$ in contrast to normal distribution whose tail decays superexponentially. This implies that under a Pareto distribution, large (or "extreme") demand values are more likely to occur compared to other light-tailed distributions such as the normal distribution. α controls the weight of the distribution; lower values of α imply a heavier tail and thus larger demand values.

Our main contribution is the characterization of the joint demand fulfillment probability (i.e., probability of satisfying all item demands) under Pareto-distributed demand in a budget-constrained multi-item inventory setting. Additionally, we investigate the sensitivity of the optimal inventory levels to the model parameters including the available budget and the shape of the Pareto distribution. Finally, we show the impact of assuming normally distributed demand when the item demands are actually Pareto-distributed.

LITERATURE REVIEW

This work is related to three streams of research: (1) literature that provides empirical evidence of heavy-tailed demand, (2) inventory management models developed under heavy-tailed distributions, and (3) multi-item inventory optimization under a budget constraint. We review each stream of research in the remainder of this section.

Empirical Evidence of Heavy-Tailed Demand

Although the heavy-tail phenomenon is widespread in disciplines such as finance, physics, and computer science (see Clauset et al., 2009 for a list of applications of heavy-tail distributions), it is relatively new in the inventory management literature. Yet, research has shown that certain product demands follow a heavy-tailed distribution. For example, Chevalier and Goldsbee (2003) estimate the distribution of Amazon book demand as a power law distribution with $\alpha = 1.2$. Gaffeo et al. (2008) show that book sales in Italy follow a power law distribution with α ranging from 1 to 1.4. Notice that lower values of α represent heavier tails and hence a larger deviation from the normal distribution. Bimpikis and Markasis (2016) analyzed the movie demand of Netflix and found that it follows a power law distribution with $\alpha = 1.04$. The same authors also looked at the demand for 626 similar shoes and showed the superiority of the power law distribution compared to normal and exponential distributions in modeling it. Finally, Natarajan et al. (2018) showed how the fit of automotive spare parts demand data also follows a power law distribution. Following these findings, we use a power law (or Pareto) distribution to model the item demand distributions in a multi-item inventory system.

Inventory Management Models under Heavy-Tailed Demand

The evidence pointing to non-normality of demand led researchers to propose inventory models under heavy-tailed distributions. For example, Aydin et al. (2012) study inventory pooling with newsvendor products, and focusing on the two-product case, show that if the product demands are extremely heavy tailed (i.e., α <1), pooling may increase safety stocks. Bimpikis and Markasis (2016) also quantify the role of heavy tails on inventory pooling in terms of the expected cost and safety stock levels. Furthermore, focusing on a single-location multi-period newsvendor setting operating under a periodic-review policy, the authors show the impact of heavy tails on pooling in time. Specifically, they find that heavy-tailed demand distributions lead to a shorter optimal review period. Natarajan et al. (2018) study a distributionally robust multi-item newsvendor setting with distribution asymmetry and show that when the underlying demand distribution is heavy tailed, the asymmetry information reduces the expected profit loss. Corlu et al. (2020) consider the classical single-period newsvendor setting as well as the single-site multi-period setting but in the presence of catastrophic disruptions. The authors derive a closed-form expression for the optimal inventory levels in the single-period inventory setting with a power law demand distribution accounting for both demand-uncertainty cost and disruption cost. For the multi-period inventory systems, the authors show the impact of heavy tail demand on the standard deviation of the mean total cost and the fill rate. Other papers that consider heavy-tailed demand include Das et al. (2021) and Yang et al. (2020). In this paper we investigate the impact of Pareto distributed demand on the optimal inventory levels and optimal demand fulfillment probability on a budget-constrained multi-item inventory system.

Budget-constrained Multi-Item Inventory Management

There is a sizable literature on budget-constrained multi-item inventory systems, dating back to the 1960s. Oral (1981) is among the first to study a multi-item inventory system with a budget constraint that operates under a base-stock inventory policy. The author maximizes the demand-weighted sum of the item fill rates using a Lagrangian relaxation method. Hausman et al. (1998) focus on maximization of demand fulfillment probability assuming that product demands follow a multivariate normal distribution. Corlu et al. (2017) focus on the same inventory setting as Hausman et al. (1998) but solve the problem in the presence of unknown demand parameters for normal, exponential, or Poisson item demands. More recently, Yang et al. (2020) focus on maximizing order fulfillment under budget constraints for normally distributed demands and Pareto distributed demands and develop a decision-support tool that assesses whether the current inventory performance is Pareto-optimal and identifies the optimal inventory levels based on the strategic goals of the firm and several performance measures. Following the budget-constrained multi-item inventory system in Hausman et al. (1998) and Corlu et al. (2017), we study the impact of Pareto-distributed demand in this setting. We provide insights into how the weight of the tail impacts the optimal inventory levels and the probability of satisfying all item demands.

INVENTORY MODEL

This section follows the inventory model introduced in Hausman et al. (1998) and Corlu et al. (2017). Specifically, we consider a P-item inventory setting, where item demands are independent of each other and are Pareto distributed. Each item operates under a periodic-review base-stock policy. In each period, the inventory is reviewed, an ordering decision is made, replenishment orders are received, and finally item demands arrive. We assume that unsatisfied demands are backlogged. We use the following notation throughout the paper:

$D_{p,t}$	item *p* demand in period *t*	*p=1,2,…,P and t=1,2,…,T*
$A_{p,t}$	item *p* replenishment arriving in period *t*	*p=1,2,…,P and t=1,2,…,T*
$X_{p,t}$	net inventory level for item *p* at the end of period *t*	*p=1,2,…,P and t=1,2,…,T*

I_p item *p* inventory target *p=1,2,…,P*
c_p item *p* unit investment cost *p=1,2,…,P*
L_p item *p* lead time *p=1,2,…,P*
k response time window satisfying $L_p \geq k$ *p=1,2,…,P*

We use demand fulfillment probability as a measure of the customer service level, defined as the probability of satisfying all item demands. We are specifically interested in the likelihood of satisfying customer demands in a particular period within a time window of k periods, which is characterized as follows:

$$Pr\left\{X_{p,t} + \sum_{i=t+1}^{t+k} A_{p,i} \geq 0, p = 1,2,\dots,P\right\} \tag{2}$$

Using the relation,

$$X_{p,t} + \sum_{i=t+1}^{t+k} A_{p,i} = X_{p,t+k} + \sum_{i=t+1}^{t+k} D_{p,i} \tag{3}$$

Equation (2) takes the following form:

$$Pr\left\{X_{p,t+k} + \sum_{i=t+1}^{t+k} D_{p,i} \geq 0, p = 1,2,\dots,P\right\} \tag{4}$$

Hadley and Whitin (1963) introduced the relationship between the item inventory level, replenishments, and net inventory level as follows:

$$X_{p,t} = I_p - \sum_{i=t-L_p}^{t} D_{p,i} \tag{5}$$

Using (5), we rewrite Equation (4) as follows (Hausman et al. 1998, Lemma 1):

$$Pr\left\{\sum_{i=t-L_p+k}^{t} D_{p,i} \leq I_{p,} \; p = 1,2,\dots,P\right\} \tag{6}$$

Our goal is to maximize equation (6) to obtain the optimal inventory levels, $I_{p,}\ p = 1,2,\dots,P$ under the following budget constraint and non-negativity constraint:

$$\sum_{p=1}^{P} c_p I_p \leq B \tag{7}$$

$$I_p \geq 0, p = 1,2,\dots,P \tag{8}$$

Normally Distributed Demand

Under the assumption that item demands $D_{p,t}$ are independent and normally distributed with mean $\mu_p, p = 1,2,\dots,P$ and standard deviation $\sigma_p, p = 1,2,\dots,P,$ the objective function in Equation (6) takes the following form:

$$\prod_{p=1}^{P} \phi\left(\frac{I_p - (L_p - k + 1)\mu_p}{\sqrt{(L_p - k + 1)}\,\sigma_p}\right) \tag{9}$$

where ϕ denotes the standard normal cumulative distribution function. This result follows from the fact that the sum of normally distributed random variables is also normally distributed. More specifically, $\sum_{i=t-L_p+k}^{t} D_{p,i}$ is normally distributed with mean $(L_p - k + 1)\mu_p$ and standard deviation $\sqrt{(L_p - k + 1)}\,\sigma_p$.

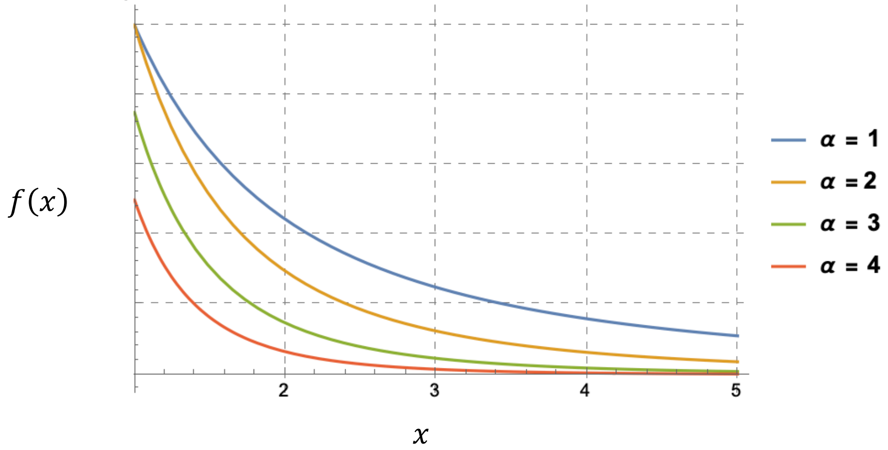
Pareto Distributed Demand

We now assume that the item demands $D_{p,t}$ are independent and Pareto distributed with shape parameters $\alpha_p, p = 1,2, \dots, P$ and scale parameters $\beta_p, p = 1,2, \dots, P$. Although (1) is the most general representation for a Pareto-distributed random variable, this paper follows Ramsay (2008) by using the following probability density function f(x) to represent Pareto-distributed demand.

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x+\beta}\right)^{\alpha+1}, \; x, \alpha, \beta > 0 \tag{10}$$

In this representation, β is the scale parameter and α is the shape parameter controlling the weight of the tail. Figure 1 illustrates that as α decreases, the distribution becomes more heavy tailed.

Figure 1: Pareto distribution with varying shape parameters



The main challenge in the characterization of the objective function in (6) for Pareto distributed demand is that unlike a normal distribution, the sum of Pareto distributed random variables is not Pareto-distributed. The exact distribution for the convolution of Pareto distributed random variables has been studied in the literature. For example, Brennan et al. (1968) and Blum (1970) obtained a formula for the convolution of Pareto distributed random variables for the restricted case where the scale parameter is equal to 1 and the shape parameter takes a value between 1 and 2. Ramsay (2006) provided an exact expression for the convolution of any number of Pareto distributed random variables with an arbitrary scale parameter and positive integer-valued shape parameter. Later, Ramsay (2008) relaxed the assumption of positive integer-valued shape parameter and obtained an exact distribution for the case where the shape parameter does not have to take an integer value. Because the Pareto demand shape parameters may take non-integer values as shown in the literature, in this paper, we use the convolution results presented in Ramsay (2008).

Letting $n_p = L_p - k + 1$, the expression in Equation (6) takes the following form:

$$\prod_{p=1}^{P} F_{n_p}(I_p), \tag{11}$$

where:

$$F_{n_p}(I_p) = \int_0^\infty \frac{\left(1 - e^{\frac{-I_p x}{\beta_p}}\right)}{x} \chi_{n_p}(x, \alpha_p) dx \tag{12}$$

$$\chi_{n_p}(x, \alpha_p) = \sum_{r=0}^{\frac{n_p-1}{2}} \frac{(-1)^r}{\pi} \binom{n_p}{2r+1} (R(x, \alpha_p))^{n_p-2r-1} (I(x, \alpha_p))^{2r+1} \tag{13}$$

$$R(x, \alpha_p) = 1 + \sum_{r=1}^{\infty} \frac{x^r}{(\alpha_p - 1) \cdots (\alpha_p - 1)} - \frac{\pi x^{\alpha_p} e^{-x}}{\Gamma(\alpha_p)} \cot(\pi \alpha_p) \tag{14}$$

$$I(x, \alpha_p) = \frac{\pi x^{\alpha_p} e^{-x}}{\Gamma(\alpha_p)} \tag{15}$$

Note that $R(x, \alpha_p)$ can be written as:

$$R(x, \alpha_p) = M(1; 1 - \alpha_p; -x) - \frac{\pi x^{\alpha_p} e^{-x}}{\Gamma(\alpha_p)} \cot(\pi \alpha_p) \tag{16}$$

where $M(a; b; x)$ is the Kummer function given by the following:

$$M(a; b; x) = \sum_{n=0}^{\infty} \frac{(a)_n}{(b)_n} \frac{x^n}{n!} \tag{17}$$

EXPERIMENTAL STUDY

This section leverages Mathematica® to solve the multi-item, multi-period, budget-constrained inventory optimization problem under Pareto demand distributions. The Mathematica notebook can solve the optimization problem in equations (6) - (8) by using non-linear optimization methods for values of α, β, n ≥ 0, and any number of items *P*.

The experiments in this section assume a two-item setting and are designed to investigate the sensitivity of the optimal inventory levels to model parameters including the available budget (B), the shape of the demand distribution (α), and the number of periods considered (n). We also investigate the impact of assuming a normal demand distribution when the item demands are actually Pareto distributed.

Impact of the Budget

We consider a two-item (P = 2) and two-period ($n_1 = n_2 = 2$) scenario under Pareto distributed item demands with the following parameters: c_p = 20, β_p = 1, and α_p = 5.5 for p = 1, 2. Table 1 presents the optimal inventory target for each product; i.e., I_1 and I_2, and the optimal demand fulfillment probability $F_2(I_1, I_2)$ under varying levels of budget.

Intuitively, as the budget increases, the joint demand fulfillment probability increases. Additionally, notice the equal inventory position for each product due to items' similar features, including their unit cost and demand parameters.

Table 1: Demand fulfillment probability for varying budget under Pareto distributed demand

Budget	I_1	I_2	$F_2(I_1, I_2)$
30	0.75	0.75	0.72
40	1.00	1.00	0.85
50	1.25	1.25	0.92
60	1.50	1.50	0.95
70	1.75	1.75	0.97
80	2.00	2.00	0.98
90	2.20	2.20	0.99
100	2.50	2.50	0.99
150	3.80	3.80	1.00

Pareto versus Normal Distributed Demand

Under the same experimental setting, we now compute the optimal inventory targets and the optimal demand fulfillment probability assuming normally distributed demand. Using Pareto's probability density function in Equation (10), the first and second moments can be taken to find the corresponding parameters, mean (μ_p) and standard deviation (σ_p), for the normal distribution:

$$\mu_p = \int_{\beta_p}^{\infty} x \left(\frac{\alpha_p}{\beta_p} \left(\frac{\beta_p}{x + \beta_p} \right)^{\alpha_p + 1} \right) dx \tag{18}$$

$$\sigma_p = \sqrt{\int_{\beta_p}^{\infty} x^2 \left(\frac{\alpha_p}{\beta_p} \left(\frac{\beta_p}{x + \beta_p} \right)^{\alpha_p + 1} \right) dx - {\mu_p}^2} \tag{19}$$

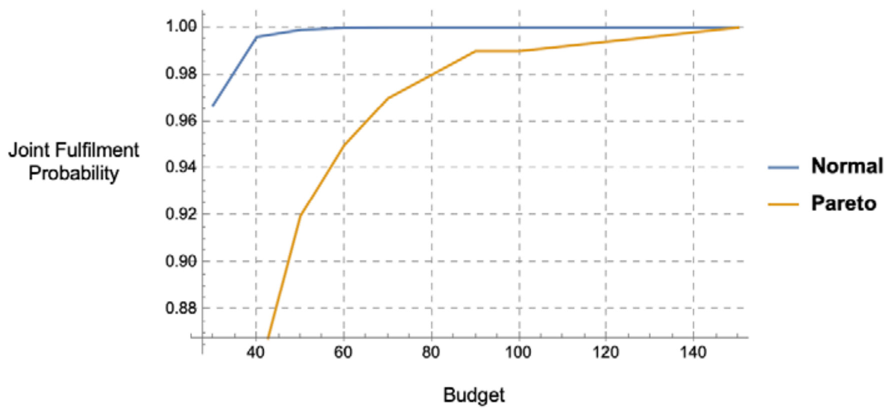
Equations (18) and (19) serve as the bridge to transform α_p and β_p of the Pareto distribution to μ_p and σ_p of the normal distribution. Table 2 tabulates the optimal inventory targets and the optimal demand fulfillment probability under normally distributed item demands.

Consistent with our observations in Table 1, the optimal inventory targets and the optimal demand fulfillment probability increase when the allowed budget increases. However, the demand fulfillment probability under normally distributed demand rapidly increases and is much higher than the demand fulfillment probability under Pareto distributed demand especially for low to medium budget values. For example, when the available budget is 30, the demand fulfillment probability obtained under Pareto distributed demands is 0.72 while the demand fulfillment probability is 0.97 under normally distributed demand. This result implies that assuming normally distributed demand when the demand is actually Pareto distributed provides a wrong sense of high fulfillment probability. The discrepancy between the optimal demand fulfillment probabilities decreases as the available budget increases, as seen in Figure 2.

Table 2: Demand fulfillment probability for varying budget under normally distributed demand

Budget	I_1	I_2	$F_2(I_1, I_2)$
30	0.75	0.75	0.97
40	1.00	1.00	0.99
50	1.25	1.25	0.99
60	1.50	1.50	1.00
70	1.75	1.75	1.00
80	2.00	2.00	1.00
90	2.20	2.20	1.00
100	2.50	2.50	1.00
150	3.80	3.80	1.00

Figure 2: Comparing demand fulfillment probability for varying budget for Normal vs. Pareto distributed demand



Impact of the Shape Parameter α

To analyze the effect of the shape parameter α on the optimal inventory targets and associated demand fulfillment probability, we considered a two-item (*P* = 2) and two-period ($n_1 = n_2 = 2$) setting with B = 1000, $c_p = 20$, and $\beta_p = 1$ for p = 1, 2, and α_2= 1.00. Table 3 shows the results with varying values of α_1, the shape parameter for item 1.

We observe that a decrease in α leads to higher inventory levels and lower demand fulfillment probabilities. This is consistent with our expectation because as $\boldsymbol{\alpha_1}$ decreases, the distribution becomes more heavy-tailed (Figure 1). Consequently, it becomes more likely to see higher demand values for item 1 leading to lower fulfillment probabilities. For example, when $\alpha_1 =$ 0.10 and $\alpha_2 =$ 1.00, the optimal inventory level for item 1 is 36.89 while it is 13.11 for item 2. This leads to an extremely small fulfillment probability of 0.07 mainly because of the extreme high tail for item 1. When $\alpha_1 =$ 2.00 and $\alpha_2 =$ 1.00, the optimal inventory level for item 1 is 13.40 while it is 36.60 for item 2. This leads to a fulfillment probability of 0.93.

Table 3: Demand fulfillment probability for varying α_1 values under Pareto distributed demand

$\boldsymbol{\alpha_1}$	$\boldsymbol{I_1}$	$\boldsymbol{I_2}$	$\boldsymbol{F_2(I_1, I_2)}$
0.10	36.89	13.11	0.07
0.25	35.32	14.68	0.29
0.50	32.24	17.76	0.59
0.75	28.71	21.29	0.76
1.00	25.00	25.00	0.84
2.00	13.40	36.60	0.93
5.00	3.95	46.05	0.95
10.00	1.64	48.36	0.96

Next, Table 4 shows results when the shape parameter is identical for each item (i.e., $\alpha_1 = \alpha_2$) and they are varied from 0.10 to 4.0. We observe that although the optimal inventory levels are equal to each other regardless of the value of the shape parameters, lower values of α_1 and α_2 lead to smaller demand fulfillment probabilities. This implies that more inventory and hence more budget is needed to be able to achieve desired higher fulfillment probabilities.

Table 4: Demand fulfillment probability when item shape parameters are identical

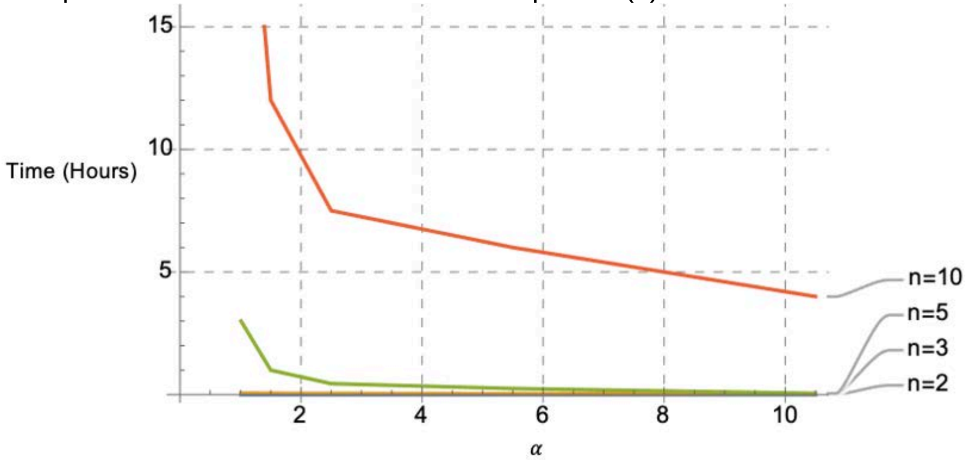
$\boldsymbol{\alpha_1}$	$\boldsymbol{\alpha_2}$	$\boldsymbol{I_1}$	$\boldsymbol{I_2}$	$\boldsymbol{F_2(I_1, I_2)}$
0.10	0.10	25	25	0.005
0.25	0.25	25	25	0.083
0.50	0.50	25	25	0.387
0.75	0.75	25	25	0.671

1.00	1.00	25	25	0.841
2.00	2.00	25	25	0.994
3.00	3.00	25	25	0.999
4.00	4.00	25	25	1.000

Impact of the Number of Periods

We investigated the impact of the number of periods and number of products to determine whether the inventory optimization can be solved within a reasonable time frame. Results show that the model can solve the optimization problem for any number of products in a timely manner. However, the computational challenges and the model's limitation are evident for an increase in the number of periods. To illustrate this, Figure 3 graphically compares the computational time needed to evaluate the objective function in Equation (6) under Pareto distributed demand over $n_1 = n_2 = n$ periods for a range of low and high values of $\alpha_1 = \alpha_2 = \alpha$.

Figure 3: Computational time needed to evaluate equation (6) under Pareto distributed demand



An insight from this experiment is that with lower values of α and more periods, the computational time increases significantly. The main reason for this is Equation (13); when n increases, the summation's upper limit increases, generating more and more complex functions. Similarly, as stated before, lower α values generate heavier tails for which the Pareto distribution function converges slowly to 1. So, for large instances of *n* and low α values, the model becomes computationally expensive.

DISCUSSION AND FUTURE WORK

We studied a multi-item, multi-period inventory optimization problem where the goal is to maximize demand fulfillment probability subject to a budget constraint on the total inventory investment. We investigated the impact of the available budget and the tail behavior of the Pareto distribution on the optimal inventory targets and the associated demand fulfilment probabilities. We further compared the optimal inventory targets and the demand fulfillment probabilities obtained under the assumption of normally distributed demand for each item to those obtained under the assumption of Pareto distributed demands.

While our experiments focus on a two-item and two-period case, our model works for any number of items without any computational burden. However, it becomes computationally expensive to solve the model for a larger number of periods. Our future work will focus on overcoming this computational burden by developing approximations for demand fulfillment probability.

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DECISION SCIENCES INSTITUTE

Meaningful work in the gendered gid economy

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ABSTRACT

The traditional form of employment, where workers were formal agents of the company without family responsibilities, is being replaced by contingent work arrangements demanding flexibility. Using a survey and quasi-experimental design to study the relationships between worker arrangement, gender, and meaningful work, results suggest contingent workers express lower levels of meaningful work than traditional employees, and women express lower levels of meaningful work than men. However, the effects are separate and do not interact. Gender and employment arrangement differences in the derivation of meaningful work are not well understood, though our results suggest they are necessary to understand the construct.

KEYWORDS: Careers of under-represented groups; contingent and temporary work; Meaningful work; Gender

INTRODUCTION

The nature of work and employment has shifted from traditional models of employment, where workers are formal, and relatively permanent, employees of the organization, to contingent work arrangements, which do not contain any explicit or implicit contract for continued employment. This new type of work, often referred to as the gig economy, presents several opportunities for individual workers, such as autonomy and flexibility. However, the wages of contingent workers are precarious and lack traditional employment benefits, like health insurance and paid sick leave. Fair wages and family-friendly benefits have been enormous gains for women in the last four decades (Kaine et al., 2020).

Contingent work is defined as any work arrangement that does not contain "an explicit or implicit contract for ongoing employment" (US Department of Labor Bureau of Labor Statistics, 2005). Contingent employment patterns have been observed in traditionally feminized industries, such as caregiving, relief teaching, and nursing (Bamberry, 2011; Ticona & Mateescu, 2018, Flanagan, 2019). Contingent work is attractive for women caring for small children who seek flexibility (ILO, 2016), though it may also lack the social cohesion and community stability provided by traditional employment (Friedman, 2014). These concepts are important for deriving a feeling of meaningful work (Steger, 2019).

Meaningful work is defined as "the global judgement that one’s work accomplishes significant, valuable, or worthwhile goals that are congruent with one’s existential values" (Allen et al., 2019, p. 502). Several outcomes have been associated with meaningful work, including organizational citizenship behaviors, job satisfaction and general health (Arnold & Walsh, 2015). While gig workers are relatively understudied in general (Keith et al., 2020), meaningful work of contingent workers has specifically been identified as imperative future research (Allen et al., 2019).

The gig economy is no longer a peripheral market for a few independent workers, it is increasingly replacing the stable, permanent jobs of the past century (Kaine et al., 2020). With the changes to work arrangements that have occurred with the Covid-19 pandemic, such as occupational status and increased work-from-home (Kramer & Kramer, 2020), and the way it has disproportionately affected women in the workplace (Petts et al., 2021; Albanesi & Kim, 2021), it is important for us to understand the way contingent work arrangements affect the meaningfulness women perceive in the work they do.

The purpose of this study is to understand how gender is related to contingent work arrangements and meaningful work. We compared the levels of meaningful work between contingent workers and traditional employees and amongst men and women. We will begin with a discussion of contingent work arrangements and the role of women in the gig economy. The theoretical framework of meaningful work is used to understand outcomes of women in contingent work arrangements. Through a survey of contingent workers and traditional employees in the fall of 2020 we found that women, in general, perceive lower meaningfulness in paid work than men and contingent workers report lower levels of meaningful work than traditional workers. Though, these explain two separate variances and the relationships do not interact.

LITERATURE REVIEW

Contingent Work Arrangements

The nature of work and employment has shifted from traditional models of employment, where workers are formal, and relatively permanent, employees of the organization, to contingent work arrangements, which do not contain any explicit or implicit contract for continued employment. This new type of work, often referred to as the gig economy, presents several opportunities for individual workers, such as autonomy and flexibility. However, the wages of contingent workers are precarious and lack traditional employment benefits, like health insurance and paid sick leave. Fair wages and family-friendly benefits have been enormous gains for women in the last four decades (Kaine et al., 2020).

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Meaningful Work

Meaningful work helps workers answer the question "Why am I here?" (Lips-Wiersma & Wright, 2012). Meaningful work is defined as "the global judgement that one’s work accomplishes significant, valuable, or worthwhile goals that are congruent with one’s existential values" (Allen et al., 2019, p. 502). It is important to note that meaningful work is a subjective construct that considers meaningfulness "in the eye of the beholder" (Michaelson, 2019, p. 118). It is a mutual process, whereby employers provide the moral conditions for meaningful work and it is the workers' responsibility to take advantage of these conditions (Thompson, 2019).

Steger (2019) argues for three dimensions of meaningful work: coherence, purpose, and significance. Meaningful work must help workers make sense of life and render it comprehensible and understandable, in other words, give coherence to their behavior. Work must also serve a purpose and propel the worker toward a sense of direction and aspiration in life. Finally, work has meaning when it holds some significance. This refer to the worker's convictions that their lives are worthwhile, and their work is intrinsically valuable.

THEORETICAL DEVELOPMENT

We adopt Bowie's (2019) Kantian view of meaningful work as the theoretical foundation for this study. In this view meaningful work must be freely entered into and the worker is allowed sufficient autonomy and rationality to complete their tasks. Workers must be afforded a sufficient salary without paternalistic oversight. Workers engaging in meaningful work develop rational capacities that do not interfere with moral development. This view has several implications for contingent work arrangements.

Contingent work arrangements imply a substantial level of autonomy. One of the greatest advantages of contingent work is the ability to "be one's own boss" and choose when to work (Hurst & Pugsley). However, as described above, profitable contingent work does not always carry such freedom. Furthermore, where direct supervision is more uncommon in contingent work than in traditional employment, contingent workers are often still confined to specific processes and customer reviews, thus presenting a form of paternalism.

Another qualification of meaningful work, following the Kantian premise, is a sufficient salary and developing rational capabilities. Compared to traditional employee counterparts, contingent workers are often underpaid (Friedman , 2014) and not as protected by employment mandates, such as for health insurance and job insecurity (Harris & Kruegar, 2015). Contingent employees may also consider their work or role to be of lower value than a traditional employee. As Lysova and colleagues describe, “workers who feel pressured to work in unsafe conditions and granted insufficient pay or status could reasonably perceive a message that they are of little value or worth.” (Lysova et al 2019, p. 379). This lowered status is likely to reduce the intrinsic value of contingent work, and therefore hinder meaningful work. Following this logic, we postulate reduced meaningful work for contingent workers:

H1: Contingent workers will report lower levels of meaningful work than traditional employees.

When we consider the gendered effects of meaningful work, it is likely women derive meaning from work differently than men. However, this topic appears understudied in the current literature (Bailey et al., 2019). While many studies measuring meaningful work include women in the analysis, results are not disaggregated by gender (Both-Nwabuwe et al., 2017). Work, specifically paid work, holds different statuses and expectations for each gender.

Consider how the concept of meaningful work is from the individual's perspective, or "in the eye of the beholder" (Michaelson, 2019). For men, paid work is an expected part of their identity. They are expected to provide for their family, to be the breadwinner and secure earnings (Hofmeister & Baur, 2015). This is not necessarily the case for women. A woman is expected to be nurturing and provide childcare and household duties (Hofmeister, 2019). Paid work may even signal a negative status, one where the woman may be considered less feminine or a bad mother for neglecting caring responsibilities (Garey, 1999; Hays, 1996; Friedan, 1963). It is reasonable to expect a woman would find less meaning in a paid work arrangement (either as a contingent worker or traditional employee) than a man.

H2: Women report lower levels of meaningful work than men

One way women may derive meaning in paid work is through relationships at work. In her dissertation, Svendsen (1997) found that relationships within paid work were a source of meaningfulness in the work itself. This is consistent with Wilhoit’s (2014) analysis of how prominent autobiographer women “opted out” of paid work when they found the work meaningless as social connections were found elsewhere, such as through neighbors and friends.

Social connection is not well constructed in contingent work. Contingent work is often independent, without much of an opportunity for social interaction (Keith et al 2020). By definition, contingent work is characterized by an element of temporality. Connections made as a contingent worker are not expected to persist past employment. While contingent work may offer flexibility and autonomy, if women generally derive meaning through relationships, then contingent work arrangements are likely to hold less meaning for women than traditional employment contracts. Following this logic, we expect gender to interact with the relationship between work arrangement and meaningful work in such a way that a woman contingent worker will express a much lower level of meaningful work than a man in a contingent work arrangement.

H3: Gender interacts with the relationship between work arrangement and meaningful work in a way that amplifies the negative effects of contingent work arrangements on meaningful work.

METHODS

Testing the relationships between work arrangement, gender, and meaningful work, was completed through a quasi-experimental design and survey. Survey respondents were recruited from a general population pool via Qualtrics Panels data. A quota was set for 100 participants of each worker type – contingent worker or traditional employee. Subjects were separated into these conditions through the analysis of two screening questions: "Think about your main job (the job from which you earn the most income in the past month). How would it be classified?". The second question asked "In other words, in normal circumstances do you expect your relationship in your main job to continue for another year or more? Respondents must have answered each question consistently to participate in the study and were assigned to the appropriate condition.

A total of 211 respondents qualified for the study, resulting in a sample of 106 traditional employees and 105 contingent workers. The total sample was well stratified with 47% men and 53% women. The average age was 36.85 years old with a standard deviation of 10.8. While most of the sample (83%) completed some college, more traditional employees completed an undergraduate degree than contingent workers in the sample. Total annual income, race, and industry were fairly distributed against groups. The full sample description is available in appendix A.

Meaningful work was measured with the Work as Meaning Inventory developed by Steger and colleagues (2012). This is a pre-validated instrument with a 7-point Likert scale ranging from strongly agree (coded 1) to strongly disagree (coded 7). Three sub-variables are measured with four items identifying positive meaning, three items related to meaning making through work, and three more items considering greater good motivations. Factor scores were obtained for the meaningful work variable through a factor analysis in SPSS 28 with a maximum likelihood estimation and loadings exceeded 0.70 (Hair et al., 2010). The single reverse coded item failed to load properly and was omitted from the analysis. The full items may be found in table 1.

A validity concern for survey data is the likelihood of unengaged responses (Meade & Craig, 2012). To reduce misspecification due to this error, we employed three mitigations in survey design. First, we ensured anonymity in order to motivate honest and accurate responses (Podsakoff et al., 2003). Second, we instilled a "speed trap", whereby respondents that were completing the survey too quickly were removed. Finally, we included two bogus questions testing attention (Meade & Craig, 2012) and incorrect responses to the bogus questions were removed.

Hypothesis Testing

The first hypothesis considers the level of meaningful work reported by contingent workers compared to traditional employees. This was evaluated through an ANOVA with the factorial score of meaningful work across the two groups. Since education was significantly different across groups, it was also included as a control variable. Meaningful work responses were not significantly different across groups, though very close to a 95% level ($F(1,208)=3.246$; $p=0.056$). The effect is small ($\eta 2 = 0.017$) and negative, indicating contingent workers indeed report lower levels of meaningful work.

Table 1. *Meaningful Work Items, adapted from Steger et al., 2012*

Sub-Variable	**Item Wording**
Positive Meaning	I have found a meaningful career
	I understand how my work contributes to my life's meaning
	I have a good sense of what makes my job meaningful
	I have discovered work that has a satisfying purpose
Meaning making through work	I view my work as contributing to my personal growth
	My work helps me better understand myself
	My work helps me make sense of the world around me
Greater good motivations	My work really makes no difference to the world (r)
	I know my work makes a positive difference in the world
	The work I do serves a greater purpose

*Scored on a scale of Strongly agree (1) to Strongly disagree (7)

To see if a specific dimension of meaningful work was different for contingent workers, we performed an ANOVA of each sub-factor aggregated by average. According to this analysis, both making meaning through work and greater good motivations were no longer significantly different between contingent workers and traditional employees. These results are displayed in table 2.

Table 2. *ANOVA of Meaningful Work for Contingent Workers and Traditional Employees*

	Contingent		Traditional				
	M	SD	M	SD	F-value	Partial η2	Sig.
Factor Score of Meaningful Work	0.128	0.943	-0.127	0.992	3.687	0.017	0.056
Positive meaning	2.950	1.313	2.547	0.326	4.802	0.023	0.030
Meaning making through work	2.883	1.346	2.601	1.365	2.200	0.010	0.139
Greater good motivations	2.820	1.290	2.500	1.336	2.999	0.014	0.085

We tested the second hypothesis in much the same way. The factorial score of meaningful work was compared across genders, with the added control of education. Gender was significantly different at the 95% level ($F(1,208)=4.016$; $p=0.046$) and including gender negated the effects of education on meaningful work. The effect is small ($\eta 2 = 0.019$) and indicates women report lower levels of meaningful work than men.

The mean of each sub-factor was also evaluated for differences across genders. Similar to the differences between contingent workers and traditional employees, positive meaning remained significant while the other sub factors were not different between men and women. The results are displayed in Table 3.

Table 3. *ANOVA of Meaningful Work for Women and Men*

	Women		Men				
	M	SD	M	SD	F-value	Partial η2	Sig.
Factor Score of Meaningful Work	0.150	1.041	-0.170	0.866	4.016	0.019	0.046
Positive meaning	2.963	1.430	2.515	1.175	4.361	0.021	0.038
Meaning making through work	2.932	1.463	2.525	1.204	3.469	0.016	0.064
Greater good motivations	2.835	1.381	2.460	1.224	2.353	0.11	0.127

The moderation effect was tested through another ANOVA with both the worker type and gender, along with education as a control. In this analysis both worker type and gender were significant at the 95% level, though the interaction effect was not significant. Considering the scores, women contingent workers report the lowest levels of meaningful work, followed by traditional employee women, then contingent working men, and finally traditional employee men reported the highest levels of meaningful work. These results are presented in table 4.

Table 4. *ANOVA of Meaningful Work by Work Arrangement and Gender*

		Mean	**SD**	**F-value**	**Partial η2**	**Sig.**
Contingent Worker	Men	-0.019	0.909			
	Women	0.266	0.961			
Traditional Employee	Men	-0.324	0.800			
	Women	0.038	1.110			
Gender				4.215	0.020	0.041
Work Arrangement				3.959	0.019	0.048

In terms of our proposed relationships, we found gender was a significant predictor of meaningful work, more so than worker type. We do not find strong support for H1, that contingent workers experience less meaningful work than traditional workers. Though, our results are consistent with support for H2, women report lower meaningful work than men. We must reject H3, there is no interaction between these variables; they are separate effects.

DISCUSSION

The purpose of this study was to investigate the way contingent workers and traditional employees experience meaningful work and whether gender has a role in this realization. While there may not be highly significant differences in meaningful work between contingent workers and traditional employees, we do see a rather important difference, particularly in terms of positive meaning. According to Steger and colleagues (2012), the positive meaning items are the "flagship" indicators of meaningful work and generally show consistently strong bivariate correlations with well-being variables. It is important to consider what this means for contingent workers.

Theoretical Contributions

An important contribution of this research is the indication women report lower levels of meaningful work than men. While we consider meaningful work a highly personal and individual construct, current research fails to view the whole person when observing the variable. It is likely the research community still considers a full-time, securely employed male breadwinner as the normal employee (Kaine et al., 2020). Foundational management theories are based on this norm and while research designs include heterogenous samples, many fail to consider the effect of important differences in outcomes. This is problematic for fully understanding the concept of meaningful work.

Consider the case of gender in medical research. Until the mid-1990s it was standard practice for clinical drug trials to preclude females in phase I and II testing (Corrigan, 2002). The male body was considered the physiological norm and the changing hormonal levels and metabolism of women were expected to impact drug efficacy (Corrigan, 2002). Even after females were permitted into later phases of drug trials, females were still largely underrepresented, and results were not separately analyzed by gender. Weinberger and colleagues (2010) reported that as recently as 2007, very few studies of depression reported gender-specific analysis. Of the 768 clinical trials reviewed, less than 1% reported an intention to analyze results by gender. Gender disparity remains a problem for medicine, as clinical trials regarding Covid-19 still fail to include explicit gender effects (Bischof et al., 2020). A lack of testing, or reporting results with consideration of gender, has led to flawed dosage of medication and knowledge of disease for women.

The same phenomenon may be plaguing our understanding of meaningful work. Will the management theories of the past, such as the seminal Job Characteristics Theory (Hackman & Oldham, 1976), which postulate the antecedents and outcomes of meaningful work, apply to our new world of work? Will a worker's gender or employment arrangement impact how meaning is derived from work? While considering gender effects in management research is complex and onerous, we must consider the likelihood of significant differences. The results of the present study suggest these differences are real and must be a serious concern.

Notably, the gender effect on meaningful work is not influenced by the type of employment arrangement. While we anticipated the lonely lifestyle of a contingent employee would lead women to derive less meaning from their work, we did not see this reflected in the data. Both women and contingent workers expressed lower meaningful work, though neither effect interacted with the other. They explained separate variances. A possible explanation may lie in how work is perceived as part of a person's identity.

Social roles in contemporary society suggest men are more predisposed to paid work than women. In the years following the second world war a social contract was made whereby men would engage in paid work and women would care for the children and household (Kaine et al., 2020). While this is no longer a rigid expectation, it is reasonable for men to conform to an identity rooted in their vocation and career. Therefore, a lower status employment arrangement, i.e. a contingent work arrangement, may significantly reduce a man’s level of meaningful work. Conversely, if a woman does not strongly identify with her paid work, then the lower status work arrangement may not be particularly important. Researchers have found women may derive meaning in work by caring for others and creating a greater good in the world. In a study of

Danish women taking care of family members, researchers found the meaning derived from this nurturing activity had a significant effect on mental and physical health (Dich et al., 2019). If a contingent working woman does not identify with the role of employment, in the same way a man does, then meaning is not moderated by worker arrangement.

Managerial Implications

As organizations move away from formal work arrangements, common in the 20th century, to contingent and flexible work arrangements enabled by technology, the core psychological and emotional state of workers are likely to be affected. Organizations keen to acknowledge the shift in meaningful work may mitigate the negative effects and promote positive meaning when possible. Though, improving meaning in work is not a simple and straight-forward process. Lips-Wiersma and Morris (2009) have noted that overt management techniques designed to elicit meaning in work may be views as disingenuous and manipulative. Instead, employers may consider other aspects of the job, such as improved job and task design to include skill enhancements, recognition for superior performance, and adding challenging tasks fit to workers expectations, as these qualities of work have been shown to be important for workers with contingent work arrangements (Bush & Balven, 2021).

Future Research

Limitations of this study include contaminating effects and possible misspecification. The survey was deployed during a particularly volatile time, September of 2020. The Covid-19 pandemic changed the work lives of many individuals and likely influenced personal attitudes and perceptions of work. One's assessment of meaningful work is not a continuous psychological state but may be altered by temporal events (Bailey & Madden, 2016; Allen et al., 2019).

While this research presents important findings regarding the differences between different types of workers, there are still important considerations for future research. This study did not consider why our subjects were engaging in contingent work arrangements. We know workers engage in contingent work arrangements for a variety of reasons, such as economic necessity, ambition, and flexibility (Keith et al., 2020). If a worker is contingent by choice, rather than by necessity, then how they derive meaning from their work is likely to be different.

Furthermore, meaningful work is impacted by individual perceptions of status, belonging, and fairness. Lysova and colleagues (2019) discuss how an individual may devalue their work when they are provided lower status or insufficient pay. With a contingent work arrangement, the company signals the position is not worthy enough for a permanent role. In much the same way, the company signals the worker is peripheral, and may not belong as part of the formal organization (Schnell et al., 2019). Additionally, Lips-Wiersma and colleagues (2020) found meaningful work is impacted by perceptions of fairness and worthy work. It is likely the type of employment arrangement will inhibit different perceptions of fairness. These individual variables, along with motivations of contingent workers, are important directions for future research.

CONCLUSION

This is one of the first studies to consider how men and women differ in how meaningful work is observed, particularly in the realm of paid work. While a greater understanding is needed to understand why men and women report levels of meaningful work, this research identifies a need for further research. This research also explores the concept of meaningful work beyond the organization, but also in terms of societal (worker arrangement) and individual (gender) levels of analysis, which has been called for by prominent scholars (Lysova et al., 2019). As we see the connection between employer and employee erode, in terms of benefits, proximity, and loyalty, we are called to better understand how our new psychological contracts will impact meaningful work for the most precarious workers.

APPENDIX

Appendix A. *Sample Descriptive Statistics*

Variable (significance across groups)	Alternative	Traditional	Total
Gender (0.947)			
Male	48 (24%)	48 (24%)	96 (48%)
Female	53 (26%)	52 (26%)	105 (52%)
Age (0.116)			
18-24	20 (10%)	8 (4%)	28 (14%)
25-34	31 (15%)	30 (15%)	61 (30%)
35-44	28 (14%)	42 (21%)	70 (35%)
45-54	16 (8%)	15 (7%)	31 (15%)
55-64	6 (3%)	5 (2%)	11 (5%)
Race (0.355)			
White	66 (33%)	77 (38%)	143 (71%)
Black	18 (9%)	11 (5%)	29 (14%)
Hispanic	9 (4%)	3 (1%)	12 (6%)
Multiracial	3 (1%)	3 (1%)	6 (3%)
Other	5 (2%)	6 (3%)	11 (5%)
Education (0.906)			
High School	14 (7%)	16 (8%)	30 (15%)
Some College	30 (15%)	16 (8%)	46 (23%)
Undergraduate Degree	18 (9%)	35 (17%)	53 (26%)
Graduate Degree	37 (18%)	33 (16%)	70 (35%)
Other	2 (1%)	0 (0%)	2 (1%)
Total annual income (0.110)			
Less than $30,000	31 (15%)	20 (10%)	51 (25%)
$30,000-$59,999	31 (15%)	29 (14%)	60 (30%)
$60,000-$119,999	19 (9%)	30 (15%)	49 (24%)
$120,000 or more	20 (10%)	21 (10%)	41 (20%)
Industry (0.384)			
Educational Services	5 (2%)	6 (3%)	11 (5%)
Healthcare and Social Assistance	6 (3%)	12 (6%)	18 (9%)
Arts, Entertainment, and Recreation	6 (3%)	2 (1%)	8 (4%)
Accommodation and Food Services	7 (3%)	4 (2%)	11 (5%)
Construction	12 (6%)	9 (4%)	21 (10%)
Information	8 (4%)	12 (6%)	20 (10%)

Finance and Insurance	8 (4%)	8 (4%)	16 (8%)
Professional, Scientific and Technical Services	15 (7%)	2 (1%)	17 (8%)
Agriculture, Forestry, Fishing, and Hunting	3 (1%)	0 (0%)	3 (1%)
Mining, Quarrying, and Oil and Gas Extraction	0 (0%)	0 (0%)	0 (0%)
Utilities	3 (1%)	0 (0%)	3 (1%)
Manufacturing	3 (1%)	5 (2%)	8 (4%)
Wholesale trade	2 (1%)	0 (0%)	2 (1%)
Retail trade	6 (3%)	5 (2%)	11 (5%)
Transportation and Warehousing	5 (2%)	5 (2%)	10 (5%)
Real Estate and Rental and Leasing	1 (0%)	1 (0%)	2 (1%)
Management of Companies and Enterprises	1 (0%)	2 (1%)	3 (1%)
Administrative and Support and Waste Management and Remediation Services	1 (0%)	1 (0%)	2 (1%)
Public Administration	4 (2%)	4 (2%)	8 (4%)
Other	12 (6%)	15 (7%)	27 (13%)

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Mediating Role of Competitive Advantage in Enhancing the Innovation Capabilities of Social Enterprises: A Conceptual Framework

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ABSTRACT

This paper highlights the strategies of social media marketing and the personality traits of entrepreneurs to build the capabilities among students with the aim of producing competitive leadership for Saudi Arabian institutions to gain competitive advantage in the region. The study will focus on the tactics of innovation in digital landscape to transform the community from traditional economic system to more advanced digital era. To date, empirical research examining the effects of social advertising and entrepreneur personality traits on the innovation capabilities of social enterprises remains scanty. Therefore, this paper tries to develop a conceptual model to examine these relationships.

KEYWORDS: Social Advertising, Personality Traits, Competitive Advantage, Innovation, Saudi Arabia

INTRODUCTION

In today era, the drastic innovation, competitive market, and globalization have created challenges for industries (Sun et al., 2016; Remane et al., 2017). Thus, firms have started search for unique, differentiated, and innovative strategies to gain competitive advantage and survive in the intensified environment (Sun et al., 2016; Anwar, 2018). In such circumstances, social advertising, entrepreneur personality traits can work as driving forces to gain competitive advantage and rapid innovation. Social advertising is a recently emerged trend in marketing due to social media around the world and is the process of gaining traffic towards social networking sites via contents to attract audience attention (Rehman, 2019; Esther et al., 2015). It is the newest internet based digital advertising system, has gained popularity around the globe, reduced consumer's anxiety, and became one of the world-leading marketing platforms to share real-time business information (Eze et al., 2021; Dwivedi et al., 2021; Hadija et al., 2012).

This study intends to evaluate the influence of social advertising, personality traits, and competitive advantage on the innovation capabilities of social enterprises amid mediation of competitive advantage.

Objectives of the Study are:

1. To determine the relationship between social advertising (informative, entertainment, credibility, privacy, contents) and the innovation capabilities of social enterprises in Saudi Arabia.

2. To determine the relationship between personality traits of entrepreneurs (market maven, stability, open minded, agreeable, and materialism) and the innovation capabilities of social enterprises in Saudi Arabia.
3. To examine the relationship between competitive advantage (differentiated strategy, cost leadership strategy) and the innovation capabilities of social enterprises in Saudi Arabia.
4. To examine the relationship between social advertising (informative, entertainment, credibility, privacy, contents) and the competitive advantage of social enterprises in Saudi Arabia.
5. To determine the relationship between personality traits of entrepreneurs (market maven, stability, open minded, agreeable, and materialism) and the competitive advantage of social enterprises in Saudi Arabia.
6. To assess the mediating role of competitive advantage between social advertising and the innovation capabilities of social enterprises in Saudi Arabia.
7. To assess the mediating role of competitive advantage between personality traits of entrepreneurs and the innovation capabilities of social enterprises in Saudi Arabia.

To achieve these objectives, we will need to conduct a study among the social enterprises of Saudi Arabia to clarify the above objectives. Hence, this study will contribute to the relevant literature by evaluating the effects of social advertising and personality traits of entrepreneurs on the innovation capabilities of social enterprises amid mediation of competitive advantage. This study will merge the literature of social advertising, personality traits of entrepreneurs, innovation capabilities of social enterprises, and competitive advantage based on the findings from Saudi Arabian economy and validating the proposed research model. The application of PLS-SEM in the proposed research model will also be a novel contribution.

LITERATURE REVIEW

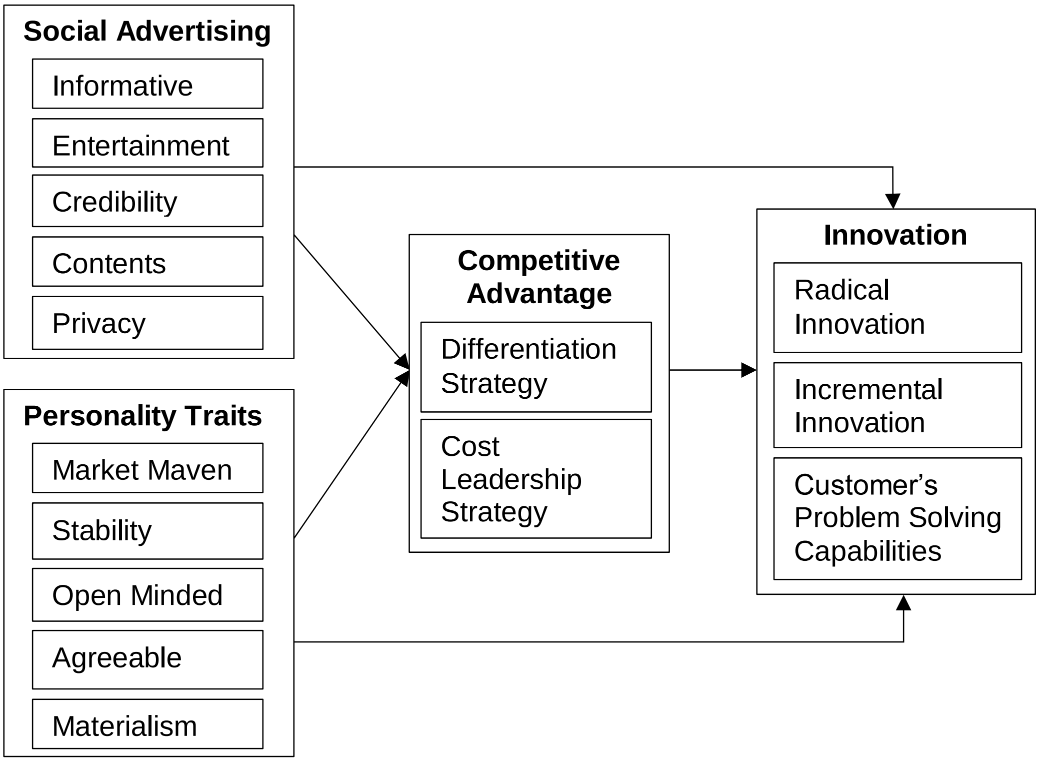
Social advertising is the arena that has received ample attention in recent literature and widely accepted among communities (Soares & Pinho, 2014). However, empirical research of social advertising in the context of innovation is still rare. Whereas, personality traits are the unique characteristics of entrepreneur that can enhance innovation and competitive advantage at firm level. Studies (Goldberg, 1999; Woods et al., 2017) have examined the effects of personality traits on innovation, widely focused on openness and conscientiousness but still atypical to examine market maven, stability, agreeable and materialism. Therefore, examining the effects of social advertising and entrepreneur personality traits on the innovation capabilities of social enterprises amid mediation of competitive advantage could be a novel contribution and can attract literature attention towards this part of the world. Hence, this study is theoretically approaching to find the answers of the following raised research questions.

1. Firstly, to what degree do social advertising, personality traits of entrepreneurs and competitive advantage affect the innovation of social enterprises?
2. Secondly, to what extant do social advertising and personality traits of entrepreneurs effect the competitive advantage of social enterprises?
3. Thirdly, does competitive advantage mediate the relationship between social advertising, personality traits with the innovation capabilities of social enterprises?

MODEL

Conceptual model provides a logical structure to connect different conceptions in a visual picture to understand the identified research phenomenon. In this study, social advertising, personality traits, and competitive advantage are proposed as independent variables, competitive advantage also as mediating variable and the innovation of social enterprises as dependent variable.

Figure 1: Conceptual Framework



METHODS

The respondents of this study will be the owners and senior managers of social enterprises in Saudi Arabia. Sample size will be calculated via G-Power, as Hair, Hult, Ringle and Sarstedt (2014) have highly recommended G-Power in PLS – SEM studies. Random sampling technique will be applied to collect data in personal way through questionnaire based survey. The collected data will be analyzed using PLS-SEM to analyze results. Questionnaire will be adapted and adopted for all the instruments of four constructs. This study will analyze the collected data through (Smart PLS 3 version 26 software) smart partial least square structure equation modeling to find results. PLS-SEM has the advantage to offer a systematic mechanism for validation of relationship among different constructs and allow testing all the relationship only in single model (Tabachnick & Fidell, 2001; Hair et al, 2006). It has also the advantage to deal with the complex models (Tabachnick & Fidell, 2001; Hair et al, 2006), and do not require normality of data distribution, no sample size restriction, can accommodate nominal, ordinal and continuous scale, and estimates multicollinearity problem (Henseler & Sarstedt, 2013). The choice of PLS-SEM over other methods is due to the nature of research problem, hypothesis, formative style of the model and predictive nature of the study.

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DECISION SCIENCES INSTITUTE
Mediating Role of Supply Chain Collaboration in Blockchain Adoption

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ABSTRACT

Organizations deploy blockchain to conduct transactions, transparently. Limited empirical investigation has focused on the drivers of blockchain adoption, which stem from supply chain collaboration. We advance this research stream using the lenses of resource dependency and social network theories. Collaborative relationships and organizational position in the supply chain network are crucial for the organizational blockchain adoption. All of our hypotheses are supported through a cross-sectional survey of supply chain professionals in blockchain domain. We add to the knowledge of complementary nature of resource dependence and social network theories and provide insights to supply chain practitioners seeking to collaborate through blockchain.

KEYWORDS: Blockchain Adoption; Supply Chain Collaboration; Prominence

INTRODUCTION

Blockchain is termed as the next digital revolution (Kamble et al., 2019). Australia's top banks have joined hands with IBM to revolutionize risk management in banking through blockchain technology (Shetty, Niyati; Nainan, Nikhil, 2019). Government of Dubai has ushered in the era of blockchain through its initiative of "Smart Dubai" aiming to streamline its operations and bring seamless, safe and efficient experiences for its citizens ("Smart Dubai - Blockchain,"). In recent years, organizations have begun to realize the importance of open standard inter-organizational information systems, such as blockchain, although enterprise resource planning systems continue to contribute in efficient execution of interorganizational transactions (Zhu, Kraemer, Gurbaxani, & Xu, 2006). This has resulted higher organizational efforts to leverage supply chain collaborations in adopting blockchain (Gulati, 1998). Blockchain supports the integration of information management capabilities and business processes of the organization (Kshetri, 2018). Systems such as blockchain have started to permeate in global supply chains, recently, (Paulraj, Chen, & Lado, 2012; Sodero, Rabinovich, & Sinha, 2013) and the research world is getting familiar with factors that lead organizations to adopt such systems. Blockchain is a peer-to-peer asset database shared across various sites, regions or institutions (Kamble et al., 2019). It can validate, record, and disseminate transactions in encrypted ledgers (Kamble et al., 2019). Extended visibility and traceability, supply chain digitization and disintermediation, increased data security, and smart contracts are some of the reasons for organizations to use blockchain. It's suitable for dynamic supply chains that demand global collaboration (Y. Wang, Han, & Beynon-Davies, 2019).

Extant research has investigated blockchain from standpoints of its capabilities, influence on supply chain resilience, adoption and use cases in sectors such as finance (Risius & Spohrer, 2017). Researchers have also studied blockchain as a mechanism to share information, applying theoretical lenses, such as transaction cost economics, contingency theory, resource-based view, resource dependency theory and relational governance theories (Kembro, Selviaridis, & Näslund, 2014). Past research has indicated that open standard information systems, such as blockchain, can orchestrate interorganizational exchanges between more than two organizations across the boundaries of a variety of business processes (Zhu et al., 2006). Predominant empirical studies are founded on perceptual measures from cross-sectional surveys, and qualitative data from case studies and they capture managerial beliefs, intentions, and expectations behind the adoption of technology (Sodero et al., 2013). We find they can be enriched by investigating the inherent dynamic relational factors, such as organizational network prominence and supply chain collaboration between organizations as drivers of blockchain adoption (Bala & Venkatesh, 2007). Also, majority of studies have measured innovation of the organization in terms of several patents filed by the organization (Schilling, 2015). We distinguish blockchain adoption to be another measure of organizational innovativeness since it reflects the aggressive organizational efforts in present times to create huge impact on ways of conducting business.

Thus, considering the dyadic view of supply chain collaboration, we find scope to investigate factors that stem from the relationships, which are formed because of partnerships, joint ventures, alliances, supplier-customer liaisons, etc. The dynamics between source organization and target organization suggests an impact on the adoption of blockchain. Since the blockchain adoption status of the source organization matters for the target organization, in deciding on blockchain adoption (Zhu et al., 2006), we define source organization as the one that has adopted blockchain and is on the initiating end of the collaboration, and target organization is the one on the receiving end. In other words, a source organization initiates information exchange, to leverage its adopted blockchain, while a target organization receives it. Specifically, our study examines following research questions:

Does network structural position of the source organization influence the adoption of the blockchain by the target organization?

Does supply chain collaboration influence the adoption of blockchain by the target organizations?

We answer above research questions by grounding our hypotheses in resource dependency and social network theories and test them through a single respondent cross-sectional survey data. In doing so, we contribute to the extant supply chain management research in various ways. First, we advance understanding of the overlap between resource dependency and social network theories, as has been advocated and justified by scholars (Hillman et al., 2009). Second, we introduce new perceptual measures of network prominence, with organization as the unit of analysis, to complement the existing quantitative metrics commonly used in social network research. Third, we contribute to a new research stream focused on a expanding blockchain adoption by investigating the underlying relational drivers.

In this paper, we present a brief review of recent research focused on blockchain adoption, build theoretical foundations, define focal constructs, and develop hypotheses. We then present our results, discuss key findings, identify significant implications to theory and practice, acknowledge limitations, and recommend future research directions.

LITERATURE REVIEW

Blockchain Adoption

Past research on organizational information systems falls in two broad channels – adoption and governance. Researchers have found that adoption of an information system is a result of trust, power differences between supplier and buyer, data transmission needs, organizational pressures, and organizational ability to accept change (Chwelos, Benbasat, & Dexter, 2001; Premkumar et al., 1994). On the other hand, governance through information systems is affected by information technology infrastructure and organizational ability to integrate this infrastructure with its supply chain partners (Malhotra, Gosain, & Sawy, 2005; Subramani, 2004). Extant research has examined the adoption of technology by organizations through different lens. The past studies are mainly based on theories such as resource dependency theory (Hart & Saunders, 1998), transaction cost theory (Son, Narasimhan, & Riggins, 2005), diffusion of innovations theory (Premkumar et al., 1994), institutional theory (Sodero et al., 2013), information processing theory (Kim & Umanath, 2005) and social network theory (Zhao, Xia, & Shaw, 2007).

Transparency and improved tracking have a significant influence on any supply chain. Kshetri (2018) investigated the use of blockchain in achieving SCM goals. The study projected, using the example of farmers, that the adoption of blockchain technology by one organization would exert pressure on other supply chain actors. Nakasumi (2017) suggests implementing a blockchain-based strategy to tackle conventional supply chain issues including information asymmetry. Korpela, Hallikas, and Dahlberg (2017) explore how blockchain integration may enable digital supply chain transformation by bridging the gap between business preparedness and existing features utilizing blockchain as a cost-effective and adaptable cloud-based integration platform (Korpela, Hallikas, & Dahlberg, 2017). Tian (2017) suggests an architecture for online shipment tracking based on a privately distributed ledger and a single public block chain ledger. According to the report, IoT and blockchain will have a significant impact on manufacturing of the future generation. Omran et al. (2017) provide a framework for a blockchain-driven supply chain financing solution (Omran, Henke, Heines, & Hofmann, 2017). Blockchain is recommended as the most promising approach to achieve supply chain effectiveness, visibility, and independence.

Research on organizational blockchain adoption is evolving, with scholars concentrating on unified theory of acceptance and usage of technology (Queiroz et al., 2021), information sharing and trading partner pressure (Wamba et al., 2020), diffusion of innovations theory (Wamba et al., 2020), technology acceptance model (Karamchandani et al., 2020), and two levels – individual and organizational. In agriculture supply chains, cost reduction, data exchange and security drives blockchain adoption for visibility of goods (Kamble et al., 2020). Blockchain adoption is driven by the support of top management and organizational readiness, particularly in large organizations (Clohessy and Acton, 2019). Organizational intention to use blockchain is influenced by its complexity, cost and relative advantages, through the lenses of the TOE (Technology-Organization-Environment) framework (Wong et al., 2020). "Perceived usefulness" has emerged as a key factor in blockchain adoption by supply chain professionals (Kamble et al., 2019). Promise of blockchain in the pursuit of continuous improvement in functional roles of supply chain professionals has been stimulating towards adopting blockchain at an individual level (Queiroz and Wamba, 2019). Even though these theories enlighten us on the factors that drive organizational blockchain adoption, extant research lacks insights on the role of relational factors, such as organizational network prominence and supply chain collaboration, on driving the blockchain adoption.

Resource Dependency Theory

Pfeffer and Salancik (1978) identify the key assumptions underlying the theme of Resource Dependency Theory: the social organization possesses some resource; the resource is considered critical by the organization for its continued survival; organizations possess self-autonomy; despite being a social organization, it has no external pressure in allocation of resources; the organization in position of influence, such as at the focus of a network, is discrete in exercising its capability to act; however, the resources, which are deemed critical for the organizational survival, are not in complete control of the focal organization; and, other organizations, being a set of social actors, are able to communicate its preferences to the focal organization (Pfeffer & Salancik, 1978). To understand the mechanism behind supply chain collaborations, and the resulting network, resource dependency theory investigates at the organizational unit of analysis (Pfeffer & Salancik, 1978). Organizations lack autonomy in collaborative networks as they bound by interdependencies. External reliance and uncertainty in behavior of partner organizations fuel speculations about organizational survival. Therefore, organizations act to limit outside dependence, leading to modification of supply chain collaboration network (Hillman et al., 2009).

According to Heide (1994), inter-organizational dependence is crucial in the development of relational structures (Heide, 1994). Unilateral dependence can create asymmetric contributions by the organizations in the collaborative relationship and can increase the chances of opportunistic behavior, while, in bilateral dependence, both the organizations in the collaborative relationship allocate equal resources, and establish a mutual commitment towards each other (Heide, 1994). Applying the resource dependency theory, Mitra & Singhal (2008) find that higher bargaining power and process efficiency bring together organizations in a supply chain (Mitra & Singhal, 2008). Bendoly et al. (2007) investigate the role of interaction of organization's internal capability and interorganizational forces in the adoption of technology (Bendoly, Rosenzweig, & Stratman, 2007). Street & Goldsmith (2004) examine the influence of interorganizational relation type on the ability of organizations to adopt new technology (Goldsmith Ronald E., 2004). In the healthcare industry, McNally (2006) investigates the link between acquisition of resources and performance of the acquiring organization (McNally, Smith, & Barnes, 2006). Blockchain adoption enables leveraging of resources for organizations that are interdependent.

Social Network Theory

A social network comprises of a finite set of actors and the relations defined amongst those (Wasserman & Faust, 1994). The network thinking paradigm uses structural and relational information to test theories by specifying the phenomenon of interest in terms of patterns of relationships (Wasserman & Faust, 1994). Scott and Davis (2007) provide a good understanding of network-based research, which has a long history in sociology, analyzing dyads and triads at large (Scott & Davis, 2007). The role of a mediating actor in a triad can be that of a broker, an arbitrator or a spoiler. Networks are typically classified based on their origin such as family, friendships or board interlocks (Gulati & Westphal, 1999). They are measured at three levels – ego network, overall network and network position. An ego network consists of a focal actor that is directly connected to all other actors. The overall network encompasses all actors and relationships. A network position identifies actor's coordinates within the network's topography. Networks are viewed as pipes that channel information flows and prisms that refract an actor's social position, indicating actor's attributes such as endorsement, status or legitimacy. Types of interorganizational networks are stable network, which is usually observed in mature industries as a result of long-lived relationships, and dynamic network, which is representative of industries with short product lifecycles. Organizations forge alliances based on attractiveness or prior history of relationships. They further influence organizational performance in terms of innovation and operational efficiency (Scott & Davis, 2007).

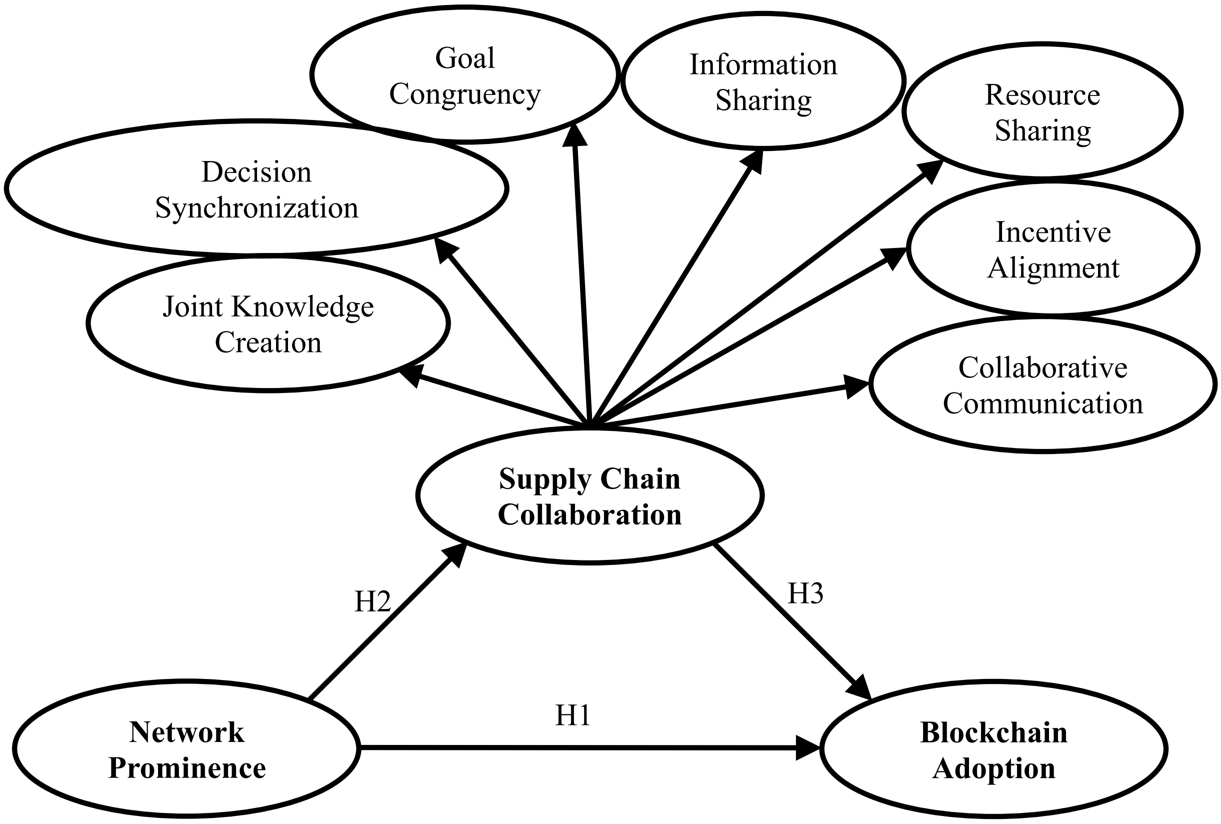
Past research that has used Social Network Theory to explain supply chain phenomenon includes various studies. For example, a partners' position is critical in the social network in the supplier selection process in the automotive industry (Choi et al., 2002). Supplier network size impacts the performance of the organization (Terpend & Ashenbaum, 2012). Notable studies explore network operating structure (Choi & Hong, 2002), network embeddedness (Choi & Kim, 2008) and triadic network relationships (Choi & Wu, 2009) in supply chain management literature. The key to organizational performance, in a network, is the access to information and resources, resulting in reduced uncertainty, risk and opportunism. Organizations leverage their networks by building structural capital through focus on the benefits incurred by the actors occupying central positions in the network. The access to resources is vital since actor's success is assumed to be the result of the quality and quantity of the resources controlled by the actor's connections (Borgatti & Foster, 2003). Interorganizational network effects are also observed in terms of social embeddedness, wherein the context of social relationships influences organizational behavior and economic outcomes through relational or structural embeddedness, as a result of dyadic trust between organizations and its reinforcement through collaborations. Organizations also view their network in terms of social capital, in which it derives benefits by virtue of membership of the network (Gulati, Lavie, & Madhavin, 2011).

From the perspective of social network theory, Carnovale et al. (2014) have examined the formation of a new joint venture between manufacturing organizations by empirically testing attributes of network structure, comprised of collaborative partnerships between manufacturing organizations (Carnovale & Yeniyurt, 2014). Researchers have investigated "social capital" (Oh, Chung, & Labianca, 2004), inter-organizational learning (Borgatti & Rob Cross, 2003), "supplier embeddedness" (Choi & Kim, 2008), complexity and trust in strategic alliances (Robson, Katsikeas, & Bello, 2008) and "social commerce networks" (Stephen & Toubia, 2010). The centrality of the organizations is found to influence the growth of the organization through inter-organizational learning network formation (Ahuja, 2000).

THEORETICAL DEVELOPMENT

Figure 1 presents our research model. In this section, we ground our hypotheses in resource dependency and social network theories.

Figure 1: Research Model



H4: Mediating Role of Supply Chain Collaboration (Network Prominence → Supply Chain Collaboration → Blockchain Adoption)

Network Prominence and Blockchain Adoption

A social network consists of actors connected by links, or nodes, and can be directed or undirected, binary or weighted (Borgatti & Foster, 2003). Social cohesiveness impacts actors' willingness and motivation to share knowledge, since network range boosts their ability to explain complicated concepts (Reagans & McEvily, 2003). Network prominence can influence actor perceptions by defining status or position in the broader social environment or attributing organizational performance to social influence communicated through particular connections (Gulati, 1998). Social impacts on perceptions might come from individuals' greater structural framework or their immediate social milieu (Ibarra & Andrews, 1993). Indirect alliances between two organizations boost the likelihood of a new partnership. Positional embeddedness reflects how organizations' places in the alliance network structure affect new cooperative partnerships. Network structural position is the location of an organization in its social network, assuming it may leverage its position through direct and indirect links and is influenced by other organizations in the network (Gulati & Gargiulo, 1999). We define "network prominence" as an organization's ability to influence positive outcomes for itself and others. Organizations with greater prominence in the network have access to information with greater prominence (Koka et al., 2008).

One of the prime purposes of an organization’s existence is to establish collaborations with other organizations through interactions and exchanges (Oliver, 1990). Organizations do this by coordinating interactions with multiple organizations to accomplish goals that may otherwise be difficult to attain, individually. According to Social Network Theory (Wasserman & Faust, 1994), these collaborative relationships matter as they provide vital channels that enable social exchanges. In addition, the structure that arises out of these relationships matter, too, as it creates opportunities and constraints not just for the organizations in a particular position but also the organizational network as a whole. A social network comprises of set of actors and the collection of ties among those actors (Ahuja, 2000). Applying this metaphor, organizations can be identified as actors and the ties between them as collaborative relationships. Some organizations will have a comparatively higher number of direct collaborative relationships or immediate connections with other organizations. So, as per social network theory, they will incur higher power over other organizations. They will be positioned in the prominent portion of the supply network, and this will create further opportunities for them to collaborate with other organizations. This prominent organization can exert its influence on other organizations in the adoption of blockchain. Also, social network theory offers greater importance to the ties above the actors involved in the ties. Thus, social network theory is suitable to examine the inter-organizational relationships to explain the phenomenon of organizations collaborating through blockchain adoption (Zaffar et al., 2014). Sociometry involves the study of the interactions between multiple organizations (Granovetter, 1973) and results in the formal construction of these interactions. Frequent interactions between two organizations result in establishing of collaborative relationship in those organizations. These interactions are documented through multiple business transactions between the organizations. Extant research has indicated the importance of network structure in forming of new collaborative relationships (Zaheer, Gözübüyük, & Milanov, 2010). These relationships are a critical organizational resource as they eventually result in gaining competitive advantage for the organization (Gulati & Gargiulo, 1999). Complex supply chain will result in a complicated network because of a huge number of organizations involved and a wide variety and magnitude of relationships between those organizations. Each organization in such network intends to identify and engage in new collaborations while preserving the existing ones (Carnovale & Yeniyurt, 2014).

Organizations can be structurally operationalized through prominence since it quantifies the position of an actor in a social network relative to other actors (Borgatti, 2005). The higher prominence of an organization will result in a higher structural power of that organization over other organizations in the social network (Carnovale, Yeniyurt, & Rogers, 2017). This interconnectedness will provide access to resources of other organizations, and prominent

organizations can control the allocation of resources (Burt, 2004) and carry higher power to bargain (Crook & Combs, 2007). The source organization that is intending to initiate a collaborative relationship with the target organization will benefit from a more prominent position in the social network. A prominent source organization will be better able to drive coordination of the information distribution channel with the target organization. Thus, a more prominent source organization will be better able to convince its target organization to adopt blockchain. Hence, we hypothesize –
H1 – Network prominence is positively associated with organizational blockchain adoption.

Supply Chain Collaboration and Blockchain Adoption
Supply chain collaboration is the extent to which organizations engage in reciprocal interactions (Ki-Hyun Um, & Jae-Young, O., 2020). This study, in accordance with Cao and Zhang (2010), draws on seven well-established characteristics of supply chain collaboration. First, the extent to which parties disclose information about exchanges is referred to as "information sharing," which is further characterized by suitability, accuracy, thoroughness and confidentiality (Ki-Hyun Um, & Jae-Young, O., 2020; Sheu et al., 2006; Cao and Zhang, 2010). Second, "goal congruence" refers to the degree to which supply chain partners value shared goals beyond their own, motivating them to explore harmonized alternatives in congruent paths (Ki-Hyun Um, & Jae-Young, O., 2020). Third, "collaborative communication" refers to the methods of message delivery that are clear, consistent, and structured (Ki-Hyun Um, & Jae-Young, O., 2020; Goffin et al., 2006). Fourth, "incentive alignment" refers to the degree to which involved parties share earnings and liabilities evenly and equitably, in relation to their obligations (Ki-Hyun Um, & Jae-Young, O., 2020; Simatupang and Sridharan, 2005). Fifth, "decision synchronization" refers to joint decision-making processes in planning and operations that incorporate all pertinent data to attain an equitable consensus (Ki-Hyun Um, & Jae-Young, O., 2020; Um and Kim, 2019; Zhang and Cao, 2018). Sixth, "resource sharing" (Zhang and Cao, 2018) refers to the level to which one party's competencies and assets are readily deployed to other partner, allowing both to expand their accessibility to external means (Ki-Hyun Um, & Jae-Young, O., 2020; Um and Kim, 2019). And seventh, "joint knowledge creation" enables supply chain stakeholders to cooperate on the discovery and accumulation of fresh knowledge in order to more effectively react to evolving markets, culminating in greater agility and financial performance (Ki-Hyun Um, & Jae-Young, O., 2020; Cao and Zhang, 2010).

Collaborative relationships provide strategic advantages to organizations (Kanter, 1994) and add value in organizational business strategy (Kay, 1993). Thus, collaborative relationships are gaining momentum as organizations strive to survive as they compete amongst themselves, and take multiple forms between coercive buyer-supplier relationships to strategic alliance (Webster, 1992). Organizations collaborate out of compulsion as well as choice. Resource based view of the organization (Wernerfelt, 1995) or resource dependency theory (Pfeffer & Salancik, 1978) support the former motivation and reason that compulsion to collaborate arises out the necessity to exchange resources. On the other hand, organizations collaborate, willingly, as evident from many research and development alliances (Sampson, 2007).
Theoretical schools, which take economic view of interorganizational exchange, include agency theory (Ross, 1973), and transaction cost economics (Williamson, 1981) and posit that organizations seek independence by exploiting their influence over related organizations. In addition, theoretical schools based on interorganizational relationship behavior include social exchange (Granovetter, 1985) and investigated collaborative relationships as a social contract (Oliveira & Lumineau, 2018). Thus, it appears that collaborative relationships are a result of social processes (Hakansson, 1982), characterized by trust, commitment and mutuality, as well as, transaction content, stemming out of power, opportunism and risk (Donaldson & O' Toole, 2000). Being consistent with Bradach and Eccles (1989), behavioral and economic approaches should be combined to investigate collaborative relationships since interactions are driven by multiple

factors such as price, authority and trust (Bradach & Eccles, 1989). Granovetter (1973) identifies four properties of a strong relationship: Amount of time, emotional intensity, intimacy (mutual confiding), and reciprocity (Granovetter, 1973). Strong ties have greater motivation to be helpful and are more easily available and they are more important in environments of severe change or uncertainty (Granovetter, 1973). Organizations form collaborative relationships when they interact with each other, have a mutual liking or shared interests and have a history of mutual exchanges at various levels (Granovetter, 1985). Such collaborative relationships generate interorganizational trust and reduce malfeasance (Terpend & Ashenbaum, 2012). We, thus, hypothesize –

H2 – Network prominence is positively associated with supply chain collaboration.

Applying the Resource Dependency Theory perspective (Hillman et al., 2009; Pfeffer & Salancik, 1978), organizations in an open system transact with each other as they are dependent on each other for resources vital for their own survival. These resources comprise of inputs required to manufacture products and sell them as per market demand at minimum possible costs. One vital resource inter-dependent organizations require is trustworthy information in various dimensions such as product specifications, market demand, manufacturing capabilities, and schedules, etc. As organizations have different levels of information, their relationship is not balanced and creates power dependence of one organization over the other. This leads the source organization to exercise its influence on the target organization by exploiting dependency in their relationship. Furthermore, a source organization strives to minimize its own operational constraints, which will lead to a reduction in uncertainty on its returns on investments in innovations, by fostering collaboration with the target organization. This increased interdependence between organizations helps both the entities in the collaborative relationship to gain competitive advantage. Blockchain, being an inter-organizational system that is based on the consensus of the participating organizations, can be viewed in the light of Resource Dependency Theory. When the target organization adopts blockchain, it benefits the source organization, too, as both the organizations share information resource and consequent ability. Such relationships provide substantive benefits when the participating organizations collaborate (Ahuja, 2000). They increase organizational knowledge through sharing (Kogut, 1988), fuse complementary skills of the two different organizations (Arora & Gambardella, 1990) and leverage economies of specialization which otherwise will require higher investments when done independently by any organization (Ahuja, 2000). All these benefits are featured in blockchain. Thus, organizations in a collaborative relationship are more likely to enjoy benefits of the blockchain when target organization adopts blockchain. Thus, we hypothesize that –

H3 – Supply chain collaboration is positively associated with organizational blockchain adoption.

Mediating Role of Supply Chain Collaboration

While social network and resource dependency theories, both, emphasize the importance of collaborative relationships, social network theory further stresses on the relative structural position of the actors in the social network. Combining the perspectives of both the theories explains the behavior of the target organization that adopts blockchain. Applying the Model of Diffusion on Social Networks (Jackson & Yariv, 2005), the choice of an actor to adopt is based on multiple factors. First, the target organization will look for the most prominent source organization or the one which has the greatest number of ties in the social network. Just as the source organization is concerned about reducing its uncertainty, so is the target organization. Second, just as source organization has choices to select a target organization, so does the target organization since collaboration is a mutual interorganizational process. Thus, target organization will examine responses of stimuli of the source organizations, which approach it for collaboration needs. This examination will be characterized by cost-benefit tradeoffs for both the organizations, source, and target. Third, prominent source organization is looked upon by several other actors in the social network by tracking its actions and initiatives. Similarly, a target organization, even if it is located on the periphery of the social network, is researched by the source organization for the potential success of the collaboration. Lastly, an individual organization's decision whether to adopt blockchain will depend on the possible actions of its peers. If a target organization finds that its peers are looking at the similar set of source organizations, it is more likely to accept the advances of those source organizations. Such popular source organizations are expected to be highly central in the social network.

This argument is further supported with the combination of "reach" and "receptivity" (Gulati et al., 2011). Organizations will benefit from access to a combination of a diverse set of resources acquired not only via inter-organizational relationships but also structural positions. Reach implies possible target organizations for the source organization, to acquire resources, while receptivity implies building effective ways to channel those resources. In other words, a target organization will look at the reach and receptivity of the source organization, when gauging the capability of the source organization in building an effective collaborative channel of information exchange. Since receptivity moderates the effect of reach on organizational performance (Gulati et al., 2011), it is likely that target organization will check for the most prominent source organization in the social network and will evaluate the quality of its collaborative relationship with each potential collaboration source organization. We, thus, hypothesize –

H4 – Supply chain collaboration mediates the association of network prominence and organizational blockchain adoption.

METHODOLOGY

Sample

This study uses a cross-sectional survey to collect data from supply chain professionals in the US. Desired respondents were those individuals currently working in various functions in the supply chain domain because they are generally cognizant of the intricacies of managing inter-organizational relationships and often stay abreast of innovative technologies in organizational operations.

The usage of Amazon's Mechanical Turk (MTurk) for the online survey has dramatically increased in the previous few years (Walter, Seibert, Goering, & O'Boyle, 2019). Our study used MTurk to gather data and follows the recent recommendations to mitigate resulting validity threats (Aguinis, H. et al., 2021). Our data collection method comprised of multiple attention checks and stringent screening criteria, as exhibited in the appendix. The survey was deployed in the form of a HIT (Human Intelligence Task) that was readily accessible to MTurk participants. A Human Intelligence Task, or HIT, is an unanswered inquiry or, in other words, a single, self-contained virtual job that a respondent can complete by working on it, submitting an answer, and collecting a reward (Aguinis, H. et al., 2021). This helped minimize signs that would reveal the study's intentions to MTurkers, or encourage self-deception or social desirability bias.

Our survey collected data from single respondents from organizations of various sizes and across a broad array of industries. This is critical to our study since it is based on a sparse population familiar with futuristic innovations, such as blockchain (Montabon, F. et al., 2018). Initially, 1965 individuals consented to participate in our study. Screening across seven criteria (see table 2) and random three attention checks resulted in a final sample of 150 responses. Recent scholarly recommendations abandon the reporting "response rate" in research involving online panel surveys (Baker et al., 2010) and prescribe using "eligibility rate" and "completion rate." The eligibility rate is calculated by dividing the number of questionnaire attempts by the fraction of respondents who cleared to advance (Baker et al., 2010). The completion rate shows how many respondents started, approved for, and finished the study (Bethlehem and Biffignandi, 2012). Based on the recommendation and formula for calculation, our study's eligibility rate was 14.9%, while the completion rate was 51.1% (Brazhkin, V., 2020). Table 1 and 2 provide details about sample demographics and screening criteria, respectively.

Table 1 – Sample Demographics

Organization Size (No. of employees)	*Frequency*	
100 - 249	45	30%
250 - 499	31	21%
500 - 749	26	17%
10 - 99	16	11%
1000 or more	16	11%
750 - 999	13	9%
Under 10	3	2%
Sample Size	150	100%

Respondent Industry	*Frequency*	
Information Technology	35	23%
Electronics	23	15%
Manufacturing	23	15%
Banking/ Finance	17	11%
Healthcare	12	8%
Food/Beverages	8	5%
Automotive	6	4%
Transportation/ Logistics	6	4%
Insurance	4	3%
Networking	4	3%
Pharmaceuticals/ Chemical	4	3%
Aviation/ Aerospace	3	2%
Electrical	2	1%
Other (specify)_______	2	1%
Plastics/Rubber	1	1%
Sample Size	150	100%

Respondent Function	*Frequency*	
Supply Chain	41	27%
Information Technology	35	23%
Finance	29	19%
Marketing	22	15%
Product/ Project Management	8	5%
Operations	7	5%
Customer Service	4	3%
Sourcing	2	1%
Human Resources	1	1%
Other (please specify)	1	1%
Sample Size	150	100%

Table 2 – Respondent Screening Criteria

Screening Level	*Screening Criteria*	*Eligibility*
1	Please indicate your level of expertise with blockchain.	Intermediate to Expert
2	Please indicate the level of blockchain implementation in your supply chain.	Low to Very High
3	Please indicate the frequency of blockchain based transactions with your organization's partners.	Rarely to Always
4	What is the level of your involvement in strategic supply chain decision making?	Average to Very High
5	Are you employed full time?	Yes
6	What kind of business are you in?	Business-to-Business
7	Are you currently based in the USA?	Yes

Measures

We followed the Dillman Tailored Design Method in scale development and data collection processes. Instrument development involved utilizing both items from existing scales and developing new items based on the extant literature. Constructs were operationalized and defined in the questionnaire to minimize potential misunderstandings about the blockchain assimilation and perceived network prominence concepts. Frequent revisions after practitioner and academic feedback were conducted over an extended duration, over each stage of scale development.

<u>Network Prominence</u>

The term "network prominence" (or "centrality") refers to the significance of an organization's network position and is defined as a source of social capital and influence for network stakeholders (Borgatti, 2005, Freeman, 1978, Wasserman and Faust, 1994). It is a subset of social network analysis (Landis, 2016) that focuses on identifying and evaluating influential actors in a social network. However, existing metrics are based on objective indicators extracted from interorganizational transactional data and do not capture the perceptual aspects of organizational position in a network. We define and quantify network prominence by building on these metrics and converting them to perceptual measures.

Based on Koka et al. (2008), this study is the first to introduce perceptual items to measure network prominence through a survey. Scale development for network prominence included construct and context formulation, response format selection, initial item pool production, item revision, and psychometric property evaluation (Dunn et al., 1994). Initially 12 items for measuring network prominence were created based on network theory literature. To improve the first scale, we iterated on three fronts: face validity, construct dependability, and overall nomological structure. The original 12 item scale was lowered to 3 items used to gauge the network prominence. A sample item for the measure is, “We are intensely involved in managing our inter-organizational network.” The first-order measure of network prominence has satisfactory factor loadings ($\lambda > 0.6$), fit indices ($\chi 2/df = 1.82$; CFI = 0.92; RMSEA = 0.07) and reliability (Cronbach’s $\alpha = 0.75$ and CR = 0.72), validating its nuanced factor structure.

Supply Chain Collaboration

The degree of organizational commitment in mutually advantageous interchange operations is defined in this study as supply chain collaboration. We use the scale developed by Cao et al. (2010) to measure supply chain collaboration without modification. Based on Cao et al. (2010), this study utilizes seven established characteristics – "information sharing, goal congruence, collaborative communication, incentive alignment, decision synchronization, resource sharing, and joint knowledge creation." Respondents reported supply chain collaboration on a 7-point Likert scale of strongly disagree to strongly agree. For example, item "We jointly lay out collaboration implementation plans to achieve the goals of the supply chain" measures the goal congruence dimension of supply chain collaboration. The second-order measure of supply chain collaboration has satisfactory factor loadings ($\lambda > 0.6$), fit indices ($\chi 2/df = 1.92$; CFI = 0.90; RMSEA = 0.07) and reliability (Cronbach's $\alpha = 0.93$ and CR = 0.98), validating its nuanced factor structure.

Blockchain Adoption

Given the novel stage of blockchain, organizations are experimenting to use it in various ways (Wamba et al., 2020). We adopt this notion in measuring organizational blockchain adoption by using the scale developed by Wamba et al. (2020). Respondents reported blockchain adoption in a 7-point Likert scale of strongly disagree to strongly agree. An example item is "My organization invests resources in blockchain-enabled supply chain applications." The first order measure of blockchain adoption has satisfactory factor loadings ($\lambda > 0.6$), fit indices ($\chi 2/df = 1.72$; CFI = 0.93; RMSEA = 0.06) and reliability (Cronbach's $\alpha = 0.72$ and CR = 0.72), validating its three-item factor structure.

Results

We evaluated our research model in four steps. First, we established an acceptable factor loading structure, with all the items, through exploratory factor analysis. Second, we evaluated the nomological structure of the model using maximum likelihood estimation in structural equation modeling. Third, we tested our hypotheses by evaluating the structural model using structural equation modeling with a percentile confidence bootstrap. Fourth, we tested for indirect and direct effects by evaluating the composite factor scores of focal constructs in PROCESS (model 4).

Psychometric Properties

We examined non-response bias by comparing variables such as 'years in present job' and 'years with present organization' between a random sample of 80 respondents and 80 non-respondents drawn from a demographic pool of 1965 prospective respondents (Yan and Azadegan, 2017). There were no significant differences, suggesting the absence of non-response bias. We separated the criteria and predictor variables in the survey instrument according to the suggestions offered by Podsakoff et al. (2003) by placing them in distinct locations within the questionnaire rather than adjacent to one another to mitigate common method bias in the survey planning stage. In addition, the marker variable method of Lindell and Whitney (2001) was utilized to identify the effect of common method bias. This strategy introduces a marker variable into the structural model that influences all observable variables. The model with and without the marker variable was evaluated to identify the effect of common method bias. Both models had a common method bias if their chi-squares were dissimilar. For sample size-sensitive chi-square fit indices, researchers advocate analyzing changes in CFI as well (Cheung and Rensvold, 2002). The difference between the CFI values should be less than 0.01 (Cheung et al., 2002). Our findings show that common technique bias has little effect. The CFI difference was less than 0.01. However, other fit indices were extremely similar, despite the marker variable test's significance. Thus, common method variance had no meaningful impact on the structural model.

Exploratory factor analysis based on the principal component extraction method with varimax rotation revealed three distinct factors, with no cross-loading amongst items and 67.90% total explained variance. The inter-item correlation (table 3) did not reveal major cross loadings and high correlations, suggesting lack of multi-collinearity. We performed confirmatory factor analysis to determine the reliabilities and convergent and discriminant validity of the constructs' scales (CFA). Each item was loaded onto its associated factor. The exploratory and confirmatory factor loadings for each item are shown in tables 4a and 4b, along with the reliability statistic for each scale. The overall measurement model fit was acceptable ($\chi2/df = 1.780$; IFI = 0.91; CFI = 0.91; RMSEA = 0.07) (Hair et al., 2010). To determine convergent validity, we examined the constructs' factor loadings. All factor loadings were significant ($p \leq .05$), showing that the factors were convergent. Additionally, the structures' composite reliabilities were all greater than 0.70. Additionally, we employed Fornell and Larcker's (1981) convergent and discriminant validity analysis. The AVE (average variance extracted) value for each construct was more than the threshold value of 0.4, indicating adequate convergent validity, since composite reliabilities of all the constructs was above 0.7 (Fornell and Larcker, 1981). However, the square root of the AVE for network prominence was not greater than all the inter-construct correlations. Therefore, we further examined all the inter-construct pairs by more stringent chi-square difference test (O'Rourke & Hatcher, 2013). The test procedure encompasses comparison of two types of measurement models – unconstrained and constrained (with inter-construct covariance set to 1). The unconstrained model is significantly different ($p < .001$) than all the possible constrained models, indicating satisfactory discriminant validity of all the constructs, as detailed in table 5 (O'Rourke & Hatcher, 2013).

Table 3 – Descriptive Statistics and Correlations

	Descriptive Statistics			Inter-item Correlations																					
		Mean	*Std. Deviation*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*
1	NProm1	5.45	1.156	–																					
2	NProm2	5.40	1.153	**.442****	–																				
3	NProm3	5.43	1.144	**.470****	**.479****	–																			
4	BA1	5.41	1.205	.269**	.407**	.395**	–																		
5	BA2	5.26	1.250	.415**	.374**	.306**	**.436****	–																	
6	BA3	5.42	1.177	.387**	.306**	.352**	**.459****	**.491****	–																
7	IS1	5.31	1.253	.320**	.263**	.197*	.289**	.386**	.335**	–															
8	IS2	5.51	1.208	.452**	.411**	.431**	.291**	.364**	.409**	**.614****	–														
9	IS3	5.46	1.219	.346**	.394**	.338**	.377**	.414**	.328**	**.544****	**.595****	–													
10	GC1	5.30	1.299	.445**	.318**	.269**	.285**	.439**	.294**	.562**	.508**	.396**	–												
11	GC2	5.47	1.133	.355**	.308**	.325**	.320**	.425**	.395**	.414**	.466**	.378**	**.542****	–											
12	GC3	5.43	1.149	.371**	.370**	.346**	.359**	.519**	.375**	.522**	.457**	.432**	**.613****	**.591****	–										
13	DS1	5.17	1.315	.226**	.330**	.320**	.340**	.348**	.330**	.436**	.463**	.511**	.488**	.378**	.434**	–									
14	DS2	5.33	1.349	.382**	.395**	.365**	.321**	.371**	.424**	.437**	.572**	.414**	.468**	.462**	.406**	**.668****	–								
15	IA1	5.25	1.247	.392**	.300**	.367**	.338**	.389**	.345**	.424**	.521**	.499**	.579**	.398**	.515**	.661**	.530**	–							
16	IA2	5.37	1.303	.368**	.338**	.391**	.328**	.373**	.383**	.476**	.491**	.504**	.476**	.540**	.581**	.499**	.549**	**.554****	–						
17	RS1	5.36	1.217	.298**	.366**	.220**	.255**	.247**	.362**	.385**	.554**	.449**	.462**	.481**	.507**	.557**	.595**	.604**	.588**	–					
18	RS2	5.23	1.397	.416**	.458**	.411**	.353**	.457**	.421**	.392**	.465**	.453**	.453**	.439**	.547**	.460**	.622**	.517**	.564**	**.578****	–				
19	CC1	5.45	1.251	.418**	.343**	.387**	.467**	.375**	.385**	.399**	.422**	.479**	.415**	.588**	.567**	.462**	.477**	.478**	.575**	.518**	.511**	–			
20	CC2	5.55	1.298	.393**	.400**	.382**	.326**	.363**	.358**	.292**	.346**	.311**	.415**	.473**	.578**	.463**	.541**	.496**	.573**	.529**	.628**	**.582****	–		
21	JKC1	5.31	1.141	.316**	.391**	.340**	.391**	.414**	.388**	.460**	.513**	.521**	.513**	.579**	.512**	.568**	.454**	.597**	.568**	.621**	.595**	.603**	.475**	–	
22	JKC2	5.37	1.303	.268**	.277**	.235**	.262**	.366**	.385**	.420**	.408**	.443**	.410**	.561**	.445**	.492**	.566**	.547**	.512**	.602**	.528**	.519**	.567**	**.565****	–

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4a: Exploratory Factor Analysis (Rotated Component Matrix)

	Component 1	Component 2	Component 3
Joint Knowledge Creation	0.836		
Resource Sharing	0.834		
Incentive Alignment	0.827		
Decision Synchronization	0.774		
Goal Congruency	0.723		
Collaborative Communication	0.720		
Information Sharing	0.666		
NProm2		0.786	
NProm3		0.721	
NProm1		0.699	
BA3			0.745
BA2			0.725
BA1			0.718

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Total Variance Explained = 67.90 %

Table 4b: Confirmatory Factor Analysis

Construct		Std. Factor Loading		Reliability (Cronbach's Alpha)	Composite Reliability	Average Variance Extracted
Blockchain Adoption				0.72	0.72	0.46
BA1	My organization invests resources in blockchain enabled supply chain applications.	0.64	***			
BA2	Business activities in our organization require the use of blockchain technologies.	0.70	***			
BA3	Functional areas in my organization require the use of blockchain technologies.	0.70	***			
Supply Chain Collaboration				0.93	0.98	0.87
Information Sharing		0.82	***			
IS1	We exchange timely information.	0.73	***			
IS2	We exchange accurate information.	0.81	***			

IS3	We exchange complete information.	0.75	***
Goal Congruency		0.89	***
GC1	We have agreement on the importance of improvements that benefit the supply chain as a whole.	0.74	***
GC2	We agree that our own goals can be achieved by working towards the goals of the supply chain.	0.75	***
GC3	We jointly layout collaboration implementation plans to achieve the goals of the supply chain.	0.80	***
Decision Synchronization		0.87	***
DS1	We jointly manage inventory.	0.80	***
DS2	We jointly plan on product assortment.	0.83	***
Incentive Alignment		0.99	***
IA1	We share benefits (e.g., saving on reduced inventory costs).	0.75	***
IA2	We share any risks that can occur in the supply chain.	0.76	***
Resource Sharing		0.99	***
RS1	We share technical support.	0.77	***
RS2	We share equipment (e.g., computers, networks, machines).	0.76	***
Collaborative Communication		0.93	***
CC1	We have many different channels to communicate.	0.77	***
CC2	We influence each other's decisions through discussion rather than request.	0.76	***
Joint Knowledge Creation		0.99	***
JKC1	We jointly identify customer needs.	0.77	***
JKC2	We jointly discover new or emerging markets.	0.72	***

Network Prominence				0.75	0.72	0.46
NProm1	We are intensely involved in managing our interorganizational network.	0.68	***			
NProm2	By affiliating with us, our supply chain partners' reputation is enhanced.	0.68	***			
NProm3	We receive new information, from outside our interorganizational network.	0.68	***			

*** p < 0.001

Table 5: Discriminant Validity (Chi-square Difference Test ($\Delta\chi2(\Delta df)$))

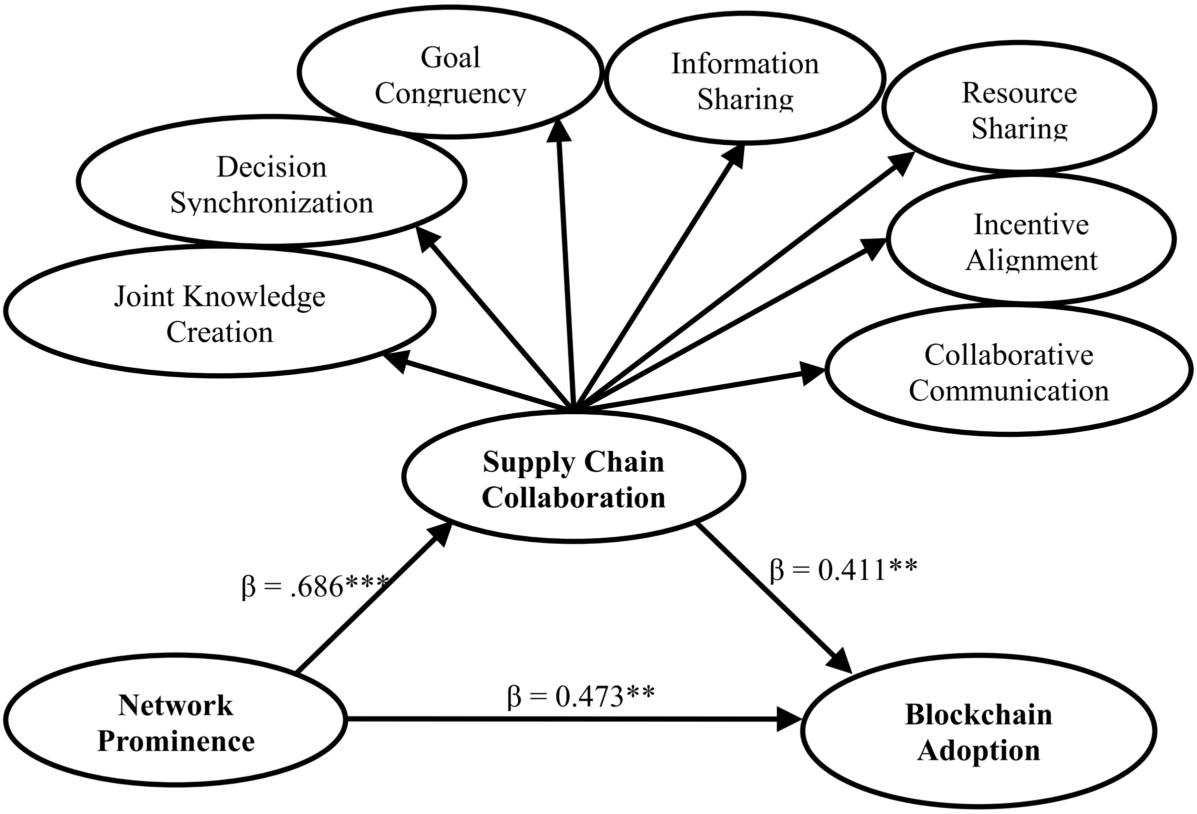
Model		$\Delta\chi2(\Delta df)$	
Model 1 (Unconstrained)			
Model 2 (COV(Nprom,BA)=1)	Model 1 vs 2	14.549(1)	***
Model 3 (COV(Nprom,SupCol)=1)	Model 1 vs 3	18.624(1)	***
Model 4 (COV(SupCol,BA)=1)	Model 1 vs 4	17.445(1)	***
Model 5 (COV(Nprom,SupCol,BA)=1)	Model 1 vs 5	21.374(3)	***

*** p < .001

Hypotheses Testing

Figures 1 and 2 present the research and path loading models, respectively. Our research model is a single mediation model, in which the effect of network prominence (X) on the organizational blockchain adoption (Y) is partially mediated by supply chain collaboration (M1). As indicated in figure 2, all our hypothesized direct effects are positive. Hypothesis 1, that network prominence of organizations is positively associated with blockchain adoption, is supported (β = 0.47, $p < .01$). Hypothesis 2, that network prominence of organizations is positively associated with the supply chain collaboration, is supported (β = 0.68, $p < .001$). Hypothesis 3, that supply chain collaboration is positively associated with blockchain adoption of the organization, is supported (β = 0.41, $p < .01$).

Figure 2 – Research Model with Path Loadings



** p < .01 *** p < .001

We further tested all the indirect and direct effects in our causal research model through omnibus ordinary least squares multi-variate regression, using PROCESS model 4 (Hayes, 2013). Results indicate statistically significant indirect and total effects between network prominence and blockchain adoption of the organization. As indicated in table 6, the influence of network prominence on organizational blockchain adoption is partially mediated by supply chain collaboration (effect size = 0.26; CI = [0.1290, 0.4231]). As indicated by the structural model test results, the PROCESS model 4 also indicated a significant positive total effect (effect size = 0.54; CI = [0.4189, 0.6806]). Thus, hypothesis 4, that supply chain collaboration mediates the association between network prominence and organizational blockchain adoption, is supported.

Table 6 – Indirect and Total Effects

Total effect of Network Prominence (X) on Blockchain Adoption (Y)			
	Effect Size	Std. Error	Confidence Interval
X --> Y	0.5498	0.0662	[0.4189, 0.6806]

Indirect effects of Network Prominence (X) on Blockchain Adoption (Y)			
	Effect Size	Std. Error	Confidence Interval
X --> M1 --> Y	0.2629	0.0744	[0.129, 0.4231]

M1 - Supply Chain Collaboration

DISCUSSION

Blockchain is an emerging technology with promise to become widely adopted (Kshetri, 2018). Blockchain promises a plethora of innovative organizational benefits. Instead of recalling the entire product line, blockchain can help identify the source of defective products, such as contaminated food. It also helps reduce waste by eliminating paper records and providing accurate quality data to supply chain partners, minimizing low-quality and counterfeit products. Blockchain can help speed up supply chain by automating processes and reducing manual interactions. Blockchain applications include safe storage and transfer of digitally signed documents can make supply chain partners more accountable and responsible for their activities, increasing reliability. Blockchain's traceable records can help supply chain partners who give self-reported data. Various existing challenges can be addressed with blockchain security. A network party can only access transactions or specific touchpoints with mutual consent. The downloaded program file integrity cannot be compromised. Blockchain technologies has promised huge organizational impact even though only a few organizations have adopted blockchain based systems, largely due to the network effect that amplifies this solution's strength. Blockchain will have more influence amongst supply chain organizations when combined with IoT (Kshetri, 2018). Our study contends that technology suppliers and other intermediary institutions can play critical roles in lowering barriers and facilitating blockchain adoption. Grounding arguments in social network and resource dependency theories, our results indicate that collaborative relationships and prominence in the supply chain network are crucial resources for encouraging and enabling effective and sustainable supply chain innovation. We investigate how supply chain interactions, characterized by networks that bind organizations, lead to blockchain deployment in supply chain operations. Results indicate statistical support for all the hypotheses. We did not use any control variables due to sample limitations. Future research can incorporate control variables that may include industry type, manufacturing indicator (i.e., manufacturing or service organization), and personnel composition. Prior research has shown that supply chain collaboration varies widely by industry and job complexity in certain industries affects both the need and aptitude to learn (Ahuja, 2000).

Implications

Our study has key implications for the managers of the technology vendor organizations that make and sell systems, such as blockchain. First, managers in sales and marketing functions will gain insights to identify target organizations, who are more likely to adopt open standard inter-organizational systems, in a global supply chain network. Second, managers in product design and development functions will be able to build better partner interface processes to align the business process areas to multi-tier organizational linkages of the adopting organization, they gain deeper perspective on the key role of supply chain relationships in the technology adoption phenomenon (Wasserman & Faust, 1994).

Interesting anomalies emerge when two complementary yet independent theories are evaluated concurrently: resource dependence theory and social network theory (Connelly et al., 2011). According to resource dependence theory, supply chain organizations will attempt to reduce external dependency. From this perspective, scholars may underestimate the relevance of inter-organizational links that bind the focal organization. However, social network theory emphasizes inter-organizational linkages that can both create interdependence and value. Thus, managers can learn about strategic initiatives without the uncertainty that comes with executing them in their own organizations, owing to collaborative relationships. By merging these two theories, we establish non-obvious contingencies that neither theory alone would explain.

Limitations

This research may be extended in two ways by delving deeper into the argument. First, it has adopted organization as the object of investigation. Due to the fact that supply chain collaboration through technology adoption can occur at numerous levels both throughout and beyond organizations (Su et al., 2017), subsequent studies should examine basic underlying arguments at the network level by taking dynamic behavior and competitive pressures into account. Second, this study has not investigated the nature of dyadic relationships between the organizations that engage in supply chain collaborations. The resource vulnerabilities between organizations are anticipated to be amplified as a result of the interdependence of organizational groups (Granovetter, 1973). Thus, future research should examine organizational dynamics in blockchain-based networks by focusing on resource interdependence at the dyad or network level.

When conducted properly, the mixed methods technique enhances the significance of the findings (Montabon F. et al., 2018). Since our study is based on a cross-sectional survey methodology, which is a mono-method approach, it is subject to inherent methodological limitations. Researchers' designs should combine a variety of complementary methodologies. One typical strategy is to conduct behavioral experiments that are based on vignettes, targeting experts in supply chain management and blockchain. Conditional manipulations, when implemented effectively in the context of navigating the nuances of blockchain-based inter-organizational networks, can potentially open avenues for a new stream of research between network theory and innovation. Thus, conducting experiments is an excellent place to start. Another beneficial addition to a survey approach is the incorporation of archive or secondary data, leading to the development of better metrics of relative positions in the inter-organizational network.

CONCLUSION

Blockchain holds promise of broadscale adoption, especially in supply chain organizations. Organizations will be drawn to blockchain to reap the benefits of blockchain as an open standard technology by using blockchain across wide range of applications. Blockchain providers and other intermediate organizations may help decrease obstacles and facilitate technology deployment is a key takeaway of our research. Following social network and resource dependence theories, we argue that collaborative interactions and prominence in supply chains are critical to profitable and enduring supply chain innovation. Supply chain interactions, defined by networked organizations, lead to blockchain use in supply chain activities. We argued that collaborative networks and organizational prominence are crucial for effective supply chain innovation. We investigated the mediating impacts of supply chain collaboration when organizations adopting blockchain are influenced by the network prominence of their collaboration partners, using supply chain organization as the unit of analysis. The results provide statistical support for all hypotheses. By using blockchain adoption, we add to the supply chain management literature by understanding the juncture between social network and resource dependency theories. Our research is useful to supply chain organizations to establish the motivation for rapid proliferation of novel technology inside current organizational structures.

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DECISION SCIENCES INSTITUTE

Driving Sustainable Operations in Multinational Enterprises through Projectification

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ABSTRACT

Plateauing growth potential resulting from the saturation of markets, dynamic culture of international markets, and the overexploitation of market diversity as a source of organizational growth, increasingly compels MNEs to pursue novel strategies to warrant their operational longevity. We thus argue in the current study for corporate sustainability as a new driver of organizational growth. This conceptual paper discusses through the lens of fit, legitimacy and institutional theories of organization, the centrality of sustainability to MNEs' performance in today's business climate.

KEYWORDS: Sustainability, Multinational Enterprises, Corporate Sustainability, Corporate Social Responsibility, Projectification, Project Management, and Sustainable Investing.

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Modeling the climate change of countries through DNN and LSTM

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ABSTRACT

Climatologists have studied the change in air and ocean temperature and have come up a set of risk-factors as the primary causes of climate-change. Reputable data sources have put together datasets for climate-change risk factors. Many of these factors are attributed to population-specifically overall population size, urban population size, educational level, life expectancy, poverty rate, population density, land usage types, energy consumption of renewable and non-renewable sources, greenhouse gas emissions. A deep neural network time-series based model was built using country specific data for 12 countries and using a 30-feature multivariate dataset from which a future prediction is made.

KEYWORDS: Deep neural network (DNN), Long short-term memory (LSTM), Climate change, Climate datasets, Tensorflow, Keras

INTRODUCTION

Long short-term memory (LSTM) layers were used to construct part of a model that was created to model climate change as a time-series basis. The target feature dataset used is supplied by (Our World In Data). Climate change is believed to be caused by multiple sources and the climate change risk-factors datasets from (The World Bank) were also integrated resulting in a multivariate LSTM DNN model. The World Bank lists 28 datasets as belonging to the climate change risk-factor category. The climate change risk-factor datasets include:

1. Access to electricity (% of population)
2. Agricultural land (% of land area)
3. Arable land (% of land area)
4. CO2 emissions (metric tons per capita)
5. Cereal yield (kg per hectare)
6. Electric power consumption (kWh per capita)
7. Forest area (% of land area)
8. Land area where elevation is below 5 meters (% of total land area)
9. Mortality rate, under-5 (per 1,000 live births)
10. Population growth (annual %)
11. Population living in areas where elevation is below 5 meters (% of total population)
12. poverty headcount ratio at $1.90 a day (2011 PPP) (% of population),
13. Primary completion rate, total (% of relevant age group)
14. Renewable energy consumption (% of total final energy consumption)
15. Urban population
16. Agriculture, forestry, and fishing, value added (% of GDP)
17. CO2 emissions (kt)
18. Energy use (kg of oil equivalent per capita)
19. Forest area (sq. km)

20. Methane emissions (kt of CO2 equivalent)
21. Nitrous oxide emissions (thousand metric tons of CO2 equivalent)
22. Population in urban agglomerations of more than 1 million (% of total population)
23. Population, total
24. Prevalence of underweight, weight for age (% of children under 5)
25. Renewable electricity output (% of total electricity output)
26. School enrollment, primary and secondary (gross), gender parity index (GPI),
27. Total greenhouse gas emissions (kt of CO2 equivalent)
28. Urban population (% of total population).

In (Hochreiter & Schmidhuber, 1998) they proposed the idea of the LSTM. A typical schematic of an LSTM looks like that shown in Figure 1. There are multiple variations on the original design by Hochreiter, but his work still stands as the primary design of the LSTM.

Fig. 1. LSTM Schematic

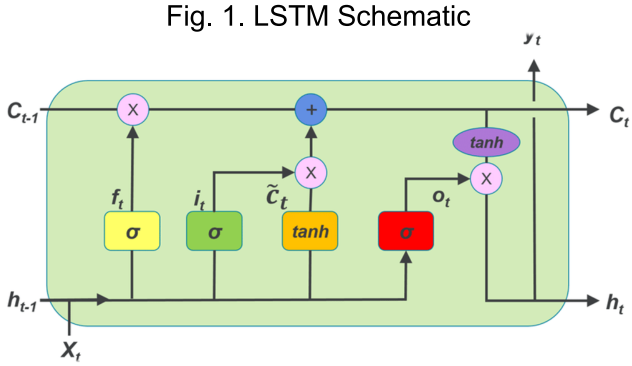
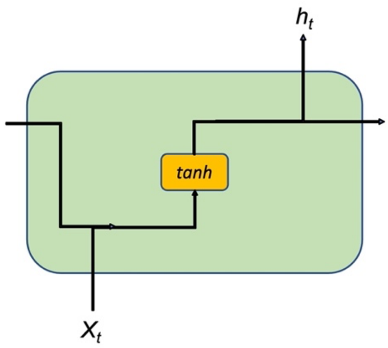


Fig. 2. Vanilla RNN



The need and motivation for the LSTMs came from the need for an improvement over the Recurrent Neural Network model (Recurrent Neural Networks) as shown in Figure 2. The LSTM's improvements come by ways of using gates for the purpose of controlling or limiting the problem known as the vanishing gradient problem (and the exploding gradient problem). Compared to an LSTM, an RNN cell shown in Figure 2, consists of one layer with a hyperbolic tangent (tanh) activation function. In machine-learning models, an activation function serves as the purpose to transform the data from one layer to another. LSTMs have a repeating module just like that of RNNs but instead of the one layer contained within the RNN there are four layers contained within the LSTM cell. In Figure 1, the four layers are the four colored boxes, yellow σ, green σ, orange tanh and red σ. The LSTM cell maintains its cell-state via the top line running across the LSTM. A cell state is considered by traversing from C_{t-1} to C_t. Only minor changes are made to the LSTM cell-state by the pink x and blue +. Because the LSTM consists of multiple hidden layers, it alone can be considered to be a deep neural network. Each of the four layers contribute to either adding or removing state from an LSTM cell. The LSTM's layers are also frequently referred to as gates. The first gate (or layer) is the (yellow σ) and is referred to as the forget-gate. The purpose of the forget-gate is to output a value between 0 and 1. The next layer (green σ) is referred to as the input-gate and its purpose is to decide which values will get updated. The third layer (orange tanh) serves the purpose of creating new candidate values that will be considered for updating the cell's state. The new cell-state becomes the old cell-state multiplied by the forget-gate plus the scaled values computed by the second and third layers which are added to the cell-state. The last layer serves as the final step and uses the output-gate (red σ). The cell-state goes through a tanh function which scales the values between -1 and 1 and are then multiplied by the output value from the output-gate. There are variations on how the original LSTM cell work and new adaptations are frequently being put forward for review.

As previously mentioned, the vanishing gradient problem is a common problem with RNNs. The RNN suffers from the vanishing gradient problem when an update happens to an RNN's weights. The "vanishing" aspect can happen when the update is proportional to the partial derivative of the error function causing the weight to remain unchanged. The vanishing gradient problem effectively maps large numbers to very small numbers. A frequent cause of the vanishing gradient problem is the tanh function as shown in Figure X. The tanh function outputs a value from the range between -1 and 1. Multiple multiplications against the tanh function can quickly shrink values to small number values. In addition, backpropagation (backward propagation of errors) computes the gradients via the chain-rule and when these small numbers are used in the beginning layers of an RNN, then the training process can either fail or takes a very long time to converge. Various techniques have been proposed to overcome the vanishing gradient problem including avoiding using a gradient-based activation function. Shallow models are not as affected by the vanishing gradient problem but when a model has multiple layers, these derivative values decrease quickly as the back propagation happens. These small values cause the weights and biases of early layers to not work effectively particularly during the training phase.

For some layers or models, it is possible to avoid using activation functions like sigmoid and tanh. A very common activation layer is ReLU (rectified linear unit.) The output of the ReLU activation is not limited to -1 to 1 (its range is limited from 0 to ∞) Another technique used to avoid the vanishing gradient is called batch normalization (Ioffe et al, 2015). With batch normalization multiple layers of a model are normalized through standardizing and normalizing operations between layers.

LITERATURE REVIEW

In (Dessai et al, 2009), the authors describe the current needs for better climate prediction models to provide for and address the vulnerability of climate- influenced decisions. In (Zhang et al, 2017) they used an LSTM model for the use of predicting sea surface temperatures on the coastal seas of China. They focused on the specific coastal areas given that they have greater fluctuation in temperatures as opposed to areas further out in the ocean. In (Zhang et al, 2017), (Yao et al, 2018), and (Li et al, 2019) they all use the LSTM to predict wind speed. In (Zhang et al, 2017) they used both LSTM and bidirectional LSTM models to experiment and evaluate the prediction of stochastic wind speed to be used in a wind farm for generating electricity. In (Yao et al, 2018) they developed a Fuzzy-Rough-Set LSTM to predict the short-term prediction of the wind speed, again for the benefit of optimizing the generation of electricity, while in (Harilal et al, 2021) they show how statistical downscaling fails to provide climate change predictions better than convolutional neural networks (CNN), residual dense block (RDB) and LSTMs. The authors capture spatiotemporal dependencies to improve precipitation predictions over India using a convolutional LSTM that includes weather related variables like humidity, atmospheric pressure, wind-velocity and more. All of the additional features the authors have chosen are not directly attributable to human behavior. Similarly, in (Chou et al, 2021), the authors use a ConvLSTM model using spatiotemporal dependencies between the climatic variables. Finally, in (Lopez & Sekeran, 2016) they combine climate change data that influences the transmission of the vector borne diseases.

METHODS

Exploratory Data Analysis and Data Preprocessing

The target feature of the temperature anomaly (Our Word In Data) is provided in the date range of January 15, 1880, to January 15, 2022 (as of the time of this writing). The temperature anomalies are given both in terms of air temperature and ocean surface temperature. Both the air and ocean temperature anomaly data points are given in both northern hemisphere and southern hemisphere. For each iteration of the model either the northern or southern temperature anomalies are used, for both air and ocean temperatures. The results of the model were compared of the top 10 GDP ranked countries (World Population Review). In addition to these 10 counties, Russia and Australia were also added based on their geographic locations and size variations compared to the other 10 countries. For each country studied, it is located on a world map either within the Northern Hemisphere or Southern Hemisphere. One small exception is the country Brazil which has a very small part located in the northern hemisphere. Only the air temperature anomaly is what is predicted with our model per each country based on the air and ocean temperature anomaly data and the 28-climate change risk-factor datasets.

This approach was used so that the same target feature could be used but still give the difference of geographical locations and their corresponding seasonal weather. These temperature values, for either northern or southern hemisphere were used and were assigned to the temperature anomaly column as our target feature data source. This dataset source states that the temperature anomaly values are: “The combined land-surface air and sea-surface water temperature anomaly is given as the deviation from the 1951 – 1980 mean”, (World Population Review). Because the dataset was based off a mean or a year range this effectively takes the seasonality out of the data, due to the preprocessing that the data source has done. Further, the temperature points are the anomaly values and not direct temperature values. The date values are given as the 15th of each month from the years 1880 to 2021. Because there is effectively no seasonality with the temperature dataset it normalized using a standard min-max method similar to (Scikit-Learn’s) MinMaxScalar that would normalize the data between 0 and 1. In addition to normalizing the target feature of the temperature anomaly, the country specific datasets were also normalized completing the multivariate dataset used for training and testing of the model. Although the (Keras) / (Tensorflow) LSTM could handle the temperature anomaly as is the dataset was normalized in total so that no feature column would dominate the model.

Each country’s climate change risk-factor datasets were given in the time range of 1960 to 2020. One data point was given per year, per risk-factor. Depending on the country, the risk-factor and the year there are missing values.

Each country processed had either 1, 2 or 3 risk-factor datasets removed due to the Pearson correlation coefficient computing to 0. The one exception was Japan that had 5 risk-factor datasets removed. Pearson correlation coefficients equaling zero typically happens when the entire dataset is a constant number or when little to no data was given for that particular country. An example of when this issue happens would be within the dataset for land area where elevation is below 5 meters (% of total land area). Many countries have 0 values for every year or only minimal values for a few years. Another example is the Access to electricity (% of population) dataset which for these large, developed countries the value is typically 100% for all years. In our previous work (Jennings, R. & Kaleemunnisa LNU, 2022) these 28 datasets played a much more significant role in defining the data given that the World column was used for each dataset which resulted in no dataset having a zero Pearson Correlation Coefficient.

The 28 risk-factor datasets plus the air and ocean temperature anomaly datasets were packed and converted into a (NumPy) array. The first problem to address was that the two data sources had different year ranges (1880 to 2021) and (1960 to 2020). The goal was to keep the entire long-time series temperature anomalies, therefore empty rows for the climate change factors were added so that each dataset had the same number of rows. The second problem was that the climate change risk-factor datasets were yearly instead of monthly like the temperature change dataset. To resolve this, every row of the climate change factors dataset were duplicated 12 times, taking a yearly data value, and replicating as a monthly data point. This was not considered to be a significant problem given that the majority of these risk-factor datasets would be very difficult to measure on a monthly basis and they are very slow changing, unlike the temperature data. For example, mortality rate would not change greatly from month to month and would also be difficult to get an accurate value if actual surveys were needed. All of this data pre-processing was done so that the two datasets, built as (Pandas) data-frames could be joined doing an inner-merge operation.

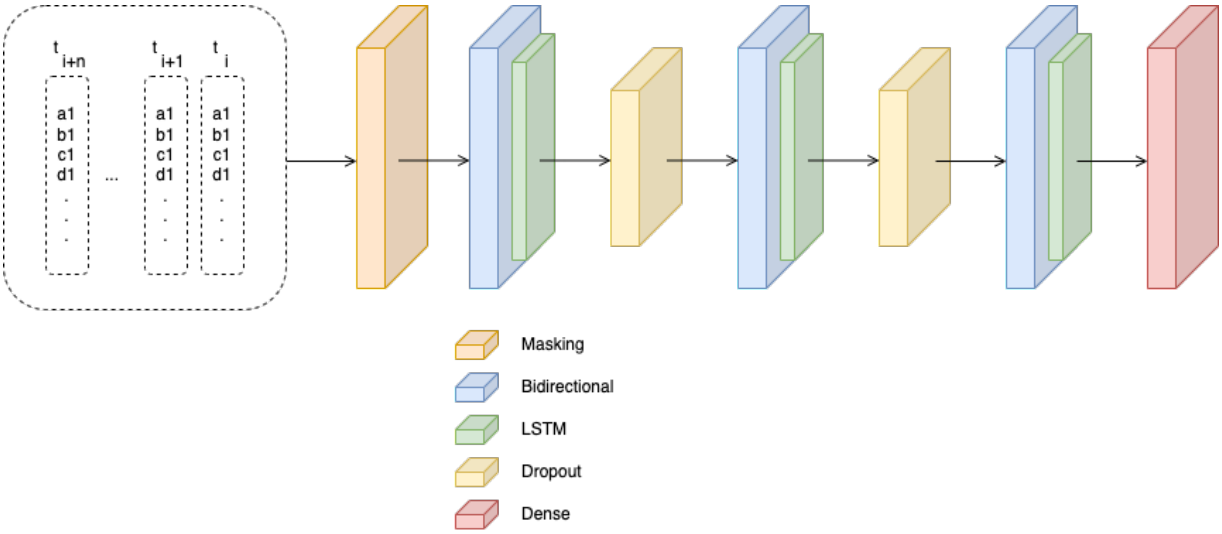
Each country was processed with its own unique multivariate dataset. As stated previously, 10 of the countries used the Northern Hemisphere air and ocean temperature anomalies and two (Brazil and Australia) used the Southern Hemisphere temperature anomalies. Each country's dataset was initially processed by the MinMaxScalar, in order to normalize the columns given that the range values varied greatly per each risk-factor dataset. Normalizing the data prevented the large-valued risk factor datasets from dominating the model during the fitting or training steps. Missing values from the risk factor datasets (or any dataset) are typically listed as NaN (not a number). Any missing values within the country's risk factor datasets had to be converted so that the Keras/Tensorflow LSTM model building could complete. Any NaN value present would not allow the model training to complete with valid values. Since each country's dataset was normalized with the MinMixScaler in the range of 0 to 1, any missing values in any country's risk-factor datasets were assigned the value of -1. This was done so that the Keras/Tensorflow Masking layer could be used. The Masking layer allows a model to ignore missing values that are assigned a particular value, in this case the value of -1.

The risk-factor datasets with a Pearson Correlation of 0 were removed from that country's multivariate dataset. It would have been possible to leave these zero correlated value datasets in place, but the preference was to remove any minor issue that they might cause. However, any low value correlation datasets (> than 0) were still included. Leaving in or removing datasets came down to a question of the calculated correlation showing no correlation or the literature stating these risk-factor datasets were in fact correlated by measurements and not just a correlation calculation. In other words, low ranking correlation datasets were kept because they are strongly believed by environmentalists to be correlated to climate change despite what the Pearson correlation calculation came up with.

Model Analysis & Evaluation Results

The multivariate DNN model performed well for all 12 countries. The final DNN model consisted of a masking layer masking out the missing values from the climate change factors datasets by marking them with a -1 value. The next layers within the model were three bidirectional LSTM layers. Two dropout layers were added in between the three bidirectional LSTM layers, which is attributed to (Srivastava et al, 2014). Each of the dropout layers used a dropout rate of 15 percent. The output layer consisted of a single cell dense layer. The dropout layers were key for this model by allowing the model to effectively ignore outliers and improve the regularization of the model. Without the dropout layers, the test validation fell off at the tail end.

Fig. 3. Multivariate Deep Neural Network Model



The first two of the three LSTM layers shown in Figure 16 were configured to output the full sequence of data. The last LSTM was configured to output a single value.

Given the experience in working with a similar dataset (Jennings, R. & Kaleemunnisa LNU, 2022) the model could be fine-tuned a little more than was used previously. The dropout probability was increased from 10% to 15% which is still within a normally acceptable range for basic models. The learning rate was kept at a constant 0.00003 for all countries. Everything within the model remained the same for each country including the layers, learning-rate and choice of optimizer (Adam optimizer). The options chosen gave the best results without overfitting or underfitting. Early stopping was used to find the near optimal stopping point during the training phase. Some countries required significantly more epochs than others. The Early Stopping feature of Tensorflow/Keras allows the training process to keep track of the validation results during the training phase. If after a certain number of epochs, called the patience level, the model shows no signs of improvement, the model's state is returned to the best previous state.

Table 1: Number of Epochs per Country

Country	Optimal Epoch	Last Epoch
Australia	211	281
Brazil	233	303
Canada	153	223
China	134	204
France	366	406
Germany	275	345
Great Britain	295	365
India	147	217
Italy	408	338
Japan	361	431
Russia	406	476
USA	255	325

As is typical in machine learning model building, there was a lot of trial and error to find the best working model. The Adam optimizer was used simply due to its all-purpose general excellent performance. All default activation functions were kept as is. Although the data was normalized to be between 0 and 1, the default Keras LSTM activation functions were kept. The goal was to see how a traditional LSTM layer would perform. One of the hyper-parameters that took some testing and evaluation was the learning-rate for the Adam optimizer. A learning rate of 0.00003 was found to give the best results without overfitting or underfitting. Like in our previous work, early stopping played a significant role in optimizing the model. The environment used was an Apple MacBook Pro, 2.4 GHz 8-Core Intel Core i9 with 64GB of RAM. Tensorflow and Keras version 2.7.0 and Python 3.8.12.

Table 2: The Multivariate Model Evaluation

Multivariate Model Fitting					
	Training		Testing		
Country	MAE	MSE	MAE	MSE	R^2
Australia	0.0474	0.0038	0.0653	0.0067	0.4003
Brazil	0.0470	0.0037	0.0593	0.0056	0.4980
Canada	0.0392	0.0028	0.0479	0.0038	0.4867
China	0.0392	0.0028	0.0433	0.0032	0.5775
France	0.0384	0.0027	0.0503	0.0043	0.4290
Germany	0.0386	0.0027	0.0534	0.0047	0.3684
Great Britain	0.0386	0.0027	0.0743	0.0083	-0.1179
India	0.0390	0.0027	0.0428	0.0031	0.5853
Italy	0.0390	0.0027	0.0764	0.0092	-02382
Japan	0.0386	0.0027	0.0514	0.0046	0.3901
Russia	0.0387	0.0027	0.0669	0.0078	-0.0489
USA	0.0386	0.0027	0.0489	0.0046	0.3870

Figure 4: Australia’s Loss Plot

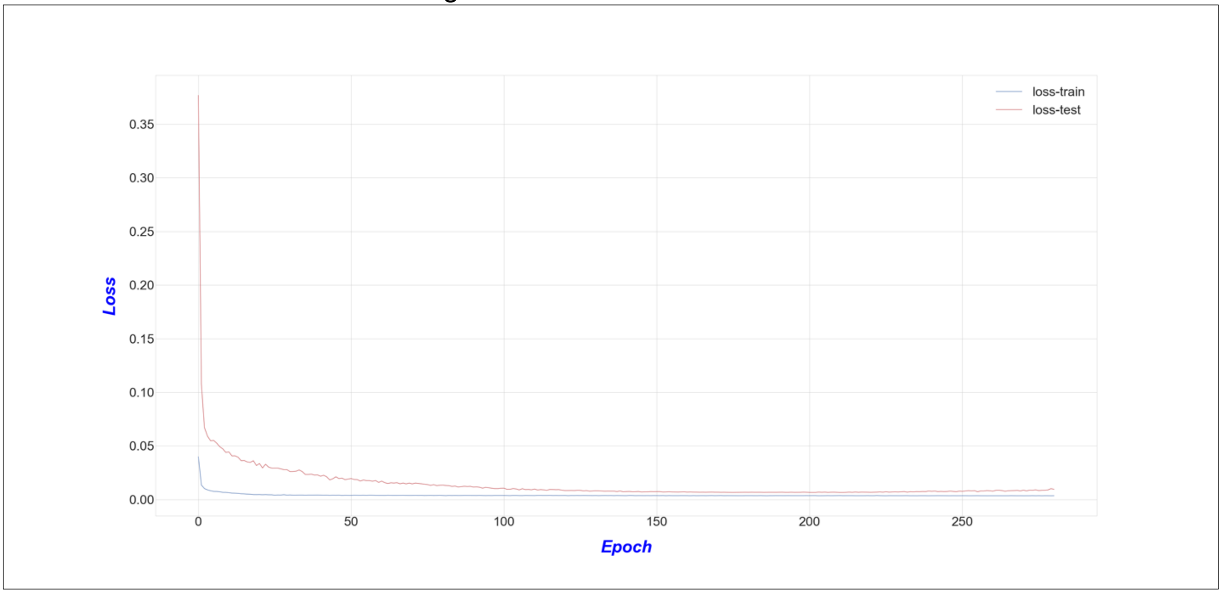


Figure 5: Australia’s Train/Test Plot

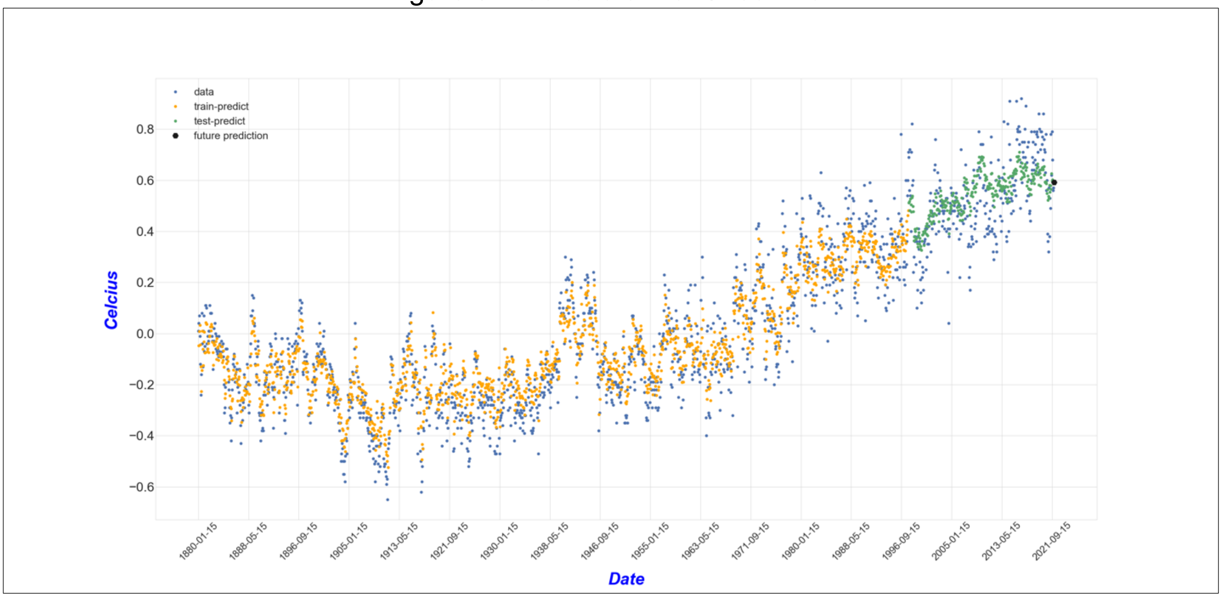


Figure 6: Brazil's Loss Plot

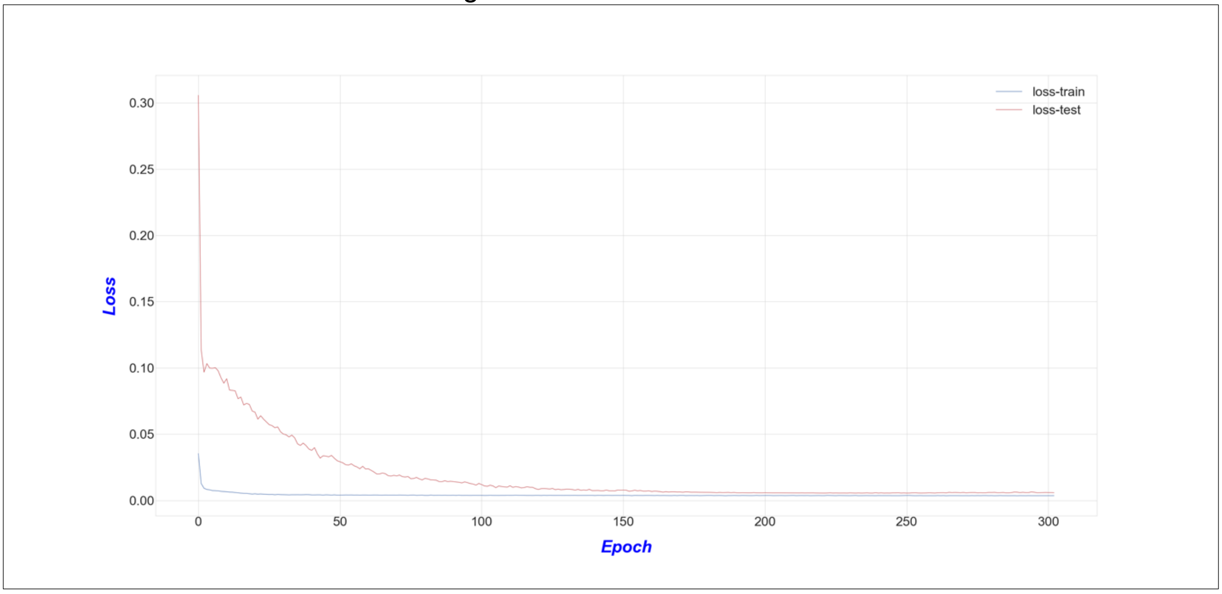


Figure 7: Brazil's Train/Test Plot

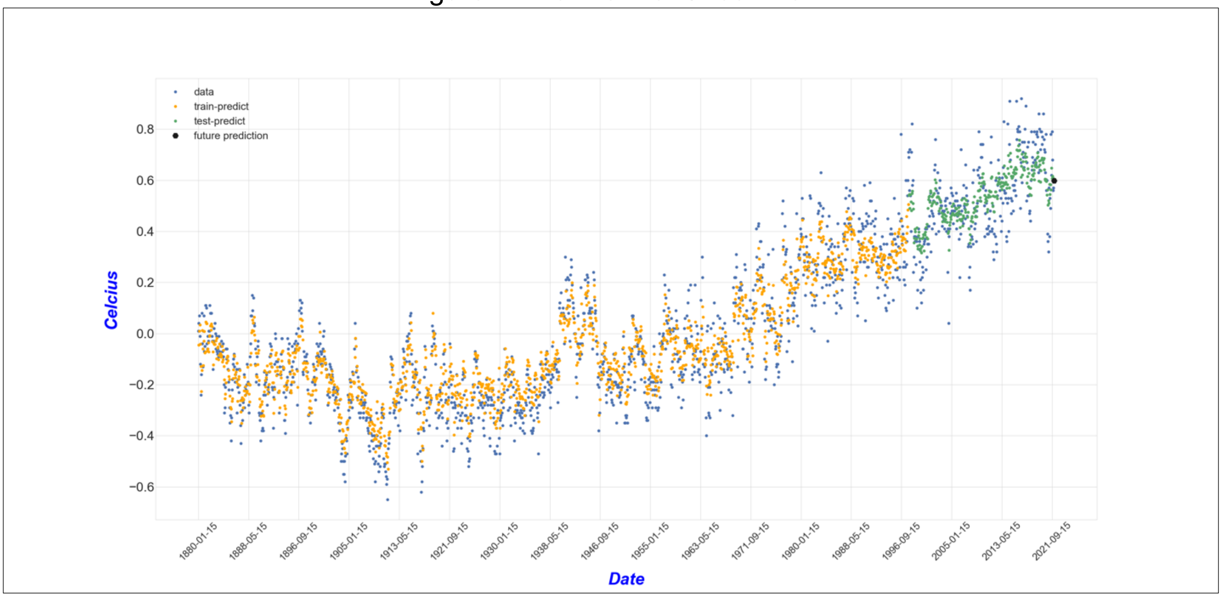


Figure 8: Canada's Loss Plot

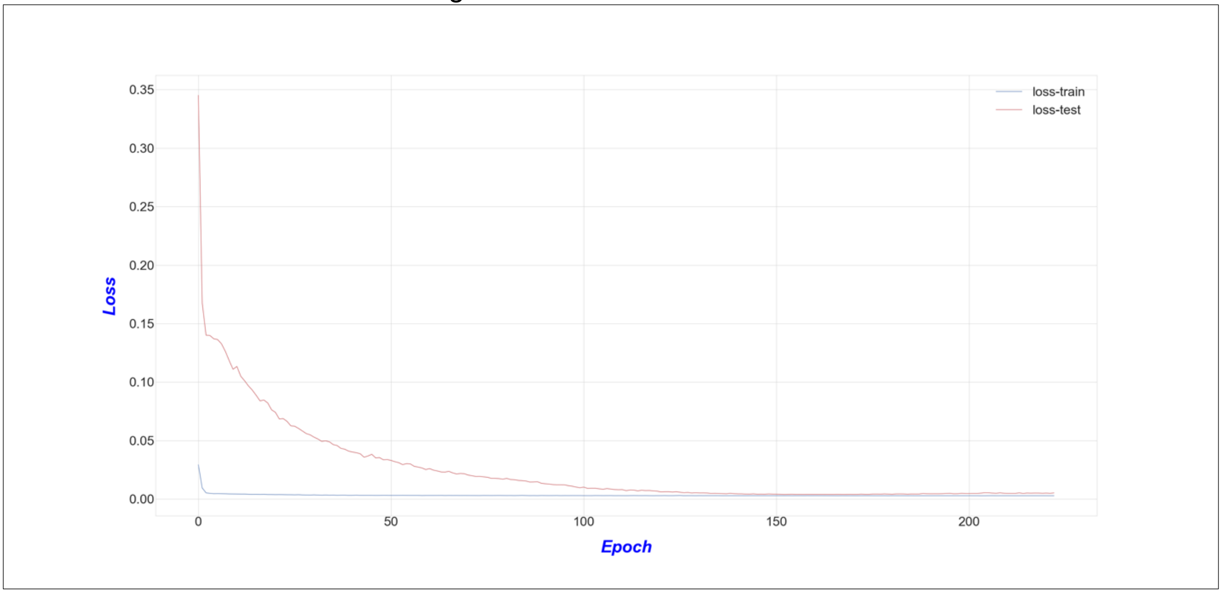


Figure 9: Canada's Train/Test Plot

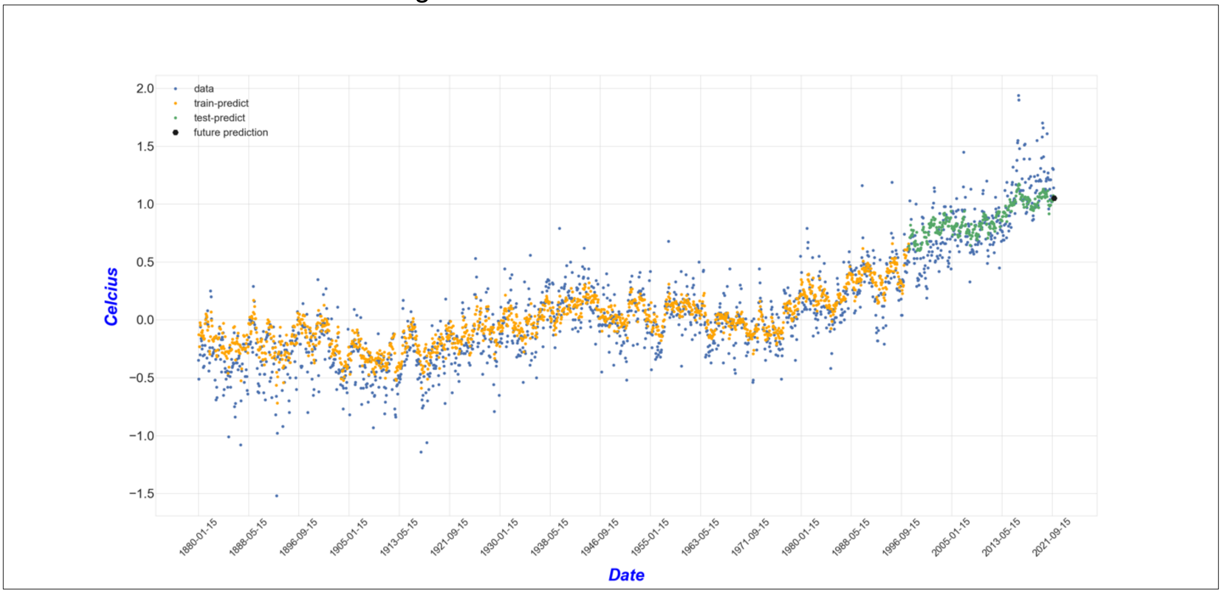


Figure 10: China's Loss Plot

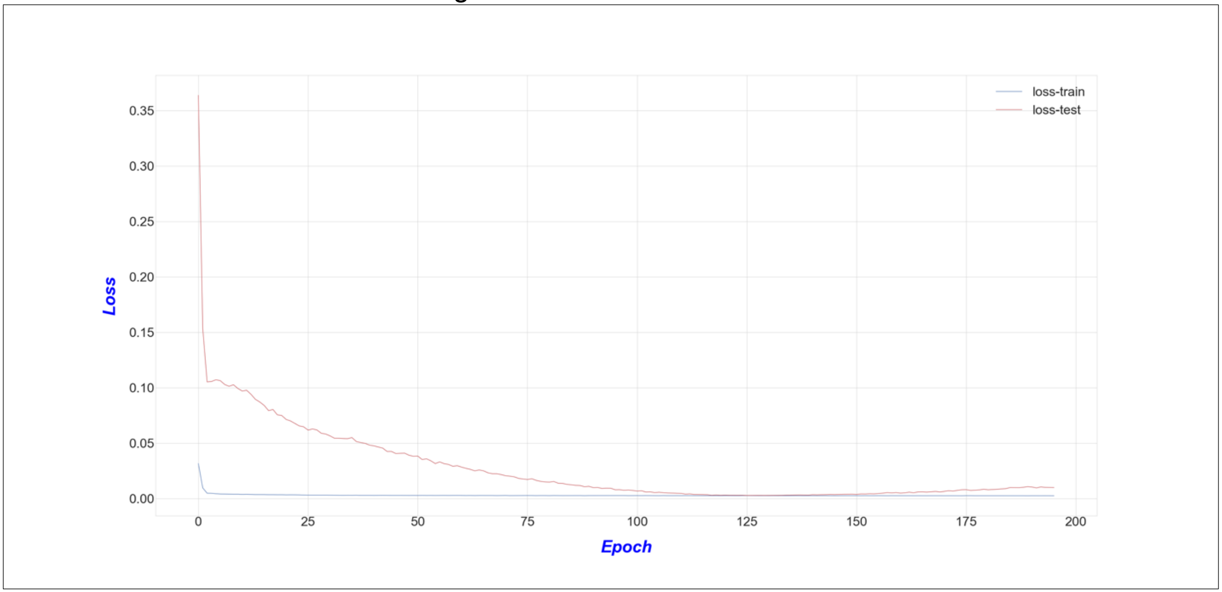


Figure 11: China's Train/Test Plot

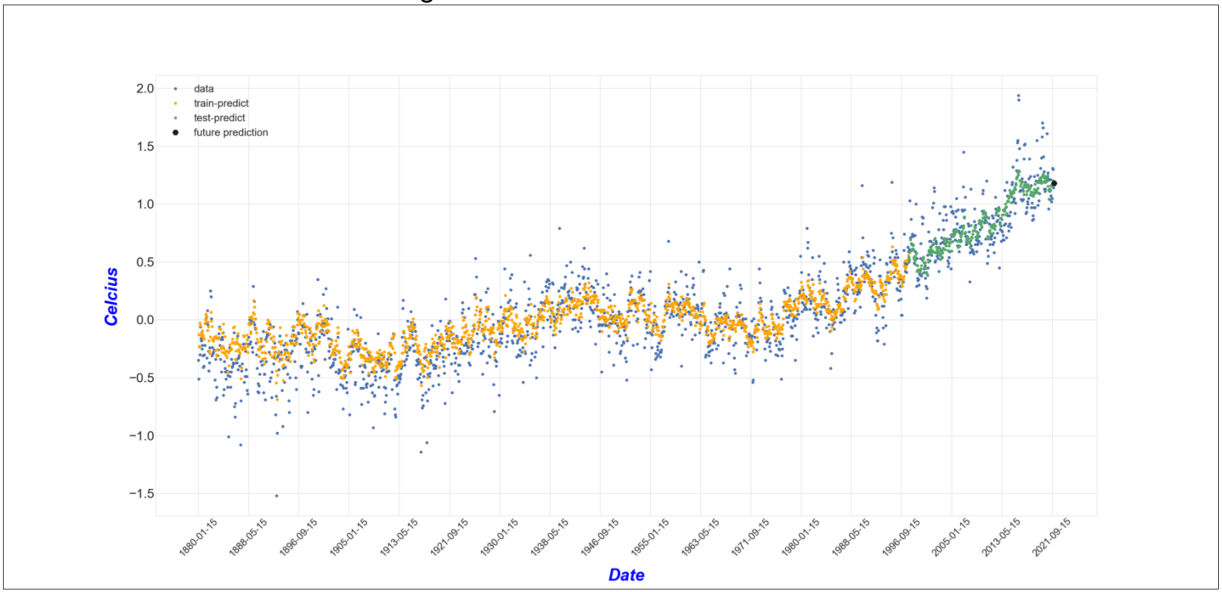


Figure 12: France's Loss Plot

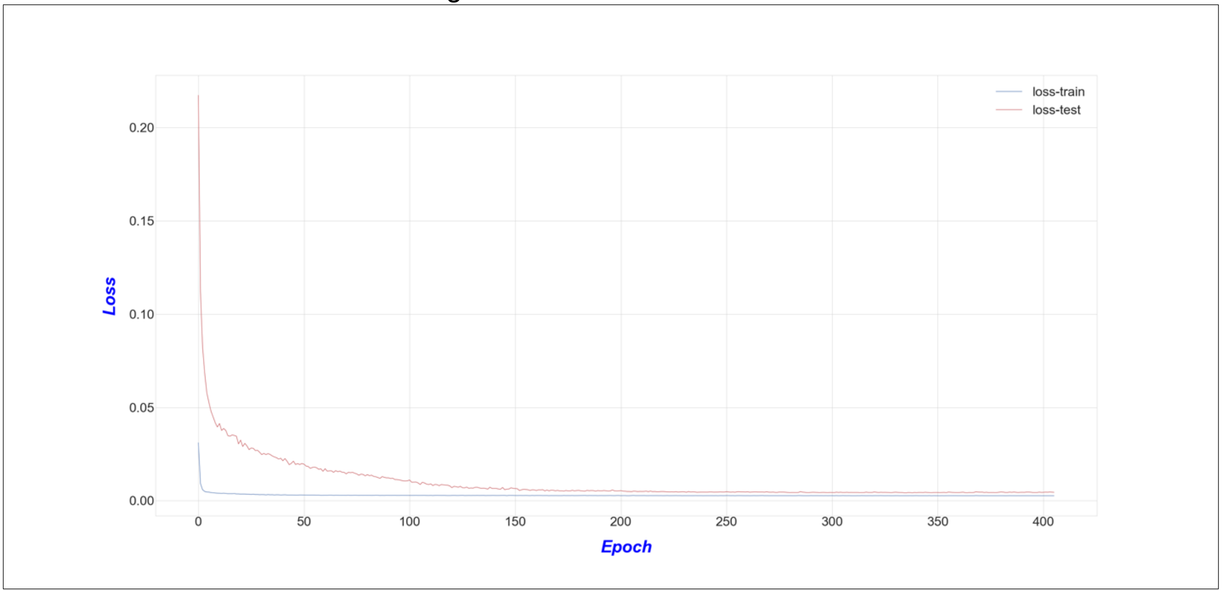


Figure 13: France's Train/Test Plot

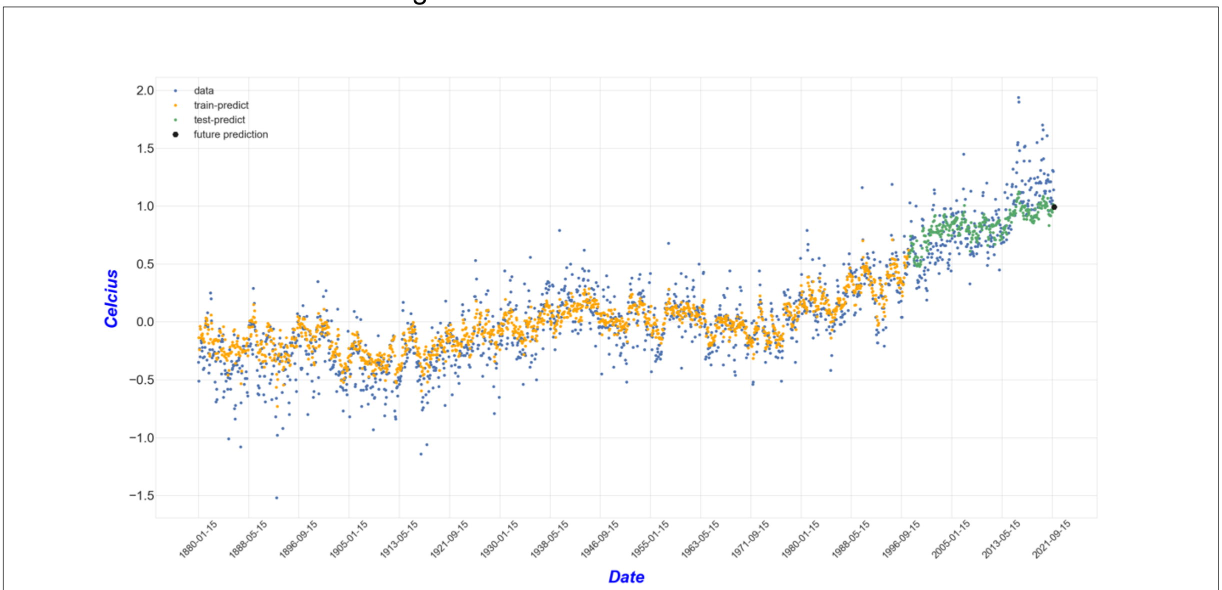


Figure 14: Germany's Loss Plot

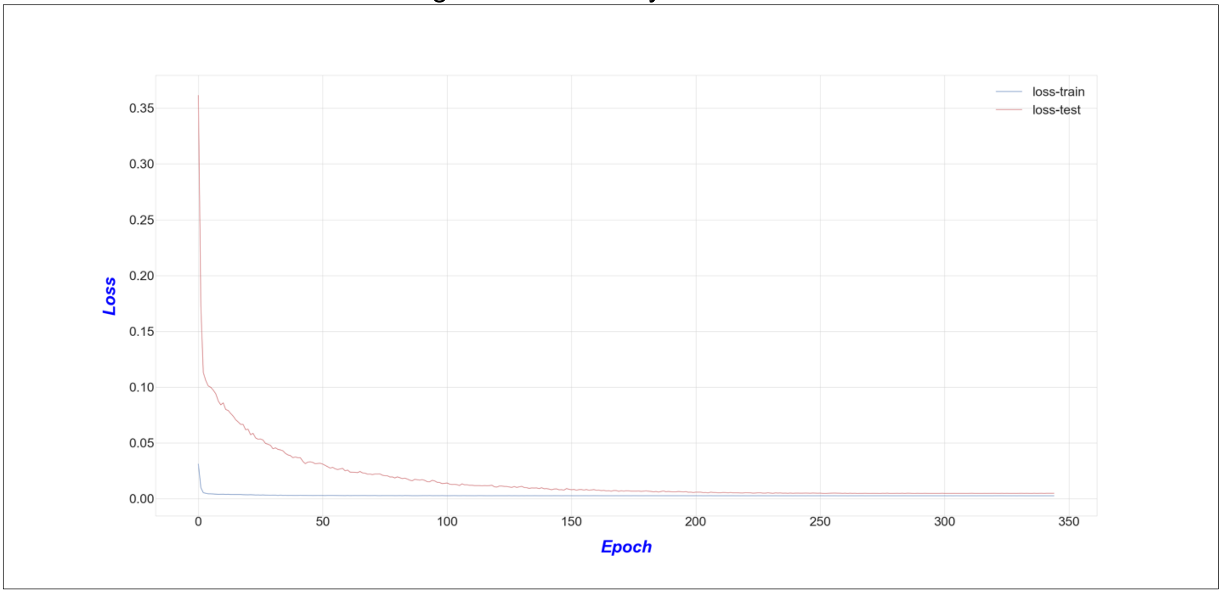


Figure 15: Germany's Train/Test Plot

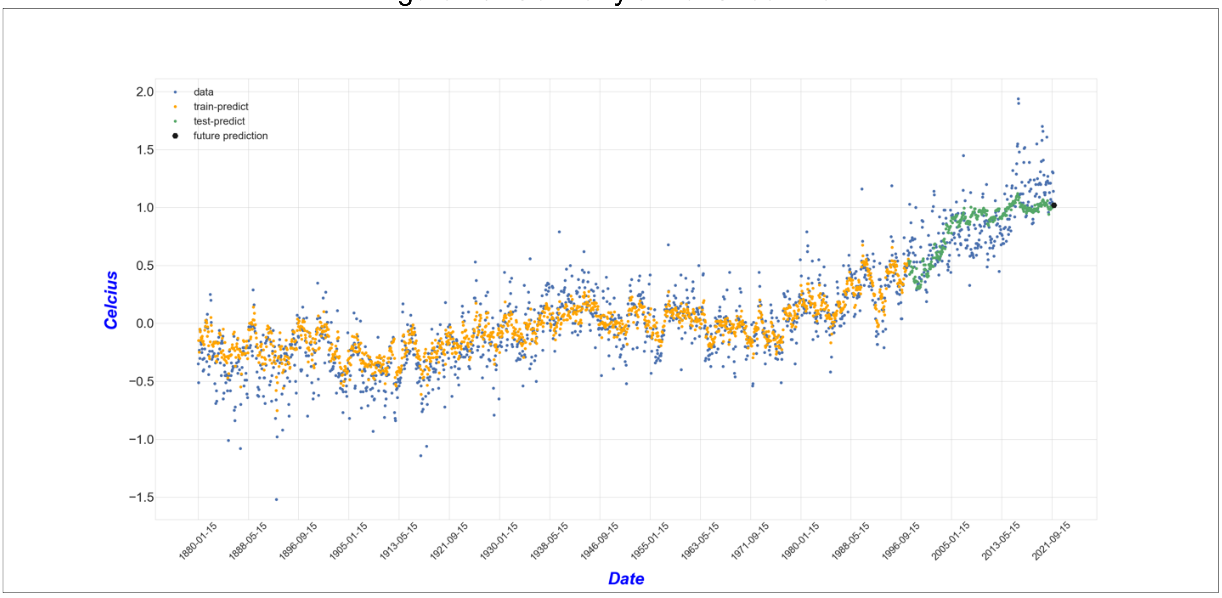


Figure 16: Great Britain's Loss Plot

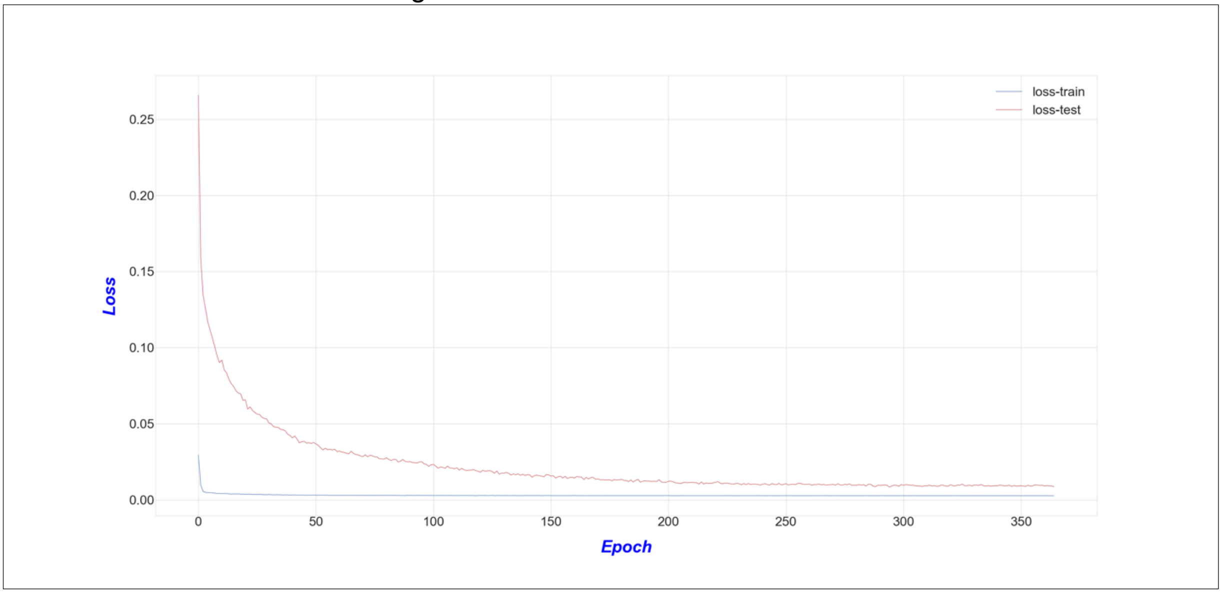


Figure 17: Great Britain's Train/Test Plot

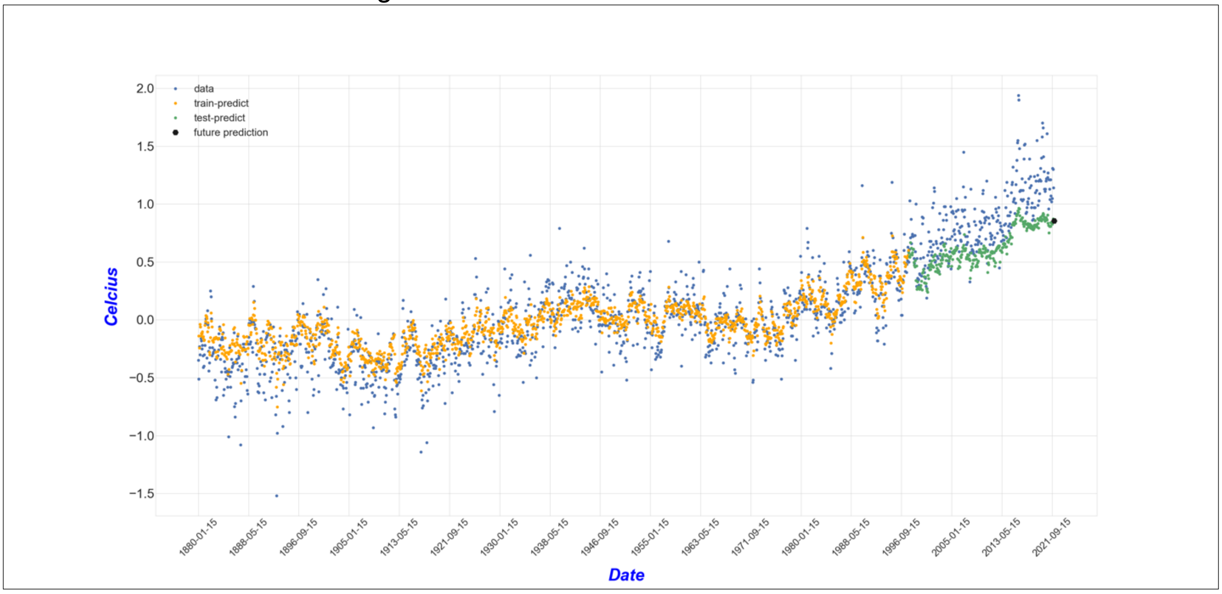


Figure 18: India's Loss Plot

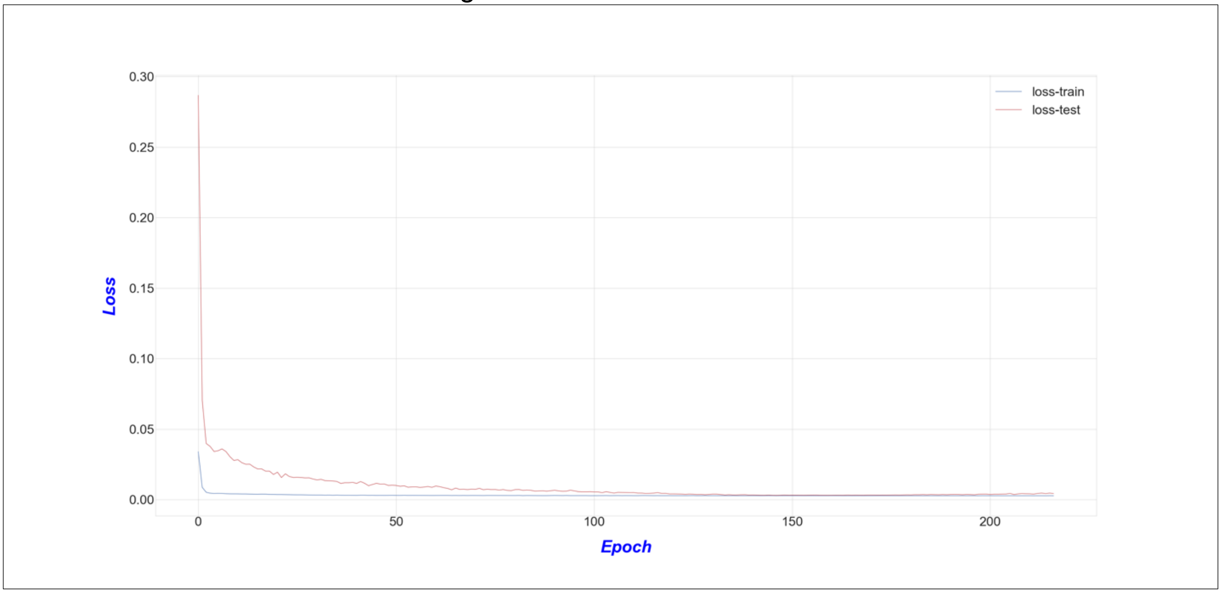


Figure 19: India's Train/Test Plot

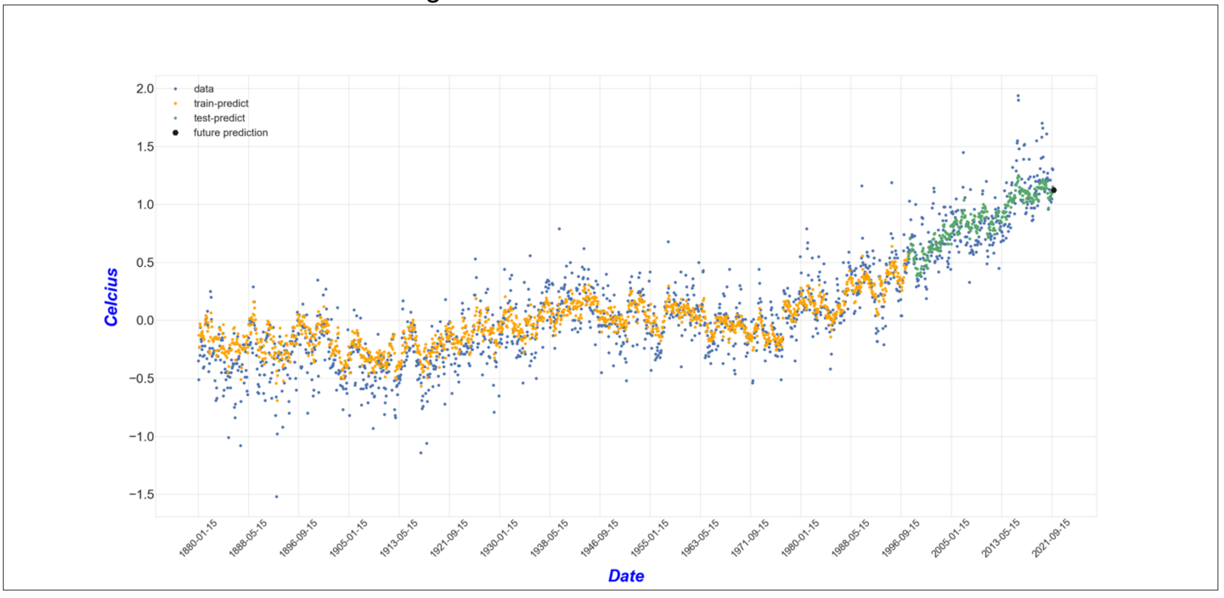


Figure 20: Italy's Loss Plot

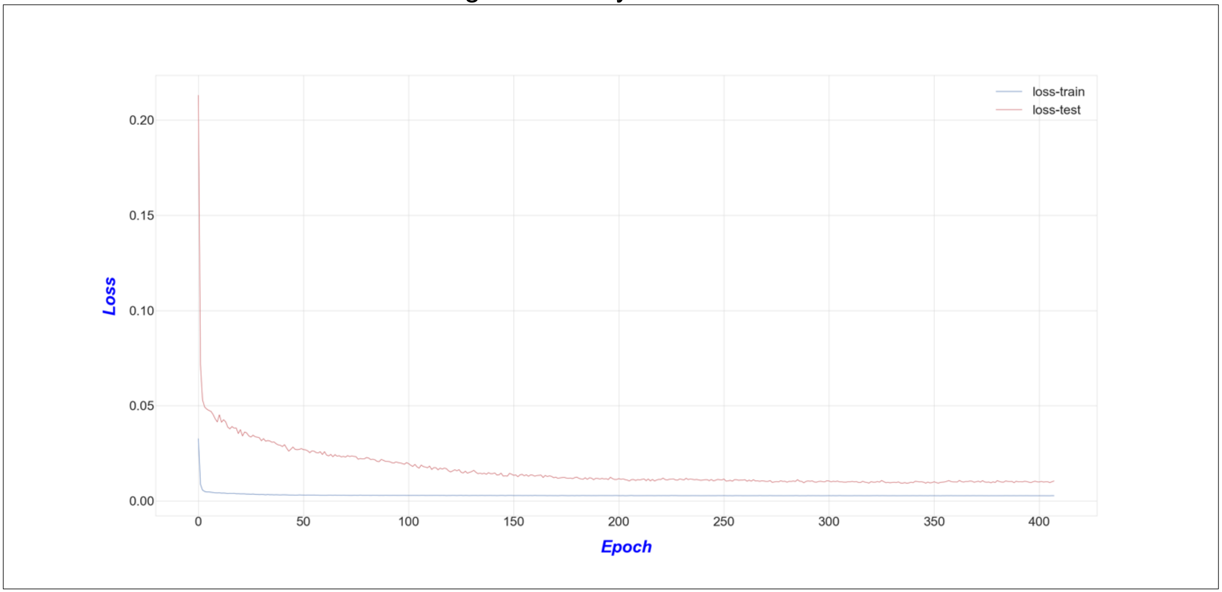


Figure 21: Italy's Train/Test Plot

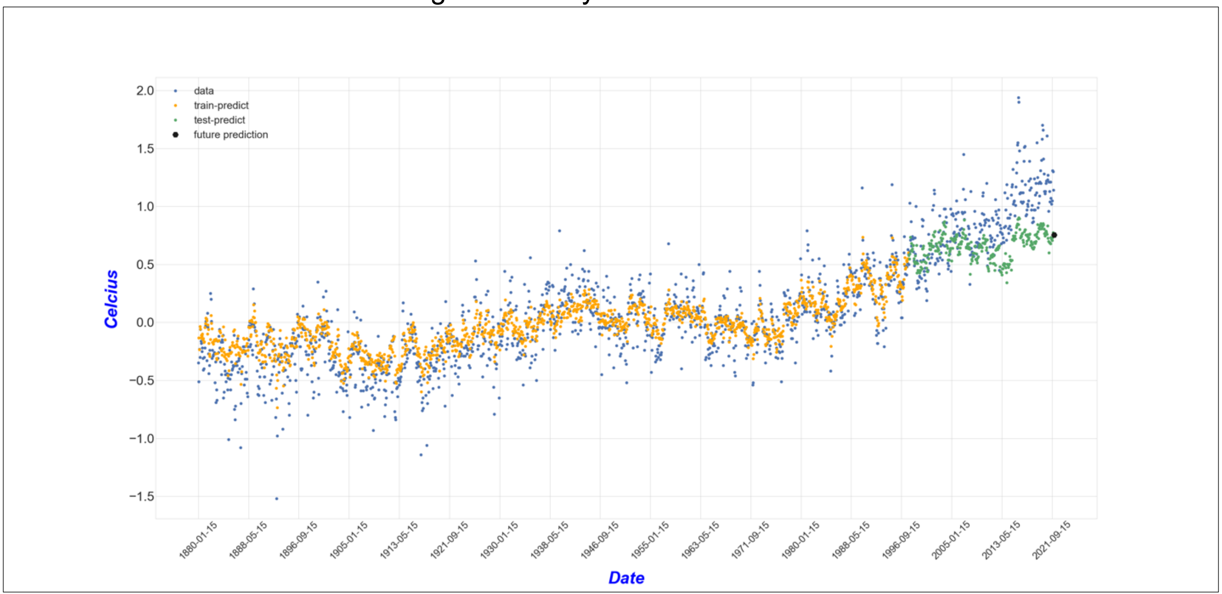


Figure 22: Japan’s Loss Plot

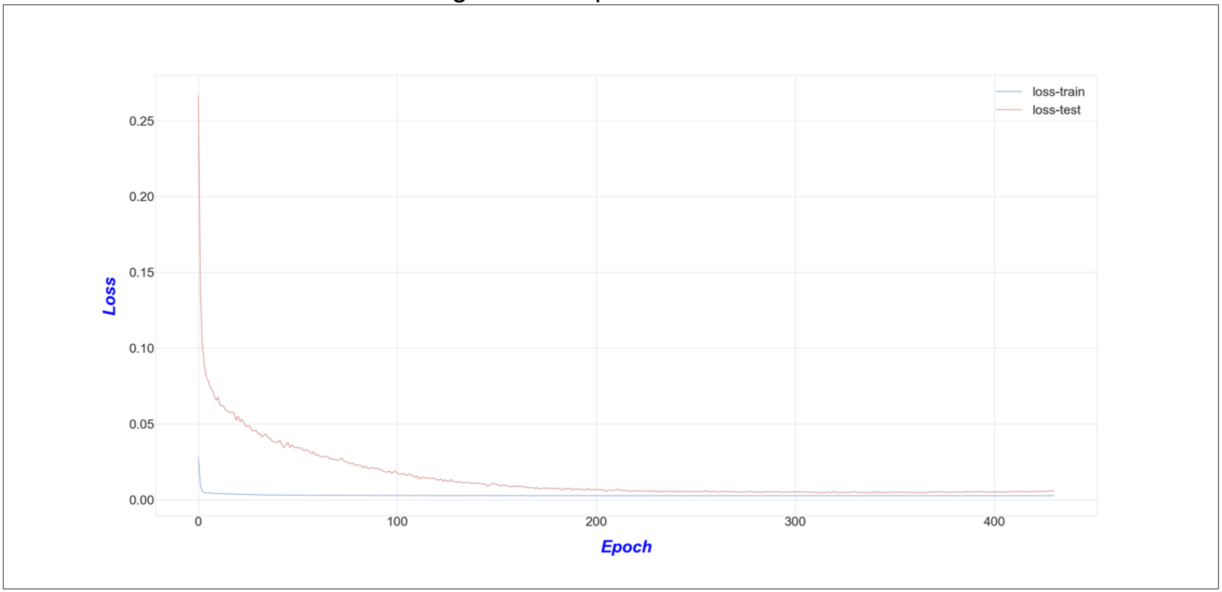


Figure 23: Japan’s Train/Test Plot

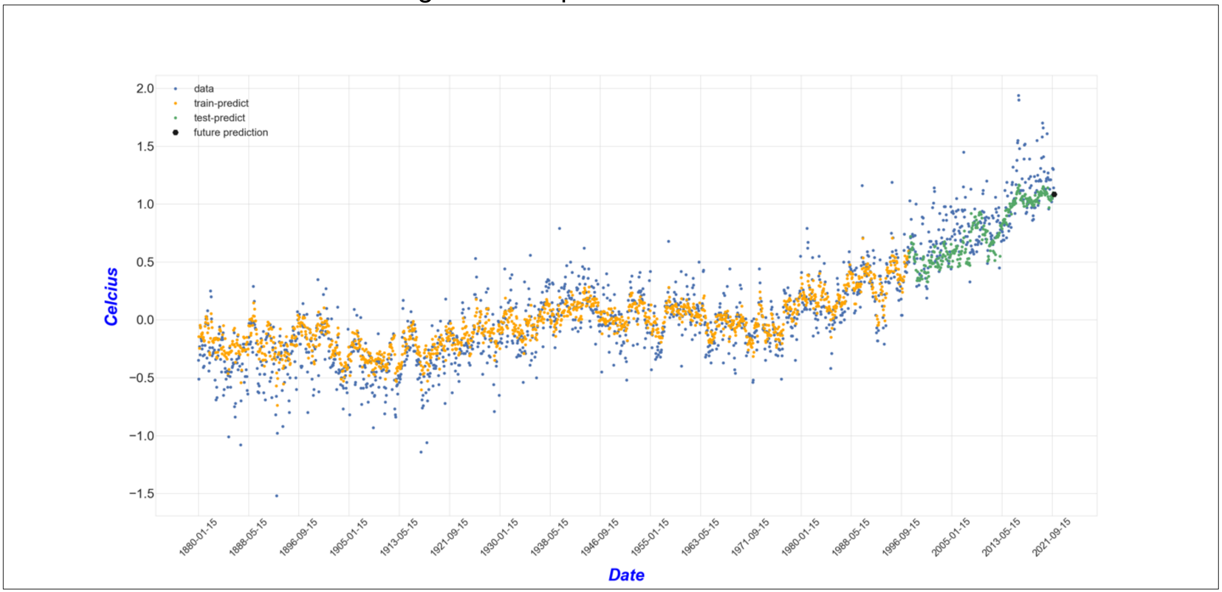


Figure 24: Russia's Loss Plot

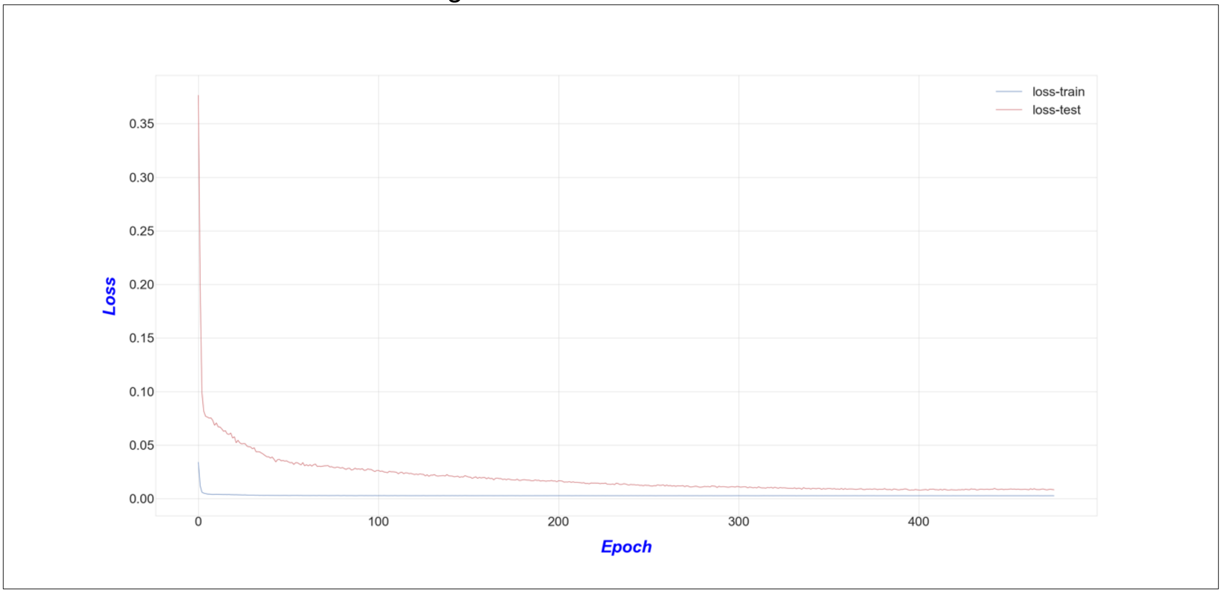


Figure 25: Russia's Train/Test Plot

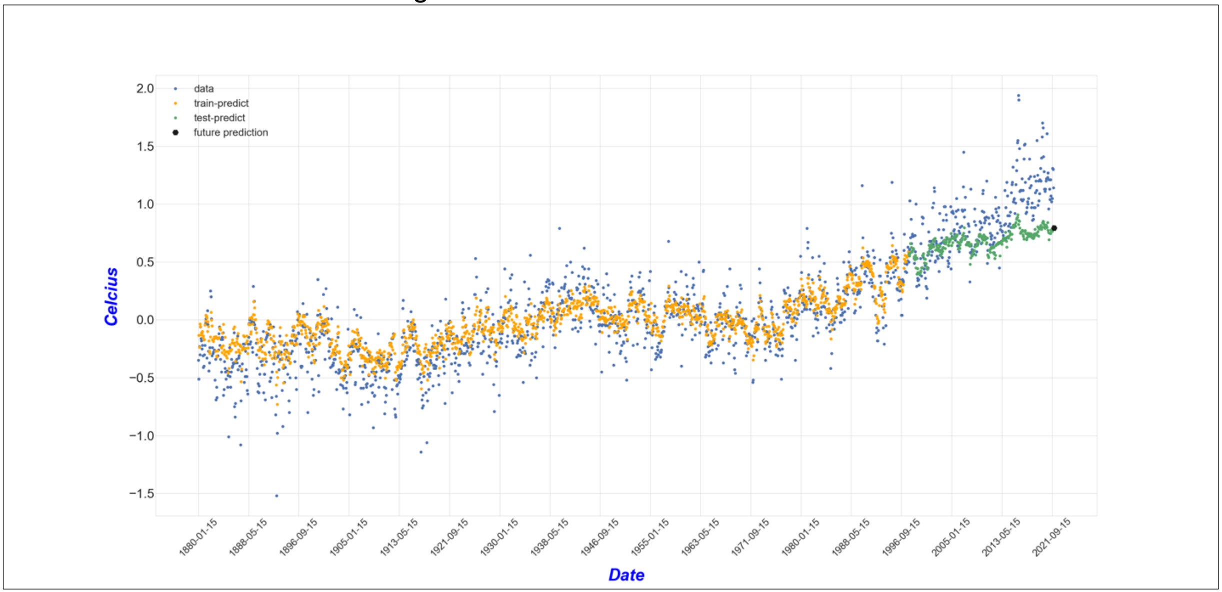


Figure 26: United States' Loss Plot

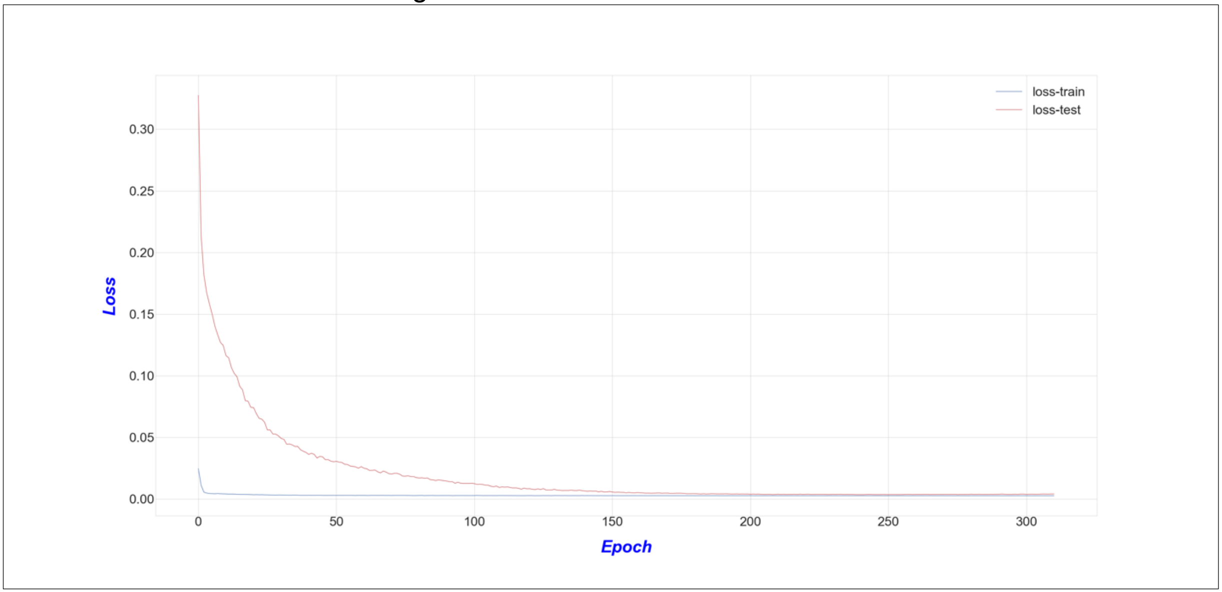
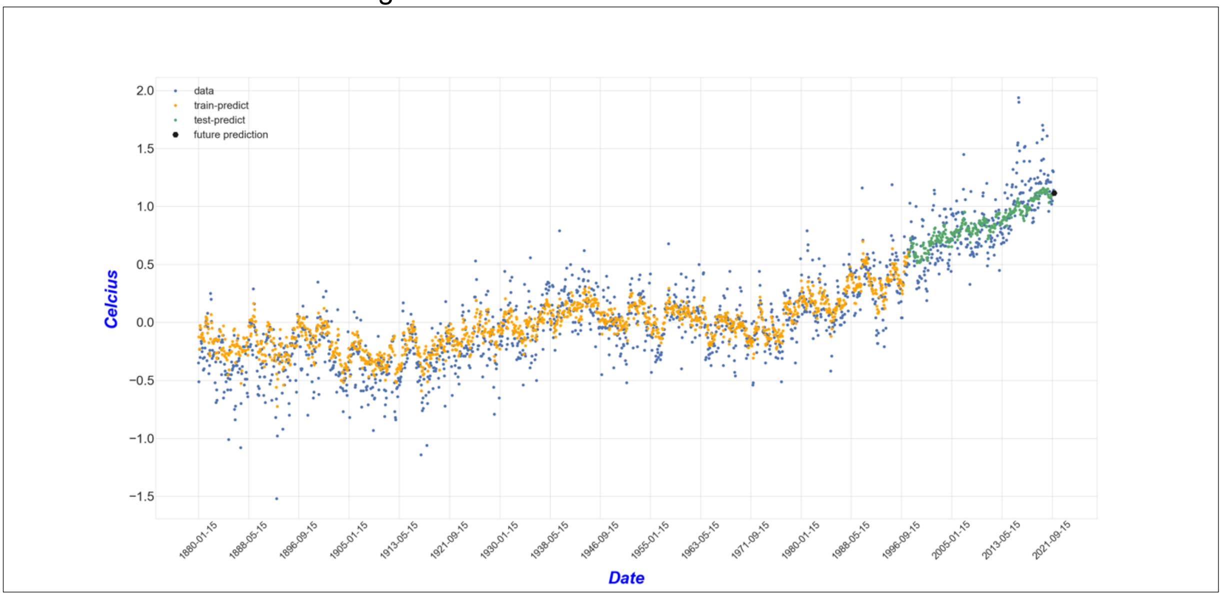


Figure 27: United States' Train/Test Plot



DISCUSSION AND CONCLUSIONS

An LSTM based model was created to predict the temperature change anomaly values for the top 10 GDP ranked countries as provided in datasets (Our Word In Data) and (The World Bank). Techniques were formulated for working with the different data sizes and missing data limitations. By using Keras LSTM layers, the created model was able to make a single prediction on a monthly time granularity. The testing started with various univariate models that took as input the single data feature of the temperature anomaly. Different variations of the model were created including LSTM, stacked LSTM, bidirectional LSTM, and stacked bidirectional LSTM. The final version created was a multivariate model that took the same temperature anomaly feature, ocean temperature anomaly feature, plus an additional 28 features relating to causes of climate change. The multivariate model used a masking layer to ignore missing data values, three bidirectional LSTM layers with a dropout layer in between them and a dense output layer which outputs a single feature value.

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Motivational Factors Impacting Students' Adoption of Synchronous Technologies

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ABSTRACT

This research-in-progress aims to investigate the factors that impact students' adoption and usage of synchronous technologies. The research model is based on and extends the Self-Determination Theory (SDT). We propose that collaboration and enjoyment are antecedents to the factors of the SDT, namely autonomy, competence, and relatedness, which play an intermediary role. To our best knowledge, no study has explored the effect and role of the SDT factors on students' adoption of synchronous technologies. Previous research has also not explored the proposed hypotheses.

KEYWORDS: Synchronous technologies, remote, adoption, teaching, pandemic

INTRODUCTION

The COVID-19 pandemic started in November 2019 in Wuhan, China, and spread very rapidly throughout the world. The pandemic affected all areas of life and caused a lockdown of educational institutions and forced them to go online. Almost all universities were shifted to online learning within a short period of time. Teachers, as well as students, were exposed to new media platforms such as Zoom, Skype, Microsoft teams, Google hangouts, WebEx, and others. Online learning is classified as synchronous or asynchronous. Synchronous technology allows for "live" interaction between the instructor and the students, while asynchronous technologies do not require students' immediate attention or live interaction, so students are free to contribute whenever they choose. Martin and Parker (2014) defined synchronous learning as "communications in which multiple users can simultaneously interact with each other via the Internet to conduct meetings and seminars, lead discussions, make presentations and demonstrations, and perform other functions". To support students to achieve their academic goals and to best resemble the face-to-face environment settings, synchronous technology tools were adopted in many cases (Dang & Zhang, 2022). Lately, the literature shows that there is a significant increase in the adoption and usage of online learning technology tools, especially synchronous ones. For example, Zoom, which is one of the popular platforms using synchronous learning, was downloaded 485 million times in 2020 (Dean, 2022). This study examines the factors leading students to adopt synchronous technologies.
The adoption of synchronous learning increased dramatically during the COVID-19 pandemic, as it was one of the most common ways to continue delivering classes during the pandemic (Chau et al., 2021). Studying the factors impacting students' adoption and usage of synchronous technology has some advantages. First, it can help the educational institutions in their future strategic plans for adopting this technology in their educational system. Second, it provides valuable information to the IT developers and instructional designers on what could be

improved since it indicates the important factors that affect the technology adoption (Merhi, 2015). By taking these factors into consideration, they can develop strategies that enhance synchronous technology to make them more accepted by students to improve their academic achievements.

Few studies have studied students' adoption and usage of synchronous technology tools. Pedroso et al. (2021) determined the factors associated with the adoption and usage of synchronous tools in online learning among 234 Philippine students in two schools. Their analysis demonstrated that attitude towards videoconferencing, perceived class engagement in virtual conferences, perceived ease of use, and perceived usefulness of videoconference technology are the important factors for videoconferencing adoption. Dang and Zhang (2022) investigated the factors that influence students' learning in synchronous technology during the COVID-19 pandemic. A sample of 428 students was selected in Fall 2020 from students who attended various classes in the college of business at Northern Arizona University that adopted the synchronous remote learning methodology. The result showed that students' IT competence (facilitating conditions, task-technology fit, and students' IT competence) had a significant impact on their learning satisfaction; however, it had no significant impact on students' intention to use synchronous remote learning in their future classes. However, social influence was found to have a significant impact on intention to use the remote synchronous technology in future classes, but not satisfaction. Tiwari (2020) assessed the factors affecting the students' adoption of synchronous classes. The study's framework was based on the Unified Theory of Acceptance and Use of Technology model in addition to perceived cost. The results suggested that performance expectancy, effort expectancy, and facilitating conditions have a strong and significant impact on students' adoption. However, social influence showed a weak but significant impact on behavioral intention towards the adoption of synchronous technology. The perceived cost has an insignificant impact on adoption.

This research is an effort to understand the factors which encourage the adoption of synchronous technology at the time of COVID-19 pandemic induced lockdown. Specifically, this study aims to answer two main research questions: (1) what are the factors leading higher education students to adopt synchronous technology? And (2) how do these factors interact and influence synchronous technology adoption? Since the goal IS to examine the motivational factors leading students to adopt the synchronous technologies, we built our research framework based on the Self Determination Theory (SDT) (Rayan & Deci, 2000). We also extend the SDT by examining the influence of collaboration and enjoyment on the SDT factors. This research is presently a "work in progress," but we hope to present the results of empirical findings at the conference.

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

As mentioned earlier, our research framework is based on the SDT (Rayan & Deci, 2000). The SDT of motivation is an empirical theory of human motivation and personality in social conditions. The three factors of SDT are autonomy, competence, and relatedness. Autonomy refers to "the desire to self-initiate and self-regulate one's own behavior" (Sørebø et al., 2009); competence means "Seek to control the outcome and experience mastery" (White, 1959); and relatedness refers to "interact with, be connected to, and experience caring for others" (Baumeister & Leary, 1995).

A few research articles concluded that SDT has an impact on students' adoption and usage of e-learning technologies. For example, Nikou & Economides (2017) examined the factors affecting students' adoption of the Mobile-Based Assessment (MBA) delivery mode. The study showed that the SDT factors (autonomy, competence, and relatedness) have a significant impact on adoption through perceived usefulness and perceived ease of use. Nikou &

Economides (2017) did not examine the direct of SDT factors on adoption. Gupta (2019) investigated the factors impacting the adoption of massive open online courses (MOOCs), using both SDT and technology-user-environment (TUE) frameworks. The findings indicate that the students' intention to adopt MOOCs is significantly affected by motivation, social recognition, perceived value, and perceived usefulness. However, the personal readiness, self-regulation of learners, and peer influence do not have a significant impact on MOOCs adoption. To the best of our knowledge, no study has yet explored the factors that influence students' adoption of synchronous technologies using STD. Moreover, in this study, we not only assess the direct role of the SDT factors (relatedness, competence, and autonomy) on students' adoption but also examine their antecedents –collaboration and enjoyment- and the inter-relationships between the antecedents.

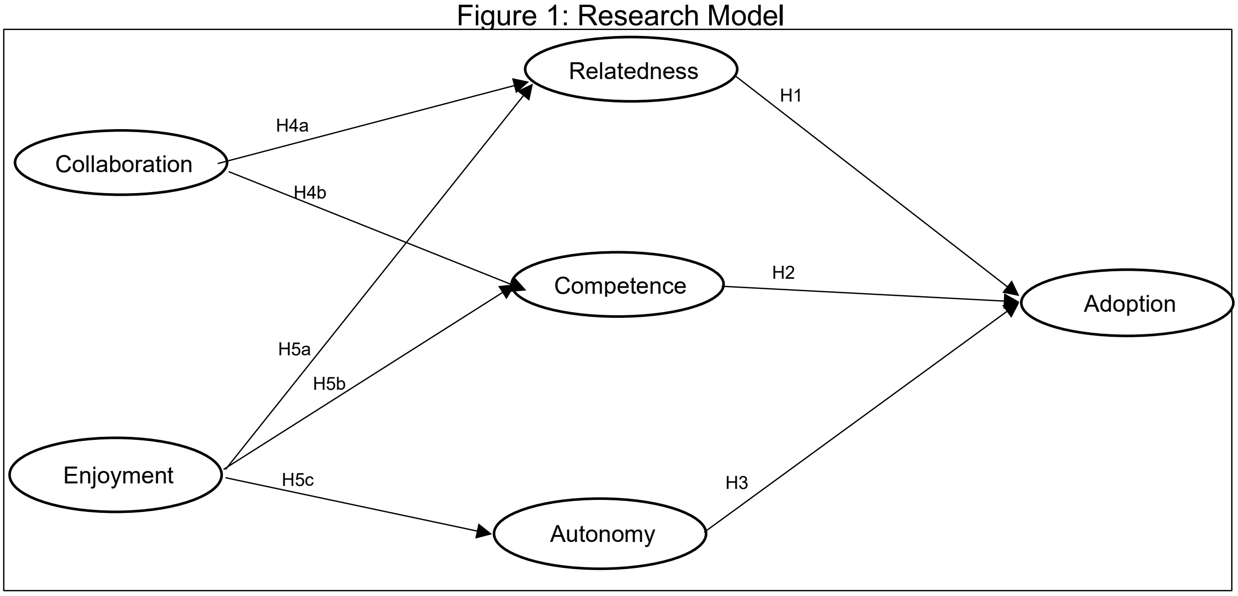
RESEARCH MODEL

In this section, we discuss the research and the hypotheses that we intend to empirically assess. Figure 1 demonstrates the research model. Adoption is a function of students' perceptions of relatedness, competence, and autonomy. Enjoyment and collaboration influence relatedness, competence, and autonomy. Below is a brief description of each of these factors along with the hypotheses.

Relatedness refers to connectedness to other peers. We argue that the feeling of relatedness impacts technology adoption. That is, the higher the level of relatedness is, the greater the adoption of synchronous technology. No study has yet examined this relationship.

H1: Relatedness positively impacts the adoption of synchronous technologies.

Figure 1: Research Model



Competence refers to the capability of the user to use the knowledge and skills to achieve the goals. We argue that the students who are knowledgeable in synchronous technology may have more interest in adopting the synchronous technology. That is the higher level of competence, the more synchronous technology adoption. Scholars found a significant relationship between competence and satisfaction with the technology (Merhi & Meisami, 2022). However, no one has assessed the impact of competence on adoption. Based on the logic we presented, we hypothesize that:

H2: Competence positively influences the adoption of synchronous technologies.

Autonomy refers to one's exposition of control over their own goals and actions (Rayan & Deci, 2000). Researchers have validated the impact of autonomy on an individual's behavior in different settings except in technology adoption. We argue that higher levels of autonomy leads to adoption due to the advantages that synchronous technologies offer. The flexibility and the mimic of the face-to-face advantages that result from using synchronous technologies lead students to adopt them. Thus, we hypothesize that:
H3: Autonomy positively affects the adoption of synchronous technologies.

Collaboration refers to any form of interaction that requires individuals to interact with each other to complete a task. Collaboration improves the way the team work together, which leads to more innovation, improved communication, and establishment of connection among the students. In addition, collaboration also helps in acquiring new skills since students help each other when collaborating. Thus, students feel more competent. Based on this brief discussion, we hypothesize that:
H4a: Collaboration positively impacts relatedness.
H4b: Collaboration positively influences competence.
We should note that no research has examined these relationships.

Perceived enjoyment is the extent to which the activity of using any technology is perceived to be enjoyable in its own right despite any performance consequences that may be expected (Merhi, 2019). Munoz-Carril et al. (2021) defined perceived enjoyment as "how enjoyable students find the process of learning in technologically-mediated collaboration, regardless of the result of the collaboration process itself." Researchers have examined the impact of relatedness, competence, and autonomy on engagement. Kim et al. (2018) found that competence, autonomy, and relatedness have a positive effect on enjoyment. Cariney et al. (2012) concluded that perceived competence was associated with higher enjoyment. Leptokaridou et al. (2015) discussed the psychological needs for autonomy, competence, and relatedness with self-reported enjoyment and effort in elementary school Physical Education. They found that all three needs directly and positively predicted pupils' enjoyment and effort. We should note that these studies were not examining enjoyment with the technology. We argue the opposite of these studies when it comes to technology. We argue that engagement is an antecedent to relatedness, competence, and autonomy. In other words, the higher the level of enjoyment, the higher the level of relatedness, competence, and autonomy will be. The reason is that when students are enjoying the activity, they will feel connected to their peers. Similarly, enjoying an activity leads to fulfilling the desire of being productive and autonomous. Based on this, we hypothesize the following:
H5a: Enjoyment positively impacts relatedness.
H5b: Enjoyment positively influences competence.
H5c: Enjoyment positively affects autonomy.
In addition to the above direct relationships, we plan to test the mediating role of the SDT factors.

PROPOSED METHODOLOGY

Research Method and Measures

We are going to use the survey methodology to assess and investigate the presented research model. We just finished the data collection and had no time to run the analysis. We will present the findings at the conference. We collected data from 420 students from a public institution in the Midwest of the United States. The instrument used for this study is based on previously validated measures. The majority of the scale items are adopted from the previous literature but adapted to the context of this study.

Proposed Analysis Methods

We will execute several statistical tests on the data we collected. The first analysis tests the data for outliers and normality. After this, we will check for construct validity, convergent validity, and discriminant validity. After confirming the validity of the instrument, we will use Structural Equation Modeling (SEM) to assess and investigate the hypothesized causal paths among the constructs. This helps us to determine if the presented conceptual model had provided an acceptable fit to the empirical data gathered or not.

CONCLUSION

The COVID-19 pandemic has forced countries including educational institutions to close down and change the way courses are offered. Many institutions adopted synchronous technologies. Many will probably continue using these technologies in the future. Thus, it is crucial to examine what impacts students' decision to adopt these technologies. The extant literature lacks studies on this important topic. This study fills a gap in the literature by extending the SDT and offering new hypotheses that have not been tested. We collected data and will present the empirical results at the conference.

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DECISION SCIENCES INSTITUTE
On the Efficiency of Sports Betting Markets

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ABSTRACT

Betting on sports is increasingly popular, and legal in the United States. Ever since the Supreme Court removed the PASPA ban on sports betting many states have moved to legalize sports betting both in-person and on-line. In this paper we evaluate the sports betting market and assess its efficiency in the financial sense. Using a large dataset of betting odds and outcomes we evaluate the weak-form efficiency across major North America sports. We find statistically significant inefficiencies in professional and collegiate football, college basketball, and MLB. We are however unable to demonstrate statistically significant inefficiencies in the NBA or NHL.

KEYWORDS: Sports Betting, Market Efficiency

INTRODUCTION

Gambling has been popular throughout human history, and gambling on sports has been popular as long as there have been sports. But the legality of sports betting in the United States has varied considerably over time. The Professional and Amateur Sports Protection Act of 1992, also known as PASPA or the Bradley Act, effectively outlawed betting on most sports throughout most of the US, making exceptions only for licensed sports pools in Nevada as well as lotteries in Oregon, Delaware and Montana. Excluded from the reach of PASPA were jai alai, as well as parimutuel horse and dog racing.

The situation changed dramatically in 2018 when the United States Supreme Court ruling in Murphy vs. NCAA struck down the PASPA law and returned the regulation of gambling to the states. In the years since many states have moved to legalize sports gambling, both in-person and on-line. Total betting numbers are uncertain, but in 2019 betting in the Vegas sportsbook alone exceeded $5 billion. In the first quarter of 2022 DraftKings Inc., one of the larger on-line sportsbooks, reported quarterly revenue of $417 million dollars, a 34% increase from the prior year (Jones 2022). Sports betting is now a large and growing financial market, increasingly legal and in the open.

In this paper we evaluate the sports betting market and assess its efficiency in the financial sense. Using a dataset of odds and results on over 140 thousand sporting contests across the major sports in North America that covers 15 seasons, we evaluate the accuracy and efficiency of the odds to assess if the markets can be considered weak-form efficient. Our analysis finds that inefficiencies exist in the odds to the degree that we conclude that some of the markets are not weak-form efficient. These inefficiencies vary from sport to sport, but are reasonably consistent over time. However, the level of inefficiency is small enough that it remains difficult for a bettor to exploit them profitably in the short term or on an after-tax basis.

LITERATURE REVIEW

Capital Market Efficiency

The focus of our analysis is on the efficiency of the sports betting markets. Market Efficiency is a concept first developed in the economics and finance literature as defined by the efficient market hypothesis. (EMH). The efficient-market hypothesis (EMH) is a hypothesis in financial economics that states that asset prices *fully reflect* all available information. A direct implication is that it is impossible to "beat the market" consistently on a risk-adjusted basis since market prices should only react to new information (Wikipedia 2022).

A key review of the theoretical and empirical literature on the Empirical Market Hypothesis is provided in Fama (1970). Fama analyzes efficient markets relative to three board information sets. Weak form efficiency is based on the use of historical prices, semi-strong efficiency on publicly available information, and strong efficiency is based on all information public and private. In this framework the possibility of trading systems based on the relevant information set generating excess returns, returns in excess of equilibrium expected profits are ruled out. Stated simply, excess profits are not possible from a trading system in a market that is efficient. The empirical analysis in this paper provides reasonably strong support for the weak, and semi-strong forms of market efficiency. The analysis however identified exceptions to the strong form of market efficiency whereby market makers and corporate insiders can exploit their monopolistic access to information to earn returns in excess of the expected risk-adjusted rate.

Sports Betting Market Efficiency

A large body of research published beginning in the 1980s and 90s examined efficiency in sports betting markets. Much of this early research focused on pari-mutual and fixed odds systems in horse racing. A comprehensive review of this literature is provided in (Kuypers 2000). Kuypers reviews 5 papers that examine pari-mutual systems, 6 papers on odds-based systems, and 4 papers on spread based systems. Seven of the reviewed papers assess weak form efficiency, while six examine semi-strong efficiency and two assess strong-form efficiency.

Kuypers uses the following definitions of efficiency in the sports betting context:

- Weak form: no abnormal returns, either to the bookmaker or the bettor, can be achieved solely from price information. An abnormal return is defined as a return different from the bookmaker's expected take.
- Semi-strong: no abnormal returns can be achieved from odds or any publicly available information.
- Strong: no abnormal returns can be achieved by any group in society incorporating odds publicly available and privately available information.

Our analysis will focus on weak form efficiency. The implication of weak form efficiency is that the return on bets in any odds range to a bettor will be negative, consistent across odds ranges, and equal to the bookmaker's average hold.

Kuyper tests weak-form efficiency in the betting market for UK football (soccer) analyzing 3882 matches from 1993-95. He divides the bets into 20 bins and calculates the expected after-tax return from taking all bets in each bin and compares those returns to the expected after-tax return of -18.5% implied by the fixed hold. The analysis finds that all returns are negative. The best return is -3.13% in the odds bin where the mid-point implied probability is 49%; the slight underdog. His analysis concludes that while market inefficiencies exist, no formula based simply on betting an odds range will yield a positive return. He further concludes that there is no systematic bias in the odds by regressing the actual win probabilities against the implied win probabilities for each group and failing to reject the null hypothesis that the slope is equal to one.

A more recent examination of English football is performed in Deschamps and Gergaud (2007). They analyze 8,377 matches between 2002 and 2006 with odds from six different bookmakers. They also find considerable variation across odds groups, but no positive returns. Another assessment of English football odds is provided in (Direr 2011). Direr evaluates 11 years of odds (200-2011) from 6-10 odds makers, for a total of nearly 80,00 games and 2.8 million betting opportunities. He finds that positive returns are available in the range of 2.8% for average odds, and 4.4% for best odds by betting on overwhelming favorites.

Other papers perform similar analysis on other sports. Levitt (2003) examines NFL games. (Hickman 2020) – looks at the NCAA “March Madness” basketball tournament. Gandar, Zuber et al. (2004) examines the National Hockey League (NHL) while Gandar, Zuber et al. (1988) looks at point spreads in NFL games. They implement two tests and come up with mixed results. A statistical test fails to reject rationality, while an economic test does reject rationality.

<u>Longshot Bias</u>

A specific type of inefficiency, and a frequent topic of analysis in betting markets, is the so-called longshot, or favorite-longshot, bias (FLB). An early review and assessment of this phenomenon was presented in the inaugural Anomalies series in the Journal of Economic Perspectives (Thaler and Ziemba 1988). This paper analyzed parimutuel betting and re-asserts the criteria that in a weekly efficient market no best should have a positive expected value, and in a strongly efficient market all bets have an expected value of (1-*t*), where *t* is the racetrack’s fixed take. The review demonstrates that the returns are systematically associated with the odds. Bets on favorites earn an above average return, while bets on longshots earn below average returns. Parimutuel odds are directly set by the amount bet so the longshot bias indicates that bettors systematically overestimate the probability that a longshot will pull off the upset. The longshot bias has at least two alternative explanations; risk seeking behavior by the bettor, or misestimation of the odds in extreme scenarios. Odds misperception is consistent with Prospect Theory’s assertion that individuals overestimate the likelihood of rare events (Kahneman and Tversky 1979). A detailed comparison of these two possible explanations is presented in Snowberg and Wolfers (2010), who argue the data support the misperception hypothesis. A textbook level description of the phenomenon is provided in (Ottaviani and Sørensen 2008). They review the two explanations discussed above, as well as several others. A more recent review of the literature on the longshot bias is presented in Newall and Cortis (2021).

One additional explanation of the longshot bias is that some bettors posses private (inside) information. This approach, sometimes known as the Shin model, was developed by Hyun Song Shin in the early 1990s (Shin 1991, Shin 1992, Shin 1993). It has been further explored in subsequent papers (Cain, Law et al. 2003). Empirical analyses of the longshot bias have been published for sports such as UK football (Peel, Cain et al. 2000) and major league baseball (Gandar, Zuber et al. 2002).

THE DATA SET

Our data set includes odds and results on major professional and collegiate sports. Data has been collected from the website Sports Book Review (TopSportsbooks 2022). Odds are provided for professional football (NFL), college football (CFB) professional basketball (NBA), college basketball (CBB), major league baseball (MLB) and professional hockey (NHL).

Sport Book Review provides a single file for each sport for each season. The type of data varies from sport to sport and even season to season, and the data is not without issue. Considerable effort was required to merge and clean the data. After eliminating records without the required odds we were left with the following data set.

Table 1- Data Set Summary

Data Set Summary

Through April 2022

League	From	To	Games	Beg	End	Seasons	Teams
CBB	2007-11-05	2022-02-28	58,874	2007-08	2021-22	15	385
CFB	2007-08-30	2022-01-10	13,023	2007-08	2021-22	15	263
MLB	2010-04-04	2022-04-24	27,776	2010	2022	13	30
NBA	2007-10-30	2022-04-24	19,098	2007-08	2021-22	15	30
NFL	2007-09-06	2022-02-13	4,025	2007-08	2021-22	15	32
NHL	2007-09-29	2022-04-24	18,814	2007-08	2021-22	15	33

The data set includes 141,610 games from August 2007 through April 2022.

BETTING ODDS AND PROBABILITIES

The menu of bets that can be made on sports is very large. Bets can be placed on almost anything related to a game, a team, or even individual performances of players. With minor variations from sport to sport, the main betting options have three different components: totals, spreads and moneyline.

- Totals: the total, or over/under, is a bet on the total points scored in the game. Bettors can bet the total points will be over, or under the stated line.
- Spreads: a bet on a team to win be a certain margin. The underdog is bet with plus points, the favored with negative points.
- Moneyline: a straight bet on what team will win the game. Moneyline bets are made with differential payouts such that a bet on a favorite will risk more than can be won, while a bet on an underdog will return more than the amount risked.

Note that both totals and spread bets are quoted along with moneyline odds so that the payout to a winner is less than the amount risked. Odds are stated in different equivalent formats in different locations and different settings. In the United States odds are most often quoted in American Odds format.

In the American format the odds can be expressed as either a positive number or a negative number. A positive number shows the profit a successful wager will return on a $100 bet. So, for example, a bettor who wagers $100 at +110 odds and wins, will earn a profit of $110, plus the original wager of $100 for a total payout of $210. Positive odds typically imply the team is an underdog. Conversely, negative odds show how much a bettor must risk to earn a $100 profit. So, for example if a bet is made for $120 at -120 odds, the successful bettor will receive a profit of $100, plus the original wager of $120 for a total payout of $220. The favorite team is given negative odds, but in some evenly matched games both teams may have negative odds. More formally the Payout *P* to a wager of stake *S*, at odds *M* are given by equation (1).

$$P = \begin{cases} S \times \dfrac{M}{100} + S & \text{for M} > 0 \\ \dfrac{S}{-M/100} + S & \text{for M} \le 0 \end{cases} \tag{1}$$

Odds of +100- and -100 are equivalent. In practice *M* is always quoted as a number with an absolute value greater than or equal to 100. So, while odds of -125 and +80 would both return a profit of $80on a $100 bet, the odds are always quoted as -125.

Moneyline odds carry an implied probability of success. The implied probability is the probability at which a bettor is indifferent to taking either side of the bet. The probability calculation in the American odds format again depends on whether the odds are positive or negative. So, for a bet with odds *M*, the implied probability *p* is given by

$$p = \begin{cases} \dfrac{100}{M + 100} & \text{for M} > 0 \\ \dfrac{-M}{-M + 100} & \text{for M} \le 0 \end{cases} \tag{2}$$

While equation (2) gives the odds on one side of a bet, the bookmaker quotes odds in pairs. So, for example, a bookmaker might quote odds of -120 for a favorite and +110 for the underdog. Converting each of these to implied probabilities gives probabilities of 54.5% and 47.6%. These odds are not fair, in the sense that they add up to more than 100%. The excess probability, in this example 2.1%, is the book margin (*k*), sometimes referred to as the *vig* or the *juice*. The book margin exists so that the bookmaker is guaranteed a profit as long as bets are made in the appropriate proportion. Book margins in the range of 3%-5% are common.

In order to convert the bookmaker's odds into meaningful probability estimates the odds must be converted to consistent probabilities. Draws are rare in the sports we are evaluating. So, if the contest ends in a draw all win-lose bets are effectively cancelled and bettors are returned their original stake. The most common way to convert the implied probabilities is a simple normalization process. So, for a contest with implied probabilities of p_1 and p_2, the normalized probability that team 1 will win the game and bets will pay is

$$p_{1_n} = \frac{p_1}{p_1 + p_2} \tag{3}$$

THE SPORTSBOOK'S MARGIN

Because the implied odds are unfair, they add up to more than one, the sports book has a built-in advantage. The excess probability gives the sportsbook a built-in margin, appropriately allocated bets on either side will guarantee the book a profit. The sportsbook's profit margin is proportional to the book sum, the excess implied probability in the stated odds. If we have a two-way bet with implied odds p_1 and p_2, then the booksum *k*, is given by

$$k = p_1 + p_2 - 1 \tag{4}$$

The bookmaker's margin (*m*), also known as the *hold*, is the sportsbook's average profit and can be shown to be

$$m = \frac{k}{k+1} \tag{5}$$

The booksum and margin varies from game to game, and league to league, but typically averages in the 3% range. Summary metrics for our dataset by league are shown in Table 3

Table 2- Average Margin

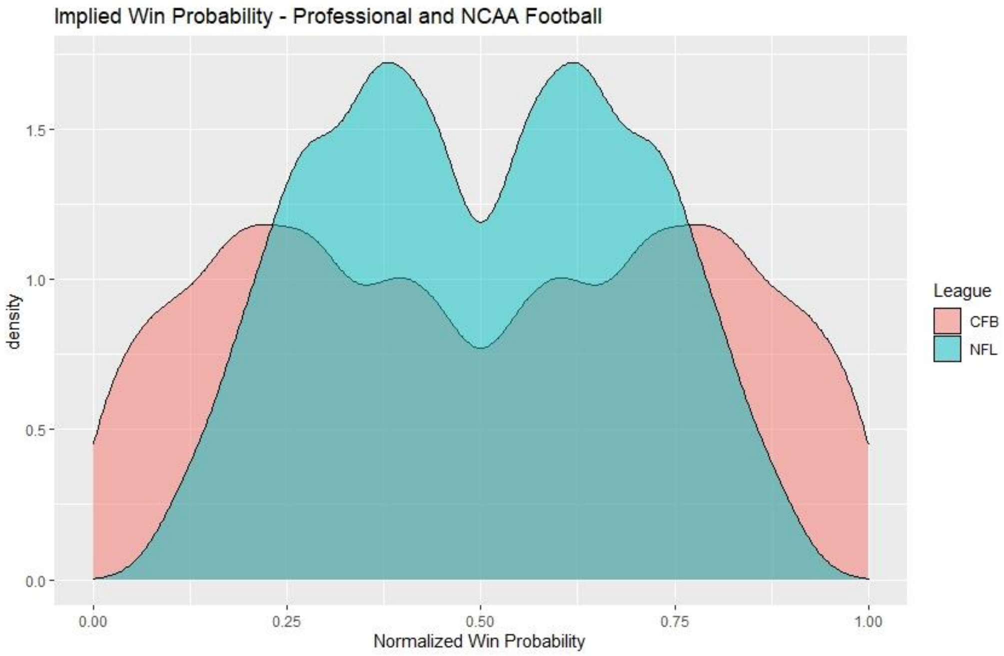
Booksum and Margin by League
2007- 2022

League	K	M
CBB	4.06%	3.90%
CFB	3.50%	3.38%
MLB	2.92%	2.84%
NBA	3.77%	3.64%
NFL	3.79%	3.65%
NHL	3.43%	3.32%

EMPIRICAL ODDS DISTRIBUTIONS

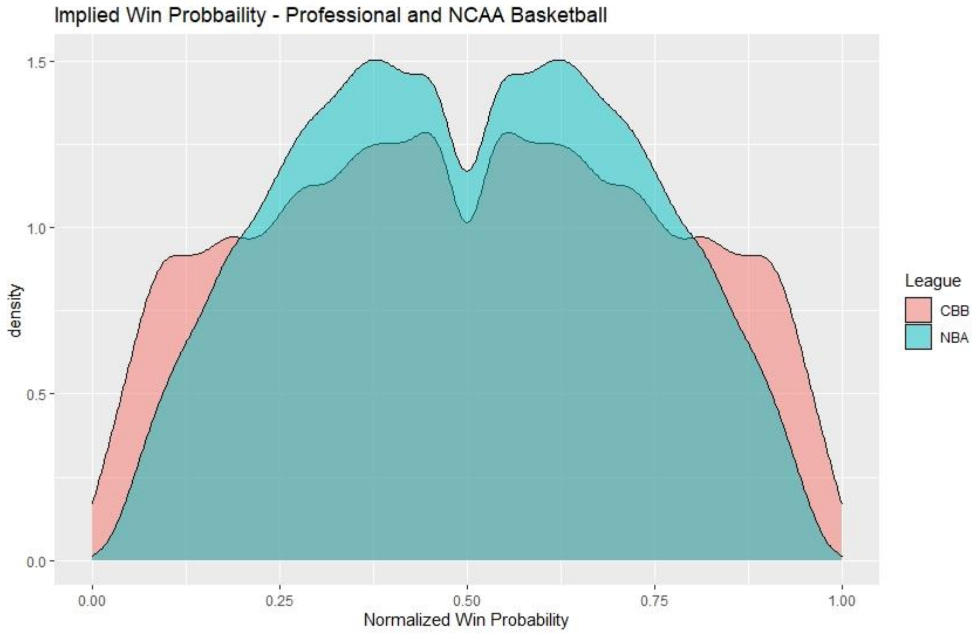
Before we investigate efficiency in detail, let us examine the distribution of odds for each major sport. The following graphs represent the normalized odds for each sport, plotted as a density graph using the ggplot library in R. Not that each graph is by design symmetrical since each game is represented by the normalized odds of the favorite and the underdog which by definition must add to one. Figure 1 shows the density plot for football, both professional and collegiate.

Figure 1-Football Odds



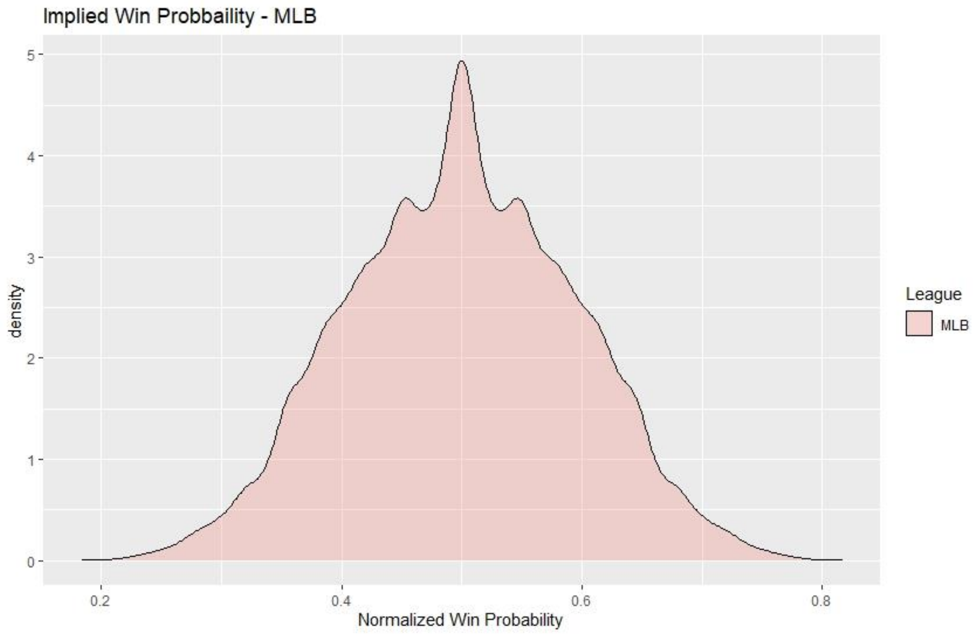
This graph reveals a few interesting properties about this data. First the odds for college football are more lopsided than for the NFL implying a higher level of parity at the professional level. Secondly, slight favorite-underdog matchups are more common then even (pick'em) odds. The NFL odds are bimodal with a peak around 65%, and due to symmetry a corresponding peak near 35%. The modal odds for NFL underdogs is +170, corresponding to an implied probability of 37%. The density drops of sharply with a trough at 50%. It appears the odds are defined so that having one team as a small favorite is more common than an even-money bet.

Figure 2-Basketball Odds



Odds for professional and college basketball have a similar distribution to football. College odds are more dispersed, and the slight favored effect is in place for both leagues. A similar trough exists for both basketball leagues with pick'em odds being less popular than slight favorite matchups.

Figure 3-MLB Odds

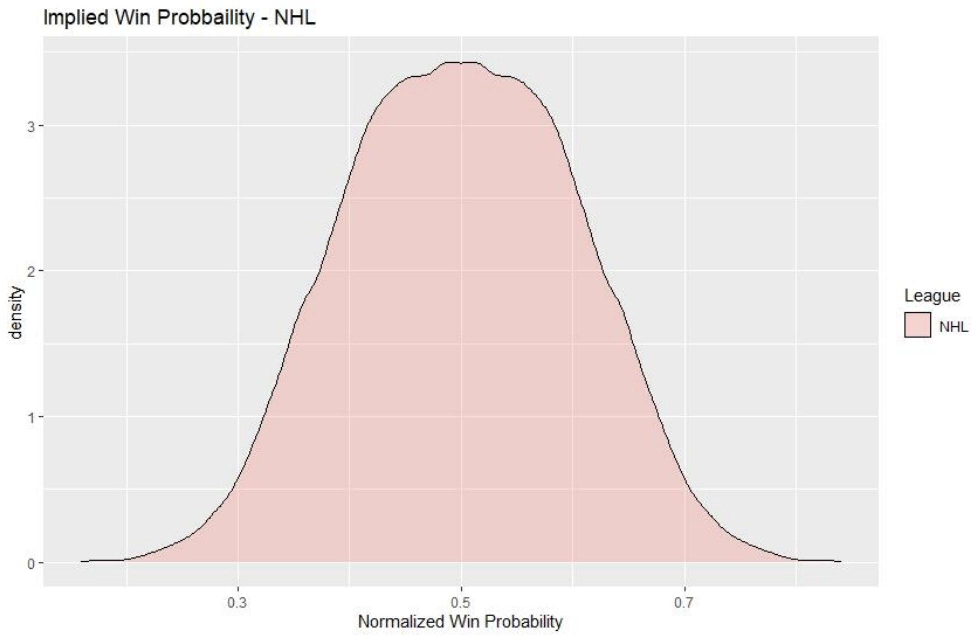


Odds for professional hockey appear quite different. The pick-'em trough is absent and the modal probability is 50%. There is in fact a small bump in the distribution near the 50% level.

Extreme odds are also much less common. Whereas football and basketball both had extreme probabilities, at or near 100%, odds greater than 75% appear quite rare.

The odds for professional hockey are similar to baseball, but with a pronounced peak near parity. Odds can be a little more extreme in hockey with the density extending to nearly 80%.

Figure 4-NHL Odds



RETURNS BY ODDS GROUPS

We now examine the return on bets made at different odds ranges. To do this we take the entire data set of games in each sport sorted by the implied probability from low to high. Note once again this implies each contest is represented by two records, one for each team. But, unlike the normalized odds this data is not symmetric since we are using the quoted odds which includes the bookmaker's margin. For the purpose of this analysis, we divide the odds into twenty bins of approximately equal count. We assume we bet $100 on every contest and determine the average profit earned on those bets. Recall that in a weak-form efficient market the returns on all these bets would be negative, equal to each other, and equal to the bookmaker's average hold. If a longshot bias exists, we would expect to see higher returns for the favorites and lower returns for the underdogs.

National Football League

In Figure 5 we see the returns for bets on NFL games. Recall that this is based on a data set of over 4,000 games over 15 seasons. The graph reveals several issues that nominally support the notion of inefficiencies in the market.

- The return on bets made in each group does not appear to be constant by group.
- The return on bets in some odds categories is positive.
- While not readily apparent from the graph, the average return across all bets is -4.13% which is lower than the expected profit of -3.65% indicated by the average hold.

The graph does seem to indicate a longshot bias, returns on bets on the lower probability teams have lower returns than bets on the highly favored teams.

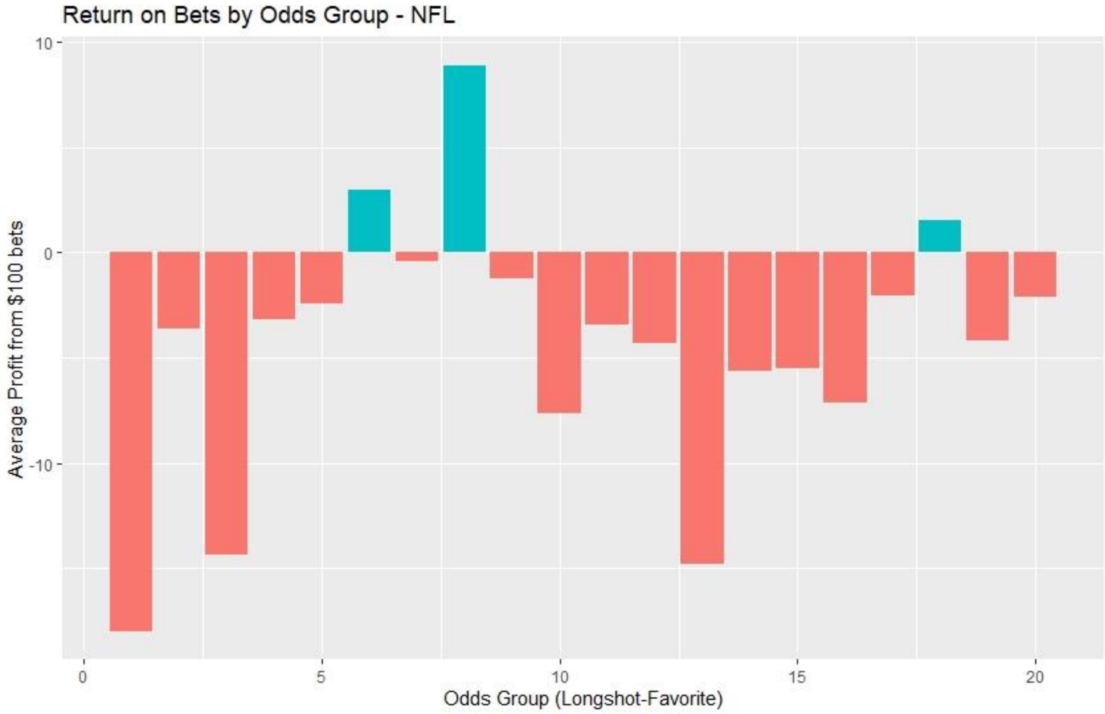


Figure 5-NFL Returns

The odds group with the strongest positive returns corresponds to a bin 8 where odds range from +125 to +144, corresponding to implied win probabilities of 41% to 44%. The two bins below that level also offer either a very small loss, or a positive return. It is worth noting that these games correspond roughly to the bump in the density of implied probabilities in Figure 1.

In Table 3. We examine the consistency of these returns over time.

Table 3- Returns on NFL Bets by Season

Return on NFL Moderate Underdog Bets by Season			
Season	[+160,+178]	[+145, +159]	[+125, +144]
2007-08	3.5%	−31.0%	43.8%
2008-09	−46.2%	15.4%	12.6%
2009-10	13.2%	12.7%	20.5%
2010-11	3.4%	20.0%	3.2%
2011-12	−6.7%	−5.0%	10.7%
2012-13	37.2%	19.8%	5.0%
2013-14	−25.7%	−61.1%	−13.0%
2014-15	−24.5%	−8.3%	29.0%
2015-16	−11.4%	10.4%	−22.1%
2016-17	19.5%	−49.0%	3.9%
2017-18	−19.9%	−28.8%	5.9%
2018-19	3.9%	5.5%	−11.9%
2019-20	26.4%	19.1%	24.9%
2020-21	18.6%	25.6%	7.8%
2021-22	16.9%	25.5%	35.0%

The returns in these 3 bins, representing 30% of the games in each season, vary considerably. Each bin has positive returns in some seasons, and negative returns in others. Bin 8, odds in the range of [+125-+144] has the highest long-term return and the most consistently positive returns; 12 out of 15 seasons.

While the odds appear to indicate inefficiencies, the statistical validity of inefficiency is marginal. A test of a systematic bias as per Kuypers we regress the predicted win probability in each bin against the actual win probability. This test failed to reject the null hypothesis that the slope of that line is one; the 95% confidence interval is [.95, 1.07]. So, we cannot conclude that there is a systematic bias across the range of odds. While the returns appear different across the bins, an ANOVA test of the null hypothesis that the returns are the same for each bin, has a p-value of .311, so our ability to reject the hypothesis of equal returns is marginal at best. If we examine the return on the most profitable bin, bin 8 with odds of [+125,+144], and test the null hypothesis that these returns are negative, we can reject that hypothesis with a p-value of .043. We cannot reject the null hypothesis for negative returns on bin 6, the p-value is .316. Finally, to perform a more formal test of the longshot bias we perform a two-sample hypothesis test on the returns in bin 1 and bin 20, the biggest underdogs and biggest favorites. While there appears to be a strong difference in the graph, the p-value of this test is .164; again, too high to confidently reject the null hypothesis with much confidence.

In summary there is evidence that would suggest that the odds on NFL games are weak form inefficient. There appears to be a variation in return against different odds groups and heavy longshot bets have historically performed the worst, but these conclusions are tentative due to the variable state of the returns. The one test that does meet the 5% conventional threshold, barely, is the return on slight underdogs in the range of [+125,+144]. We can reject the null hypothesis that returns on these bets have a negative return and therefore conclude that the weak form efficiency does not strictly hold.

College Football

In

Figure 6 we see the graph for college football. The CFB graph is similar to the NFL graph; returns are uneven, heavy longshots yield very low returns relative to other groups. There is also a set of profitable bets in the slight underdog range, in the case of CFB those odds are in the range of +285 to +150. These represent implied win probabilities of about 26% to 40%.

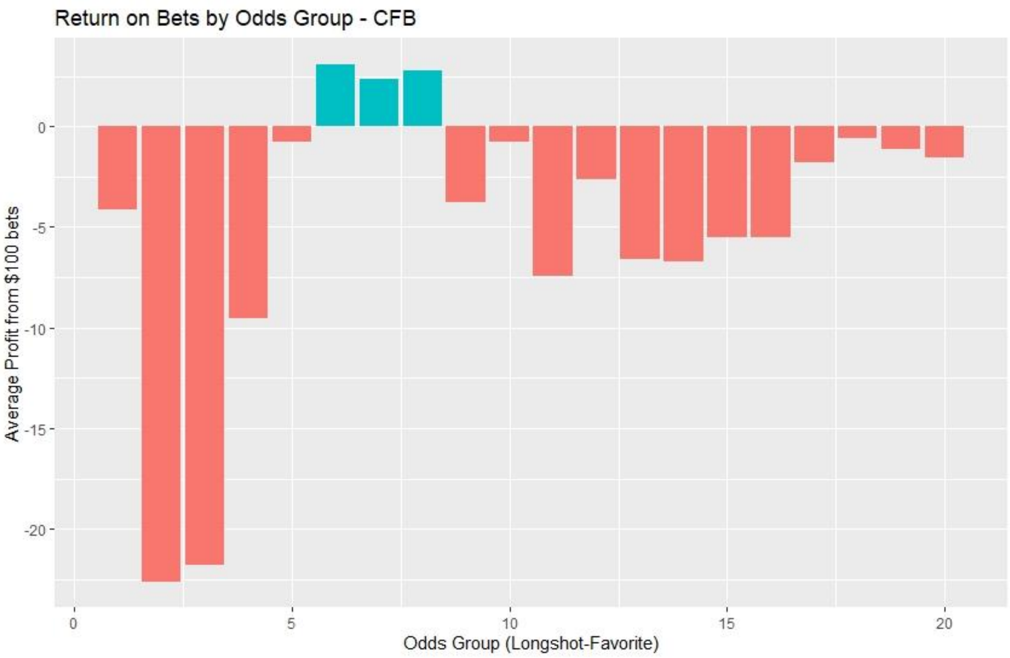


Figure 6-CFB Returns

As was the case with professional football, the returns in these bins are sometimes positive and sometimes negative over the course of a season, thought there is less consistency than there was for the NFL.

Table 4- Returns on CFB Bets by Season

Return on CFB Moderate Underdog Bets by Season

Season	[+235,+289]	[+185, +234]	[+120, +149]
2007-08	−4.9%	−8.2%	2.3%
2008-09	23.5%	−30.1%	7.8%
2009-10	−8.5%	−6.8%	3.5%
2010-11	3.0%	3.7%	15.8%
2011-12	8.0%	23.6%	14.3%
2012-13	−10.2%	11.8%	5.2%
2013-14	−10.9%	9.9%	−19.6%
2014-15	23.4%	−3.8%	0.1%
2015-16	3.6%	−7.8%	−32.8%
2016-17	18.2%	17.2%	−2.9%
2017-18	3.0%	−6.5%	9.9%
2018-19	−4.4%	5.9%	10.2%
2019-20	−17.7%	5.9%	20.6%
2020-21	8.6%	12.2%	−5.1%
2021-22	15.1%	11.2%	−4.4%

There is some weak evidence that there is a general difference across all bins, the ANOVA test has a p-value of 0.108. While the returns on bins 6-8 have been positive over an extended period of time, we have limited evidence that this is a statistically significant difference. If we test the null hypothesis that the returns are negative the p-values on these tests are 0.316, 0.281, and 0.219 respectfully. To test for a longshot bias we compare bins 2-19, and 3-18. For the bin 2 bin

3 test we can safely reject the null hypothesis with a p-value of 0.0068. For the bin 3-18 test we can reject the null with a p-value of 0.00077.

So, in summary we have some evidence to reject the weak form efficiency of CFB odds. The strongest evidence to reject efficiency is the longshot bias of bets on teams with odds in the range of [+480, +1495] have statistically significantly lower returns that betting the favorites in those contests at [-652, -3000]. While these are better bets, they have negative returns. The odds that do show positive returns are positive with questionable significance.

Professional Basketball

The returns for professional basketball are shown and Figure 5. (Figure 6 shows the returns for college basketball.) These graphs are quite different than what we saw for football. Pro basketball returns are generally negative, with a very small positive return in bin 8. The p-value for the ANOVA test of equal returns is 0.866. A small positive return is shown in bin 8, but the p-value of 0.463 provides very low confidence that this is a meaningfully positive return. The longest odds have a negative return of about -9.2% as compared to its complement -3.01%. The p-value for the difference being non-zero is only 0.347.

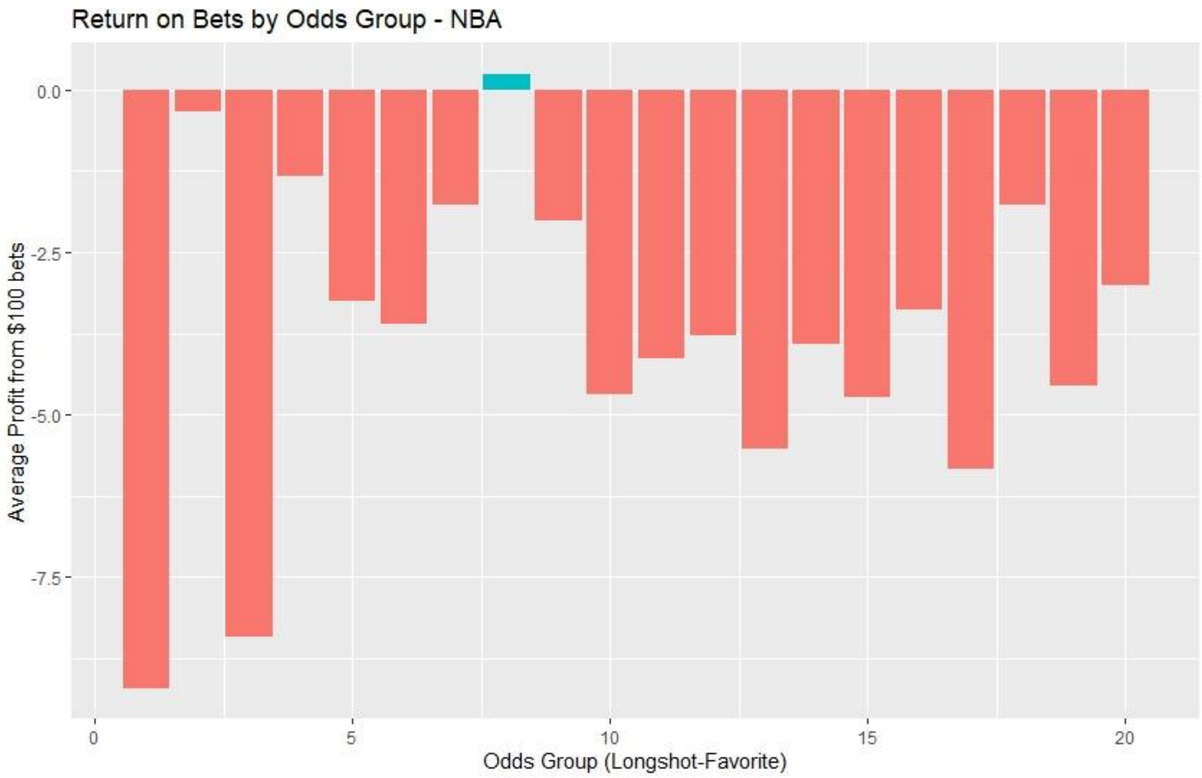


Figure 7-NBA Returns

So, while the graph for NBA odds shows some variation, a small positive return for some bet ranges, and a modest longshot bias, none of these claims can be substantiated at a reasonable level of statistical significance. We therefore cannot conclude that NBA odds are not weak form efficient.

College Basketball

The returns on best in college basketball show significant variation. A formal ANOVA test confirms this with a p-value of less than 2E-16. College basketball returns also show the most significant longshot bias of all the sports examined in this paper. While returns are negative on all bins, the biggest longshot bin has a negative return of approximately 50%. Betting on the corresponding favorite has a return of -0.002. The returns are different with a p-value of less than 2.2E-16. Recall that the odds are more lopsided in college vs. pro basketball and there are more mis-matches. Betting on the heavy underdog to pull of the big upset in college basketball is on average, the worst bet among the major sports. The longshot bias also holds for bins 2-19 (p-value 2.84 E-05), bins 3-18 (p-value 5.52 E-05), bins 4-17 (p-value 1.56 E-05) and bins 5-16 (p-value .00013).

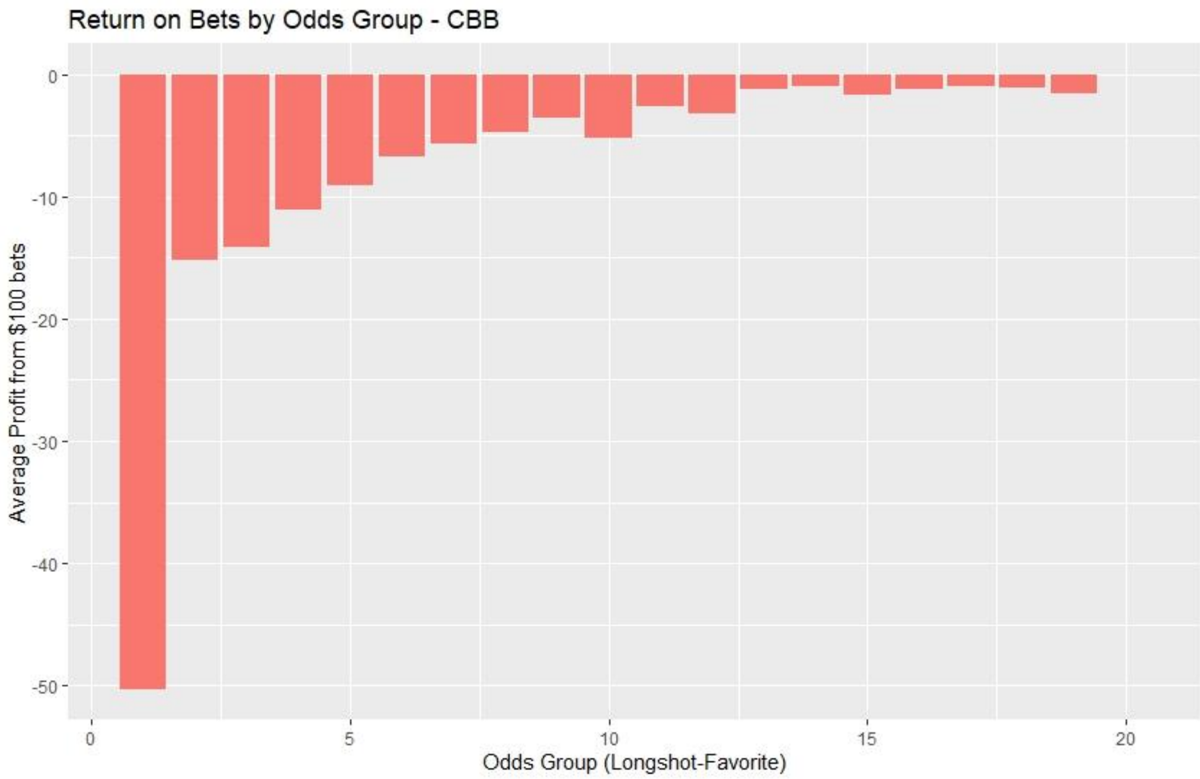


Figure 8-CBB Returns

So, in conclusion, while all odds ranges in college basketball have negative returns there are some bets clearly worse than others. College basketball shows a very strong favorite-longshot bias. Bets on extreme underdogs have very poor returns, and in general bets on underdogs perform significantly worse than bets on favorites. So based on the inconsistency of returns on odds groups, and longshot bias we can reject the hypothesis that college basketball odds are strictly weak-form efficient.

Major League Baseball

Bets in baseball appear generally consistent, at least more consistent than the other sports we have looked at. The returns on bets in each odds group is shown in Figure 9. The p-value on the ANOVA test that all returns are equal is 0.203. Generally, have a negative return over time, though there is a small positive return on bet in bin 14 corresponding to odds of [-125, -131] a slight favorite. The return is 1.48%, but the p-value associated with the test that it less than zero is 0.196.

A longshot bias is clear with bets on the biggest underdogs yielding a return of -7.51, with the corresponding favorites yielding a -0.44% return. The returns are different with a p-value of 0.016.

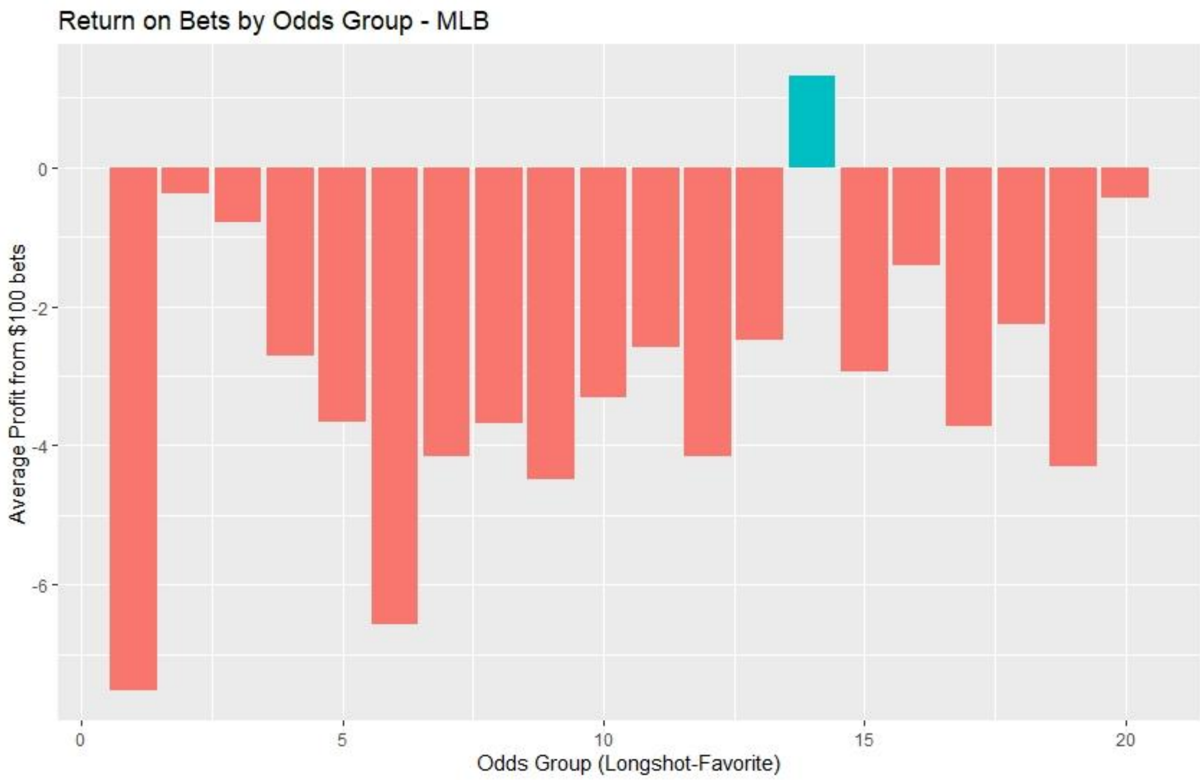


Figure 9-MLB Returns

So, again we can reject the hypothesis that MLB odds are strictly weak form efficient. In this case the rejection is based on a statistically significant longshot bias. While one band of favorite odds has a nominally positive return, we can not conclude that these returns are non-negative at a reasonable level of statistical significance.

Professional Hockey

Professional hockey returns are shown in Figure 10. They are similar to baseball in that they are all mostly negative and reasonably consistent. The p-value for an ANOVA test of the hypothesis that all returns are equal is 0.876, so we can not reject the null hypothesis.

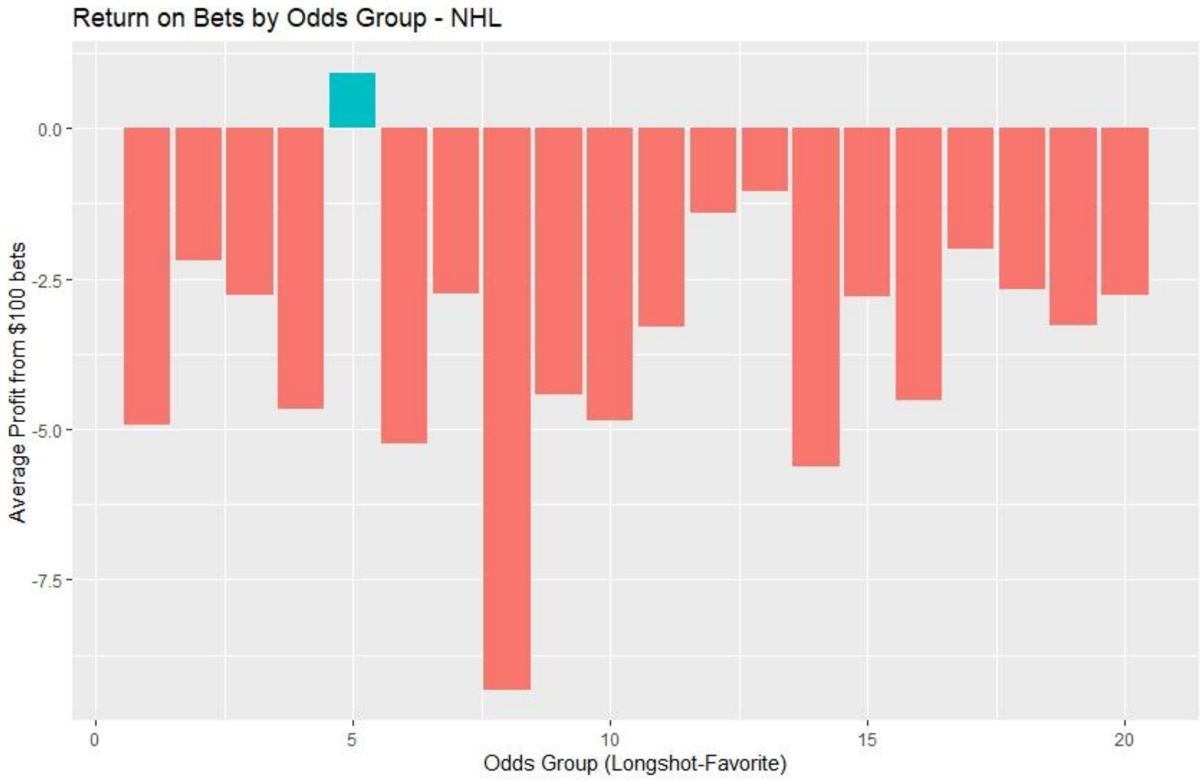


Figure 10-NHL Returns

The returns in bin 5 [+130, +136] are nominally positive at 0.929%. The p-value with associated with the hypothesis test that the returns are negative is 0.364, so we cannot reject the null hypothesis. There does not appear to be any clear longshot bias in the hockey odds. The return on the biggest longshots, bin 1 [+190, +505] are -4.92%, slightly worse than the returns on the complementary odds in bin 20 [-700, -219] which are -2.77%. We fail to reject the null hypothesis that these returns are different with a p-value of .546. The returns on the set of bins 2 and 19, show a nominal reverse longshot bias. Bin 2 returns are -2.19% and bin 19 returns are -3.28%, but the null hypotheses that these returns are different is 0.76%.

NHL odds appear to be the most efficient of the odds set we have examined. While there are some nominal differences in the historical returns, and one bin is slightly positive, none of the differences can be shown to be the result of anything but statistical noise.

CONCLUSION

Betting on sports is becoming increasingly popular, and legal, in the United States. Profitable betting is however very difficult. The sportsbook has several advantages, the most significant of which is their ability to offer unfair bets. These unfair bets create a margin for the book which allows them to profit regardless of the outcome as long as bets are placed in the appropriate proportion.

With the odds literally stacked against the bettor, it is difficult to win. That being said, our analysis has shown that not all bets are equally risky, and the odds markets are not weak form efficient across all sports. With the exception of the NBA and NHL, we have been able to identify inefficiencies in the odds markets using a large set of bets over an extended period of time. In that sense the moneyline betting market on major North American sports is inefficient.

At the most basic level the returns on bets placed on different ranges of odds yield different returns. But many of these differences are indistinguishable from random variation, while others are meaningful. Bets on slight underdogs in the NFL have a statistically significant positive return. Bets on extreme long shots in college basketball yield very poor returns while bets on corresponding heavy favorites in college basketball also yield negative returns, but these returns are significantly better. Our data indicates a statistically significant longshot bias in college basketball that extends over much of the odds range. Betting underdogs in general, and longshots in basketball is in general a losing proposition

In summary, with the exception of the NBA and the NHL, we have identified some level of statistically significant inefficiency in each of the sports analyzed. In summary:

- Professional football: bets on slight underdogs [+125,+144] have statistically significant positive returns.
- College football: a statistically significant longshot bias exists. Bets on underdogs in the range of [+480, +1495] have statistically significantly lower returns that betting the favorites in those contests at [-652, -3000].
- College basketball: an ANOVA test strongly rejects the hypothesis that returns are equal across all odds ranges. A statistically significant longshot bias exists with returns on underdogs up to +254 having statistically lower returns than bets on their opponents.
- Major League baseball: a statistically significant longshot bias holds where bets on the most extreme underdogs, up to +180, have lower returns than bets on the corresponding opponents.

While our analysis shows that inefficiencies exist in some betting markets, it does not imply that making money betting on sports is in anyway easy. Where positive returns exist, the pre-tax returns are small. And while they are positive over the long run, they are punctuated with long periods of negative returns. The strategy analyzed in this paper, bet on all opportunities in a certain odds range, is not recommended, nor is it likely to be profitable after tax in the short to medium term. But what our analysis does show is that some bets are better, or worse, then others. Betting on longshots in college basketball, is for example a strategy very unlikely to be successful. Bets on slight underdogs in football, on the other hand, are more likely to be successful.

A limitation of this paper is that we only analyzed a strategy of placing bets based on the odds, and therefore tested for weak form efficiency. An open issue, and an area for further research, is semi-strong efficiency. In a world of big data, AI, and machine learning, is it possible to build models that will predict outcomes successfully enough to overcome the sportsbook’s hold and yield profitable results? While models may be very accurate in terms of predicting outcome, the efficient market hypotheses suggests that the output of those models would be quickly reflected in the price of the bets and profitable opportunities would be removed.

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Online Reviews for Agile Development Tools – Jira

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ABSTRACT

We present research examining online reviews for the agile development tool Jira. End users' reviews on Jira software suggest that functionality and value for the money are the two main features the end users' perceive as the most important on using this software. The analysis on frequency of phrases used in the comments suggest that end users' value how user friendly and efficient task management tool the software is, while highlighting the steep learning curve of the software.

KEYWORDS: Online reviews, Project management tools, Agile development methodology

INTRODUCTION

Customer reviews are a convenient way to obtain useful information from other consumers who purchased and used the products that potential buyers are looking for. Reading reviews is an important step in the purchasing process when a consumer is unfamiliar or unsure what that product or service can do for them. Consumers often believe that the information provided in review comments represents the latest information and experiences related to the products and therefore use the reviews as a basis for making a more informed purchase decision. Research suggests that buyers read online review comments to seek opinions on the merits, demerits, prices, and costs of products (Hussain et al., 2018). About ninety percent of consumers read online product reviews, about 88% of them trust such reviews as they are personal recommendations, and 72% of them will act after they read a positive review (Saleh, 2015).

Customer reviews on software used at work, such as project management software, give an opportunity for software users to share their experiences with such tools, and help potential end users' to select and implement the right software for their team and project. Websites like Softwareadvice.com, Google Trends, pcmag.com, etc provide a forum for exchanging opinions on end users' perception of using such tools. Data collected on Google Trends about the most appreciated agile project management tools confirm that Jira and Trello are listed at the top tools for agile projects and increasing over the years. Sentiment analysis on tweets posted between September 2014 and March 2015 about such agile project management tools had respectively 32% (Jira) and 51% (Trello) positive comments, meanwhile, the negative comments about Jira had more detailed feedback about the problems of using that tool which provides more information about this tool (Matta & Marchesi, 2015).

This study analyzes the end users' reviews about Jira software and intends to achieve two objectives: 1) understand customer perceptions of using Jira as a project management software; and 2) explore the correlation between factors that impact customer perceptions.

LITERATURE REVIEW

Online Reviews and Their Helpfulness to Readers

The online sentiment of reviews posted on the websites, positive versus negative comments, have been the focus of much research on the topic of electronic word of mouth (eWOM) (Jo & Oh, 2011; McAuley & Leskovec, 2013; Popescu & Etzioni, 2007). Research on this topic suggests that negative comments can actually improve the perception of favorable ratings more so than the absence of negative reviews. Consequently, all product reviews have the potential to provide useful feedback on product qualities and value and can help to deepen the social influence on buyers (Jha & Shah, 2019). For example, explicit negative comments in an online hospitality review draw more attention and help the decision-making process of readers who are assessing their options for such services. Lack of competence or negative attitudes drive users to write negative recommendations, while positive feelings lead to positive online comments (Guerreiro & Rita, 2020). A neural network model suggests that for electronic products, the number of positive comments has a stronger positive effect than the negative comments. A combination of positive reviews and marketing promotions can lead to higher sales of electronic products (Chong et al., 2017).

Consumers increasingly rely on anonymous reviews before they purchase products online. A well-written review allows consumers to know more about the product and make more informed decisions (Zhao et al., 2018). Research on the online reviews written by the experts of that particular domain suggests that positive expert's reviews can positively affect the perception of the quality of the products and, therefore can increase the user adoption of such products. Companies need to carefully manage the interaction with experts in the field and their reviews since such reviews can encourage more users to share their experiences as well (Zhou & Duan, 2016). A study of 900 online reviews found that sentiment is increased if comments are combined with star ratings of the products and reduced if the length of the review gets longer, usually above 40 words (Al-Natour & Turetken, 2020).

Agile Project Management Discussion and Issues

Agile methodologies are perceived as more suitable in small-scale IT projects which have high uncertainties in the project requirements. In the same time, agile development approaches are used by organizations which have a time urgency to develop the project. Less time an organization has to develop an IT project, more agile development methodologies, they will use. Much research has been on the agile system development and how these projects differ from the traditional methodology. The scope of the agile projects and the dynamics of the team communication and management are found to include new dimensions as many studies are conducted to identify the differences between agile and traditional methodologies. Drury-Grogan (2014) found that ASD teams focus on functionality, schedule, quality, and team satisfaction when discussing sprint (iteration) objectives which could extend the "golden triangle" of project performance in the ASD context to a diamond model (functionality, quality, budget (cost), and schedule).

Martin (2017) discusses the impact of agile software development (ASD) in creating an agile organizational change. Based on her experience, an ASD approach can contribute in three main ways to the organization; firstly: an ASD preserve the functionality of the core system while constantly prioritizing the main features and realignment of goals keeping the team focused on delivering the critical features. New ideas and tactics are constantly supported. Secondly, working in small, cross-functional teams that include end-users and developers allows a collaborative environment where ideas are evaluated based on merits. Lastly, the ASD allows constant adaptation while the sprints are released very frequently. While new requirement become evident, the team can adjust the priorities and shift the work without wasting any time. The challenge for a successful ASD stands in the fact that the small team approach in a large and complex software, may bring the issue of coordination across teams.

It is well-known fact that IT projects have a high failure rate which keeps increasing over time (*Http://Edocs.Nps.Edu/Licensed/CHAOSSummary2009.Pdf*, n.d.) and identifying success and failure factors of system development approaches has become paramount to slower the failure trends. Project risks management in an agile environment can be addressed in two different ways. Firstly, the team leader can assess and emphasize the projects risks by conducting the risk analysis and communicating it with the team. Another way is to include risk as a natural element of the project and manage it through transparency by immediately responding to changes in both the requirements and technologies of the project (Trzeciak, 2020). The ability of team members to engage with project stakeholders and therefore be able to manage the change of priorities is confirmed by other studies as well. The agile methodology is a customer-centric methodology with customer satisfaction as the highest priority (Khoza & Marnewick, 2021).

Given the extent to which the agile development methodology is being used to develop new information technologies, understanding the factors that make the methodology a successful approach is very important. One factor is the effective use of project management tools to keep agile projects on track. While studies have explored the relative value of project management tools (Alomar et al., 2016; Katsma et al., 2013; Pereira et al., 2013), more remains to be understood about their characteristics that make them effective. One opportunity for extending our knowledge of project management tool value is to mine online user reviews, which remains a relatively unexplored area of research. Therefore, the focus of this research project is to analyze online reviews of a project management tool to identify what professional users value the most from the software in support of their work.

METHODS

To achieve our research objectives, we acquired secondary data in the form of customer reviews from Software Advice (www.softwareadvice.com), a website that provides consolidated research on industry-specific software. We selected Software Advice as our data source based on its use by CIO magazine as a referral source for unbiased opinion on business software. Software Advice reviewers can provide both qualitative and quantitative data as part of their review. The qualitative component of the review allows the reviewer to describe the pros and cons of the software, their reason for choosing/switching to the software, and an overall summary impression of the software. The quantitative component of the review asks the reviewer to rate the software on factors that include ease of use, value for the money, customer support, and functionality. Each factor is rated on a scale from 1 to 5. In addition, reviewers are asked to provide demographic information on their industry, company size, and the length of time they have used the software. The demographic information enables those searching for advice on a piece of software to limit the reviews they consider to a specific demographic profile.

Data Collection

We used ParseHub, which is a free and powerful web scraping tool, to scrap the review data on Jira and download it as an Excel file. We selected Jira because it is one of the most popular tools for managing agile projects. Data was scrapped in October 2021 and then cleaned for completeness and language. Reviews could be submitted by those who had only used the free trial version of the software but our data included only four reviews from free trial users, so we did not include those reviews in our analysis. A total of 1504 reviews were suitable for further analysis in this research study.

RESULTS

Table 1 shows the descriptive statistics of the four quantitative factors. Functionality was ranked highest among all four factors while ease of use was ranked the lowest, but the difference between the factor ratings were modest.

Table 1: Descriptive Statistics

	MIN	MAX	MEAN	STD. DEVIATION
Ease of use	1	5	4.15	0.91
Value for money	1	5	4.32	0.82
Customer support	1	5	4.17	0.88
Functionality	1	5	4.46	0.71

Table 2 displays the correlations between the factors. There is a consistent correlation between all the factors that is right at the transition between moderate and high correlation values.

Table 2: Correlation

	Ease of use	Value for money	Customer support	Functionality
Ease of use	1			
Value for money	0.53	1		
Customer support	0.49	0.54	1	
Functionality	0.46	0.53	0.50	1

Table 3 shows the factor scores in relation to how long the reviewer had been using Jira. Ratings were consistent across usage time with reviewers consistently rating functionality and value for money higher than ease of use and customer support.

Table 3: Factor Scores in Relation to Usage Time

FACTORS	TIME	N	MEAN	STD. DEVIATION	STD. ERROR	MIN	MAX
Ease of use	< 6 months	342	4.15	0.93	0.05	1	5
	6-12 months	139	4.01	0.98	0.08	1	5
	1-2 years	238	4.14	0.92	0.06	1	5
	2+ years	785	4.17	0.89	0.03	1	5
Value for money	< 6 months	342	4.27	0.87	0.05	1	5
	6-12 months	139	4.35	0.81	0.07	2	5
	1-2 years	238	4.32	0.74	0.05	2	5
	2+ years	785	4.34	0.82	0.03	1	5
Customer support	< 6 months	342	4.16	0.87	0.05	1	5
	6-12 months	139	4.24	0.82	0.07	1	5
	1-2 years	238	4.26	0.83	0.05	1	5
	2+ years	785	4.14	0.91	0.03	1	5
Functionality	< 6 months	342	4.42	0.79	0.04	1	5
	6-12 months	139	4.41	0.67	0.06	2	5
	1-2 years	238	4.45	0.73	0.05	1	5
	2+ years	785	4.49	0.68	0.02	1	5

Figure 1 shows perceptions of ease of use by usage time. Customers who had used the Jira software between 6 and 12 months had the lowest average rating at 4.01, but there was not a substantial difference by time of use.

Figure 1: Ease of Use Ratings by Usage Time

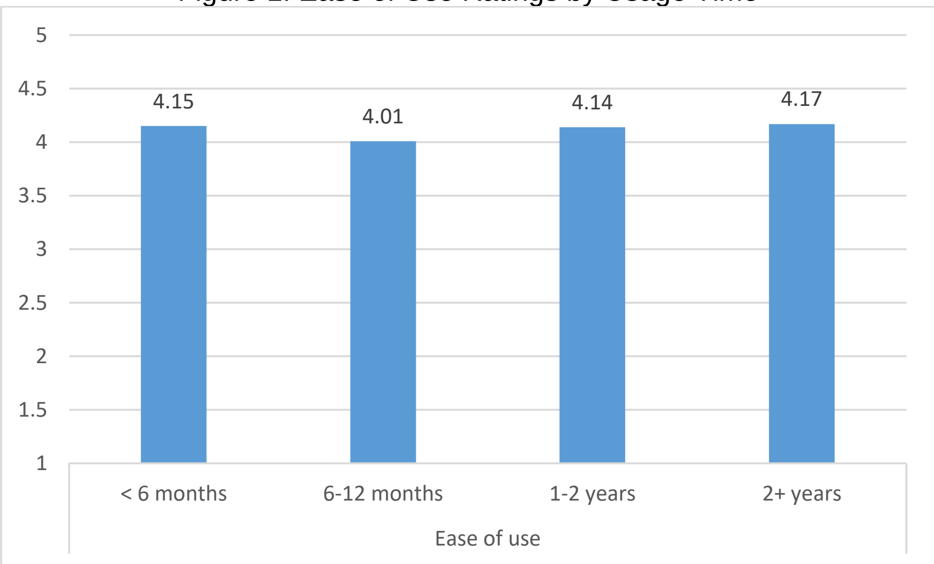


Figure 2 shows perceptions of value for money by usage time. Again, the ratings did not change substantially over time.

Figure 2: Value for Money Ratings by Usage Time

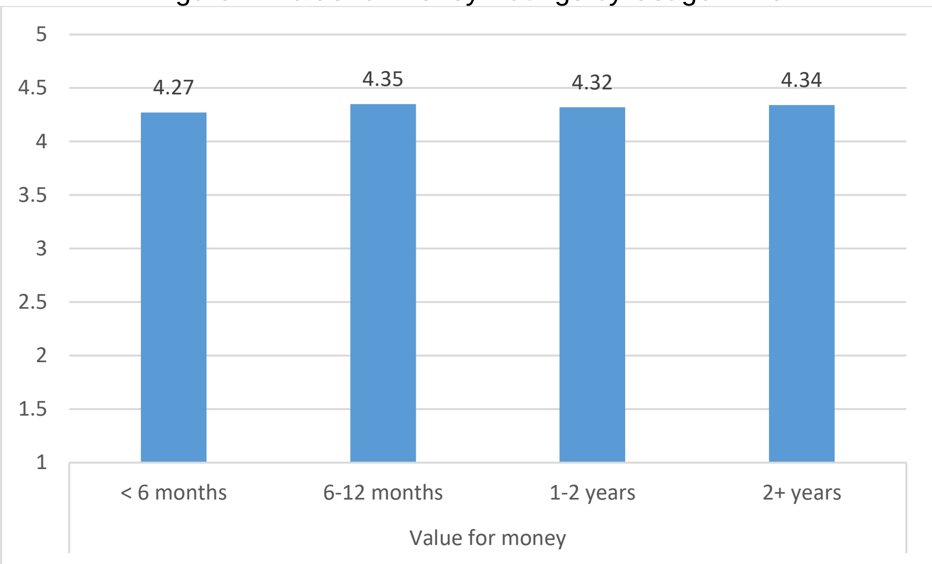


Figure 3 shows perceptions of customer support by usage time. Lower ratings were found at the extremes of usage time, but the differences were again modest.

Figure 3: Customer Support Ratings by Usage Time

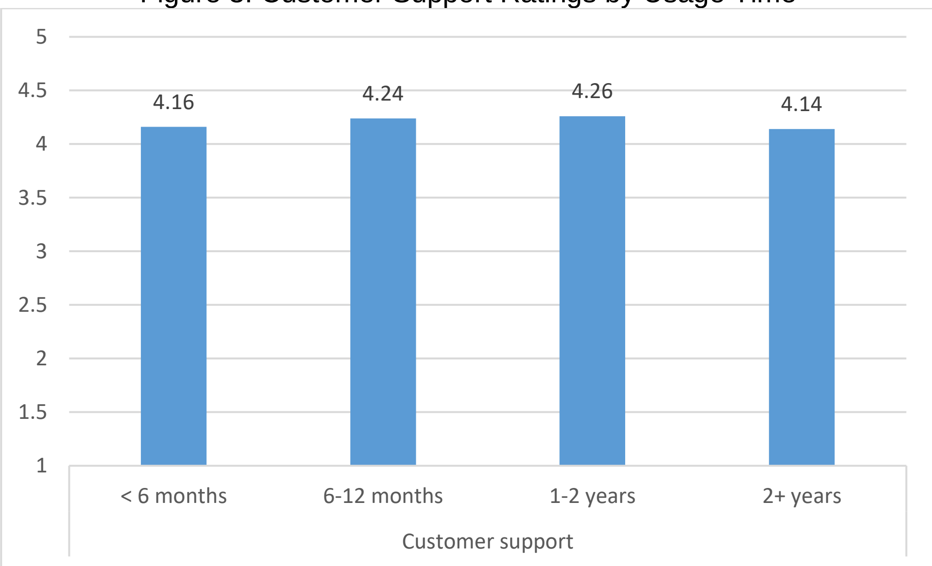
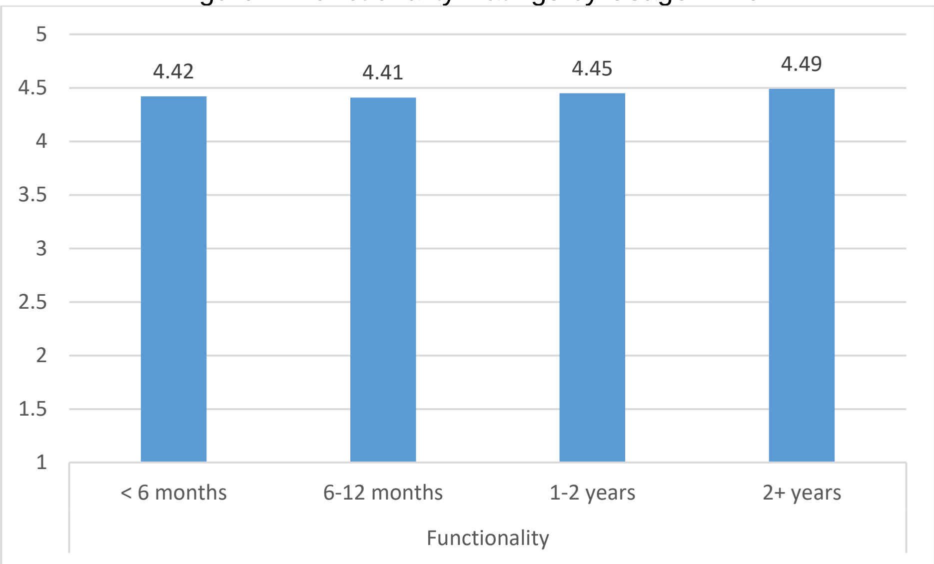


Figure 4 shows perceptions of functionality with quite stable ratings across usage time. Across factors, ratings for functionality were consistently the highest with means between 4.41 and 4.49.

Figure 4: Functionality Ratings by Usage Time



We further explore how time impacts customers' perceptions of experiences with Jira and what factors they like more. Table 4 shows the four factors (ease of use, value for money, customer support, and functionality) grouped by usage time (less than six months, six to 12 months, one to two years, and more than 2 years.

Table 4: Descriptive Statistics on Time vs Factors

TIME	FACTOR	N	MIN	MAX	MEAN	STD. DEVIATION
< 6 months	Ease of use	342	1	5	4.15	0.93
	Value for money	342	1	5	4.27	0.87
	Customer support	342	1	5	4.16	0.87
	Functionality	342	1	5	4.42	0.79
6-12 months	Ease of use	139	1	5	4.01	0.98
	Value for money	139	2	5	4.35	0.81
	Customer support	139	1	5	4.24	0.82
	Functionality	139	2	5	4.41	0.67
1-2 years	Ease of use	238	1	5	4.14	0.92
	Value for money	238	2	5	4.32	0.74
	Customer support	238	1	5	4.26	0.83
	Functionality	238	1	5	4.45	0.73
2+ years	Ease of use	785	1	5	4.17	0.89
	Value for money	785	1	5	4.34	0.82
	Customer support	785	1	5	4.14	0.91
	Functionality	785	1	5	4.49	0.68

To analyze the qualitative components of the reviews, we used Wordstats 9 to create the word cloud presented in Figure 6. Word clouds visualize the frequency of terms/phrases in a data set by displaying more frequently used terms/phrases in larger font sizes. In this data set the most frequently used terms/phrases described both the characteristics and purpose of the software (e.g., software development, management tool, agile project) as well as the sentiment toward the software (e.g., great tool, great experience, user friendly). Phrases with a sentiment quality (e.g., highly recommend, love Jira) we almost entirely positive, which matches the generally high factor scores presented earlier. End users highlight the steep learning curve of the software in their comments which is more evident in the early months of using such tool.

Figure 6: Word Cloud of Jira Review Terms

DISCUSSION AND CONCLUSIONS

This research project scrapped end users' comments from softwareadvice.com to study and examine how Jira software is helping end users with their project management tasks. Jira is a powerful project management tool with many capabilities for which customers must pay a high price. Users appreciate the functionality that Jira offers, but they also want the software to be easy to use. Jira developers should pay attention to customers' ratings and feedback. When designing and making improvements, project management tools must focus on ease of use and the software's learning curve so that in the long run, such tools will be able to both retain existing customers and attract new customers. Further analysis for a journal submission will include testing for the significance of review timing and additional content analysis of review comments.

Disclosure statement: The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

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DECISION SCIENCES INSTITUTE

Optimal Service Level for Repair Part Inventory Considering the Cost of Holding Other Parts

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ABSTRACT

Optimal inventory service levels are determined for repair parts used by public transportation systems, such as the MBTA in Boston. Vehicles that were purchased decades ago exist, so repair demand is uncertain and intermittent, and part inventory is substantial. This work uses deterministic, stochastic, and simulation models to solve a cost minimization function for each part that includes holding costs for all parts needed for a repair because if one part is unavailable other parts are held unnecessarily. Optimal service levels depend on demand rate, procurement lead time, and the part's percentage contribution to the total cost of the repair.

KEYWORDS: Repair part inventory, Inventory management, Intermittent demand, Public sector, Optimization

INTRODUCTION

Many organizations operate extensive repair systems. For example, automobile dealers operate systems to repair cars, airlines operate systems to repair jet engines (Arnheiter, 2007), and public transit systems operate systems to repair buses, trains, and other vehicles. In Boston, the Massachusetts Bay Transportation Authority (MBTA) is the organization that operates and manages the public transportation in system greater Boston. At the MBTA, dozens of garages perform maintenance and repairs that require an extensive spare part inventory system. These parts are stored in a central warehouse from which parts are distributed to garages on a daily basis. The warehouse includes tens of thousands of spare parts, and its inventory investment totals tens of millions in USD. This article addresses inventory policy at the central warehouse for parts needed to do repairs at the garages.

Repair part inventory management for a system like the MBTA is challenging for a number of reasons. First, the myriad of vehicle types that were purchased over many decades results in a large number of different repair parts, each of whose demand is intermittent. Second, the lead times for procuring many of the parts needed for a repair can be long. Third, a repair cannot be accomplished until every part needed for the repair is available. And fourth, the distribution of this low-volume part demand is discrete and usually right-skewed. Any inventory policy at the warehouse needs to take these issues into consideration.

The aim of this work was to determine optimal inventory service levels for low-volume repair parts whose demand is a Poisson process. It requires consideration of the repair frequency, part procurement lead time, the fixed cost of ordering the part, the cost of holding the part, and the cost of part shortage. The part shortage cost will take into consideration the cost of holding every part needed for the same repair.

LITERATURE SEARCH

This section addresses some prior work in relevant topics, including public transit inventory management, repair inventory management, the quantification of shortage costs, the forecasting of intermittent demand, and the determination of difference service levels for different product groupings.

The management of spare part inventory for public transit systems is costly. Boddupalli et al (2019) found that rail maintenance and repair costs at America's four latest public transportation systems were greater than budgeted amounts, which in turn impacted labor costs. The use of safety stock models for spare parts that optimize part allocation to public transport hubs has been proposed (Sun et al, 2020). Others have proposed the use of mathematical programming models to optimize spare parts inventory for high-speed transit trains (Lin et al, 2017). Other approaches include the development of a system to closely monitor the health of bus fleets (Corazza et al, 2018). An operational challenge appears to exist for both public and private transportation systems (Kabacinski et al, 2020).

Readers unfamiliar with the basics of inventory management may consult Silver et al (2017, Chapter 6). Inventory systems at warehouses that hold repair parts subject to intermittent demand with fixed ordering costs. These systems are often a continuous review (r, Q) system or a periodic review (r, s, S) system (Shenoy & Rojas, 2017). In these systems, r is the review frequency, Q is the order quantity, s is the reorder point (sometimes called the min), and S is the order-up-to level (sometimes called the max). The various models that have been developed are distinguished by their underlying assumptions.

This work proposes a new approach to the quantification of shortage cost, which generally consists of lost sales or backlogs (Xu, 2017). In practice, shortage costs include a fixed cost (e.g., a contractual penalty or re-order processing) and a variable cost that depends on the number of shortages (Benkherouf & Sethi, 2010). Some authors treat shortages as a fixed cost per shortage event (e.g., Ting et al, 2009; Huang & Wu, 2017) and others allow some (but not all) shortages to be backlogged (Kumar, 2021). An option may exist to expedite the order or substitute a product (Kornai & Weibull, 1978). Differences in customer priorities make modeling of shortage costs more complex when there are multiple customer groups (Sadeghi et al 2021). Practitioners should be aware that customers may order more parts than needed when they anticipate the potential for shortages (Foster et al, 2019), which can inflate future demand forecasts.

Intermittent demand for repair parts can be difficult to forecast and it cannot be modelled reliably using the normal distribution. This type of demand may be responsible for 20% of sales that can account for 80% of inventory cost (Stephan & Siemsen, 2015). Jiang et al (2020) propose forecasting intermittent demand by considering the effects of external factors using a mixed zero-truncated Poisson model, then calculating the probability of occurrence of zero value at each period. Taleizadeh et al (2013) create an inventory model to determine the optimal order and shortage quantities of a perishable item, assuming Poisson demand and shortage cost. Meisheri et al (2022) expands this work by considering lead time impacts in a multi-product, multi-period environment.

Engelmeyer (2015) provides a systematic explanation of various supply chain inventory models, including some methods to manage intermittent random demand. The structure of a central warehouse and garages is referred to as a two-echelon inventory system (Axsater, 2005). Nicholson et al (2004) emphasized the importance of service levels for different kinds of distribution networks. Determining service level targets that vary according to part characteristics is often done based on the ABC or similar classification scheme, with many authors suggesting that A items should be managed with higher service levels than B or C items (Hu et al, 2018).

Teunter et al (2009) determined optimal service levels for parts based on demand, holding costs, shortage costs, and average order quantity, where the shortage costs are based on the criticality of the item. Millstein et al (2014) determined the optimal number of inventory groups and their associated service levels using a MILP formulation, where optimal service levels were directly proportional to the profit margin of the product. But Lolli et al (2019) cautioned that groups can change over time and used a machine learning framework to create testing samples from existing parts to adjust service level targets.

METHODOLOGY

Repair inventory is unique because of the inter-relationship among the parts used in the repair. Table 1 shows an example bill-of-material (BOM) for a repair that requires 16 parts, where the total cost of all parts is $400. In the table, “Quantity” represents the number needed for one repair, the lead time to procure the part is in weeks, the unit cost is purchase price per part, the part cost is the total purchase price for all parts in one repair, “percentage” is the share of the total $400 represented by the part, and other part cost is the cost of all other parts (e.g., the other part cost for Part A is $399 because its cost is $1.00 and the parts for the entire repair total $400).

The range of part costs for a single public transit repair job can be large, because a repair often requires one or more expensive components (e.g., brake drum for a bus) that are assembled using various less expensive components (e.g., hoses, screws, or clamps). In this respect, although repairs may differ from another repair in criticality, all parts within a single repair’s BOM are equally critical.

Table 1: Example Repair Bill-of-Material

Part	Quantity	Lead Time	Unit Cost	Part Cost	Percentage	Other Part Cost
A	4	30	$0.25	$1.00	0.3%	$399.00
B	5	10	$1.50	$7.50	1.9%	$392.50
C	3	15	$6.30	$18.90	4.7%	$381.10
D	2	15	$100.00	$200.00	50.0%	$200.00
E	5	5	$2.30	$11.50	2.9%	$388.50
F	22	25	$0.05	$1.10	0.3%	$398.90
G	3	10	$0.50	$1.50	0.4%	$398.50
H	10	15	$2.50	$25.00	6.3%	$375.00
I	8	20	$2.00	$16.00	4.0%	$384.00
J	10	5	$0.50	$5.00	1.3%	$395.00
K	9	10	$1.50	$13.50	3.4%	$386.50
L	10	25	$2.75	$27.50	6.9%	$372.50
M	8	25	$7.50	$60.00	15.0%	$340.00
N	1	15	$0.25	$0.25	0.1%	$399.75
O	4	20	$1.50	$6.00	1.5%	$394.00
P	7	10	$0.75	$5.25	1.3%	$394.75

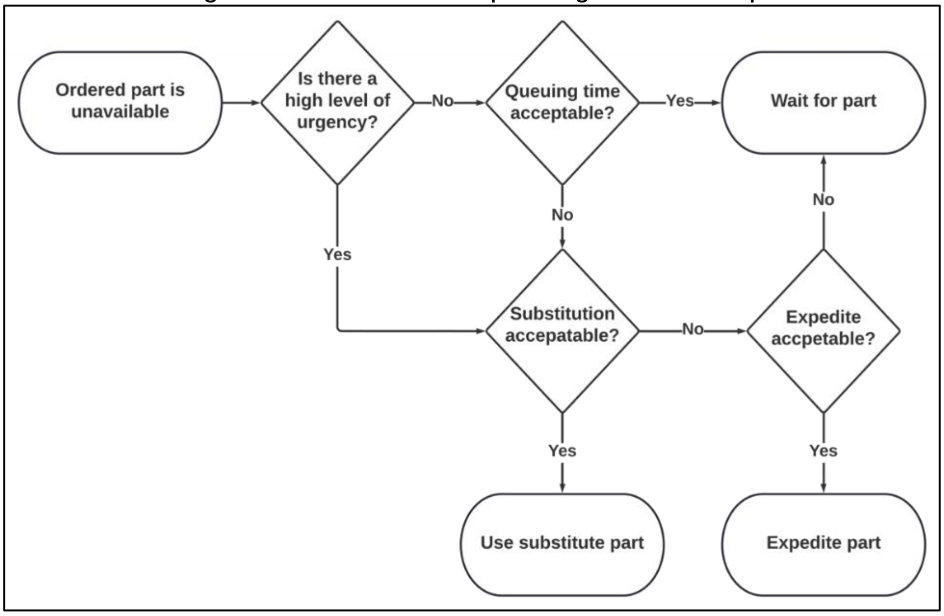
Cost Structure

The assumed cost structure for inventory modeling accounts for the following relevant costs: the part's purchase cost, the fixed ordering cost, the part's inventory holding cost, and the part's shortage cost. For a repair inventory system, shortages would be backlogged because the repair needs to be done, even if it will not be done immediately. That is, repair garages have no recourse other than to wait for parts to be delivered from the central warehouse. Figure 1 shows the basis for shortage cost used in the inventory model.

In the models presented below, shortage costs are handled in a unique way that is commensurate with the repair parts system. In a public transit system, the ideal scenario would be all parts for a repair being available when demand exists. If one required part is unavailable, an expense of holding all of the other parts need for the same repair would exist. The unnecessary holding time for this group of parts would correspond to the part's procurement lead time. This cost will be referred to as the "holding other part" (HOP) cost.

HOP cost behaves in a counter-intuitive way. It would tend to be high for an inexpensive part that makes up a small percentage of the repair's total part cost and low for expensive part that makes up a large percentage of the repair's total part cost. When expediting the shipment of a part can be accomplished, shortage costs would include both the HOP and fixed or variable expediting cost although the HOP component would be based on a shorter lead time. In some cases, the potential for substitute part may be considered before determining if expensive expediting is undertaken.

Figure 1: Substitution/Expediting Process Map



Inventory Models

The inventory system at the central warehouse is assumed to be the periodic review (r, s, S) system with a one-week review period. Shortages are backlogged. Part demand is intermittent because it is characterized by low demand volumes and high demand uncertainty. The normal distribution does not apply because the demand distribution should be discrete, and the demand distribution intermittent items is often right skewed. The model assumes that the demand distribution is Poisson, because breakdowns often follow a Poisson process (Silver et al, 2017, P. 275).

The inventory system was modeled in three ways, using: (1) a deterministic model, (2) a stochastic model with fixed cycle time, and (3) a simulation model. These models represent a hierarchy, ranging from model (1) that is the easiest to implement but potentially inaccurate, to model (2) that requires software to create and evaluate probabilities, to model (3) that is most accurate but time consuming to implement.

The system assumes that orders are placed and received at the end of the review period. The assumptions are as follows:

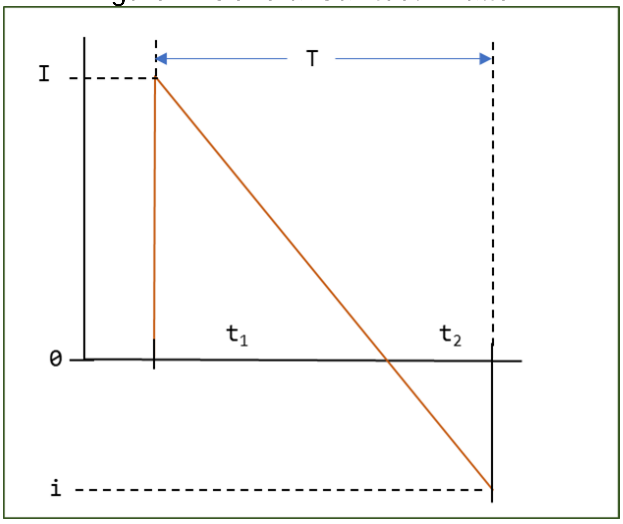
1. The part being ordered is one of many parts required to complete one repair.
2. The review period is one-week.
3. The length of one ordering cycle (i.e., time between receipt of orders) averages T weeks.
4. The inventory policy is (s, S) system with periodic ordering.
5. The forecast (i.e., average weekly demand rate) for the part is μ.
6. The distribution of the demand for the repair is Poisson.
7. The lead time for receiving parts is L periods.
8. The part cost is C per unit.
9. A backlog will be created when demand exists and inventory is unavailable.

10. The total cost of “other” parts needed for the same repair is B per unit.
11. The fixed ordering cost is P.

Deterministic Approach

Figure 2 represents one ordering cycle, with I representing the inventory status after part receipt, t_1 representing the duration of a cycle for which inventory is positive, t_2 representing the duration of a cycle for which a backlog exists, and i represents the inventory status at the end of the cycle.

Figure 2: General Sawtooth Pattern



The intermediate values needed for the derivation of total annual cost are included in Equations 1 through 5.

$$\mathrm{T} = \frac{S - s + 1}{\mu} \tag{1}$$

$$I = S - \mu L \tag{2}$$

$$i = s - \mu L - 1 \tag{3}$$

$$t_1 = \begin{cases} \dfrac{S - \mu L}{\mu}, & s < 1 + \mu L \\ \dfrac{S - s + 1}{\mu}, & s \geq 1 + \mu L \end{cases} \tag{4}$$

$$t_2 = \begin{cases} \dfrac{\mu L - s + 1}{\mu}, & s < 1 + \mu L \\ 0, & s \geq 1 + \mu L \end{cases} \tag{5}$$

The annual total cost model assumes that $S \geq \mu L$. It will differ spending on the value i, as shown in Equation 6.

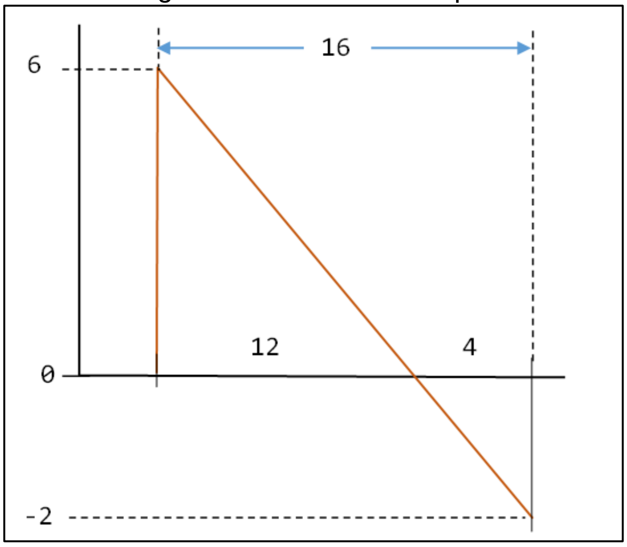
$$TC = \begin{cases} \dfrac{hC(S-\mu L)^2 + 2Lh\mu B(1+\mu L - s) + 104\mu P}{2(S-s+1)}, & s < 1+\mu L \\ \dfrac{hC(S+s-2\mu L-1)}{2} + \dfrac{52\mu P}{S-s+1}, & s \geq 1+\mu L \end{cases} \quad (6)$$

Stochastic Approach

A revision to the deterministic model is necessary to account for Poisson demand variation. This revision will consider all potential inventory levels for a cycle while maintaining the expected cycle length determined in Equation 1. Consider the following scenario that generated the deterministic sawtooth pattern in Figure 3. In this case, average weekly demand 0.5 parts per week, the lead time is 6 weeks, and (s, S) is $(2{,}9)$.

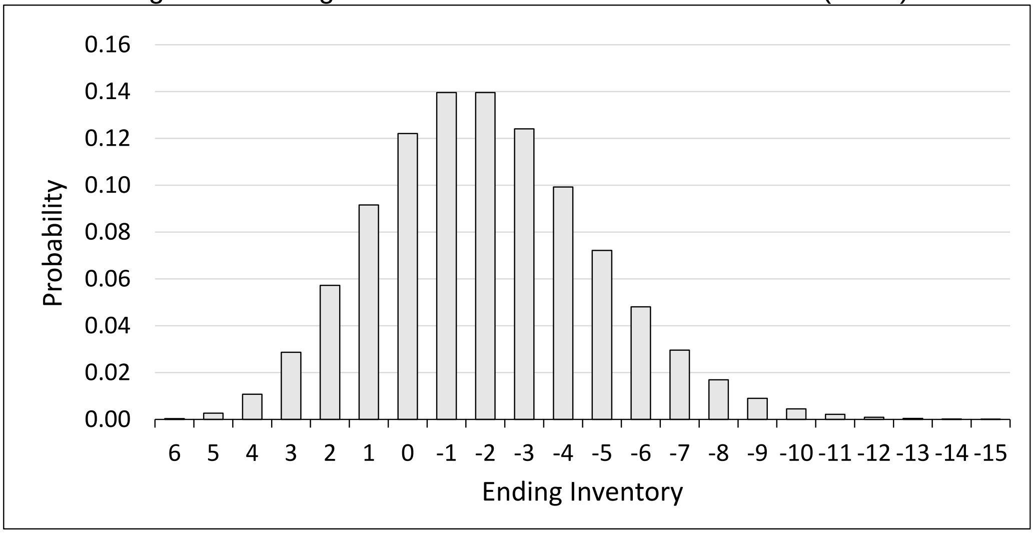
Although the average ending inventory is -2 (a backlog of 2 parts), the actual ending inventory will vary based on the demand variation during the ordering cycle. Figure 4 shows the potential ending inventory values. The ending inventory is the difference between the beginning inventory ($I = 6$ parts) and the demand during the $T = 16$ week cycle time. Demand during a cycle follows a Poisson distribution with mean $\lambda = \mu T = 8$ parts.

Figure 3: Sawtooth Example



The total cost function for the stochastic model includes the sum of the expected holding cost, expected setup cost, and expected shortage cost. The expected holding cost (Equation 7) is determined by the average inventory and their likelihoods. The expected shortage cost (Equation 8) is determined by the number of parts backlogged and their likelihoods. The expected setup cost is not affected by these stochastic assumptions. The expected total cost is provided in Equation 9.

Figure 4: Ending Inventories with Poisson Probabilities ($\lambda = 8$)



$$\bar{I} = \sum_{x=0}^{[S-\mu L]} (S - \mu L - \frac{x}{2}) \frac{\lambda^x e^{-\lambda}}{x!} + \sum_{x=[S-\mu L]+1}^{\infty} \left[\frac{(S - \mu L)^2}{2x}\right] \frac{\lambda^x e^{-\lambda}}{x!} \tag{7}$$

$$\bar{b} = \sum_{x=[S-\mu L]+1}^{\infty} (S - \mu L - x) \frac{\lambda^x e^{-\lambda}}{x!} \tag{8}$$

$$TC = \frac{\bar{I}Ch(S - s + 1) + \bar{b}BLh\mu + 52P\mu}{(S - s + 1)} \tag{9}$$

A cycle's expected service level is given in Equation 10.

$$r = \sum_{x=0}^{[S-\mu L]} \frac{\lambda^x e^{-\lambda}}{x!} \tag{10}$$

Simulation Verification

A simulation model was created in Python to mimic the repair inventory system for a part. Unlike the stochastic model above, no assumptions were made regarding the ordering cycles. The model is not described because it played a limited role in the overall analysis regarding service levels. It was used merely to verify that the optimal ordering parameters were valid and it served this purpose.

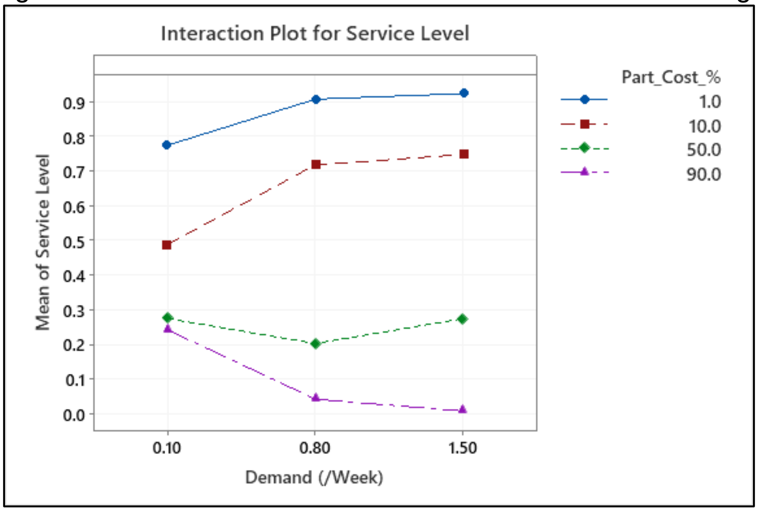
RESULTS

The focus of this analysis was on the optimization of service levels and how they vary according to the parameters that constitute the part's demand and cost characteristics. Once the optimal service level is determined, the ordering policy would be easy to determine using traditional methods that determine safety stocks based on cycle service times (Silver et al, 2017, Chapter 6). In this analysis, expediting was assumed to be impossible (i.e., parts can only be obtained from suppliers who will not send parts any faster than the quoted lead time). Demand was assumed to be Poisson, with perfect positive correlation across lead time periods. The assumption of perfect correlation across period can be relaxed while maintaining the basic structure of the models described here.

The optimal service level was analyzed with a metamodel. Data for the metamodel were created with a factorial experimental design consisting of four factors: (1) mean demand (0.1, 0.8, and 1.5 parts/week), (2) lead time (5, 15, and 25 weeks), (3) inventory holding rate (0.15 and 0.3 per year) and (4) the percentage of the total part cost represented by the part being analyzed (1%, 10%, 50%, and 100%). Setup cost, which has little effect on optimal service level, was held at a constant value.

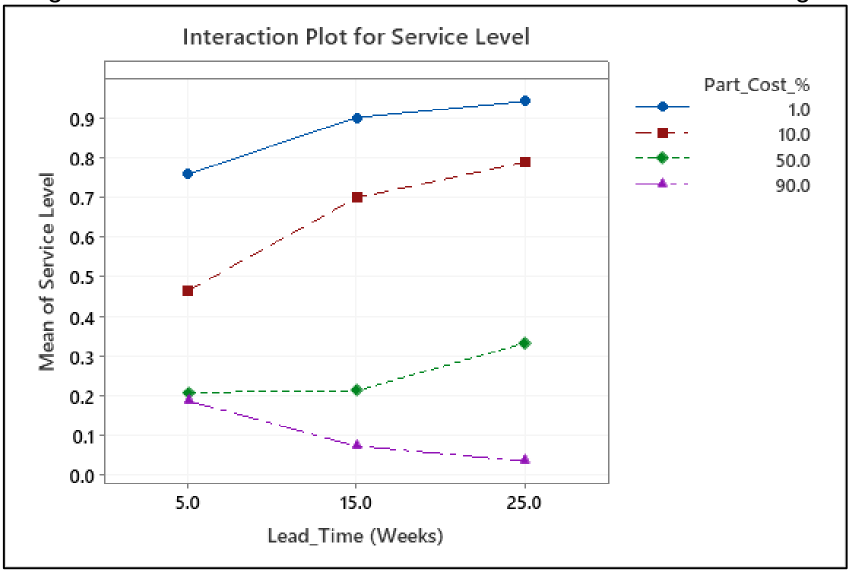
The optimal service level was determined for the 144 scenarios using the deterministic and stochastic models, and verified with the simulation. The interaction of demand and part cost percentage (Figure 5) and the interaction of lead time and part cost (Figure 6) both have a significant effect on optimal service levels ($p<0.001$ in both cases). The results show that parts making up a lower percentage of repair part cost should be assigned a higher service level when creating inventory policies. This higher service level would be even higher for parts with longer lead times. Correspondingly, parts that make up a high percentage of repair part cost should be assigned a lower service level.

Figure 5: Interaction Plot for Demand & Part Cost Percentage



The interaction of demand and lead time (Figure 7) also had a significant effect on the optimal service level ($p<0.001$). It is interesting that optimal service levels become higher for long lead time parts as demand is higher, but optimal service levels become lower for short lead time parts as demand is higher.

Figure 6: Interaction Plot for Lead Time & Part Cost Percentage



Based on the determination of the significant variables, a multiple regression model was created. The interaction plots did not include strong nonlinearity, so a linear regression model was created for the significant effects. It is shown in Equation 11.

$$\hat{y} = 0.558 + 0.0105\, x_1 + 0.00614\, x_2 - 0.00219\, x_3 + 0.01037\, x_1 x_2 - 0.003572\, x_1 x_3 - 0.000222\, x_2 x_3 \quad (11)$$

Relevant information concerning the data included in Table 1 were repeated in Table 2, where Equation 11 was used to calculate the optimal service level for each part. As expected, parts having low contributions to the total price have high optimal service levels. Those low priced parts with longer lead time have even high optimal service levels (e.g., Part A vs. Part J). The part that contributes 50% of the total cost of the repair shows the lowest optimal service level (Part D).

CONCLUSION

The traditional ABC classification does not appear to be an effective categorization for repair inventory. With repairs that consist of many parts, it would be frustrating for a technician to delay a repair when all parts were available except for one very inexpensive part that takes a long time to procure. This common-sense reaction is supported by the models above that account for holding cost for all "other" parts needed for a repair. The models included here show that the optimal service level would depend on three main part characteristics: (a) its demand, (b) its lead time, and (c) its percentage contribution to the total repair parts' cost.

Figure 7: Interaction Plot for Demand & Lead Time

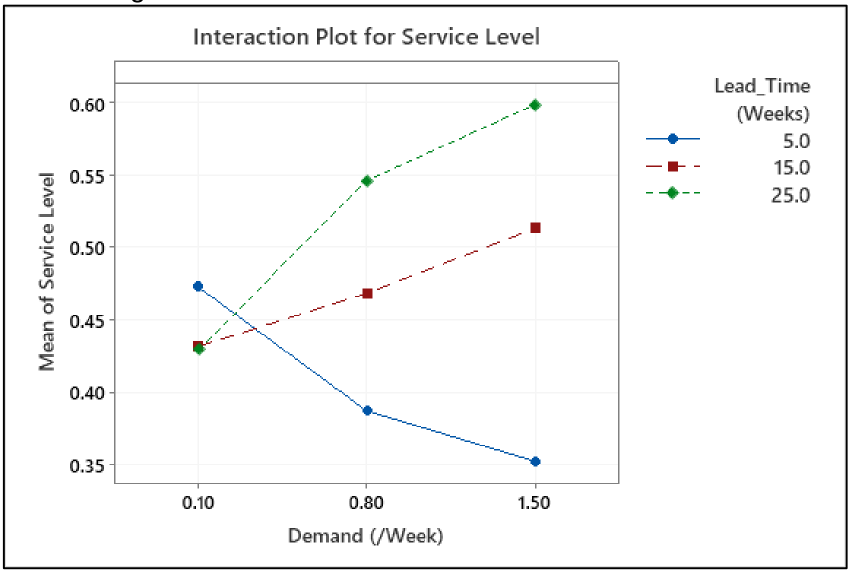


Table 2: Example BOM with Optimal Service Levels

Part	Lead Time	Part Cost %	Service Level
A	30	0.3%	0.900
B	10	1.9%	0.665
C	15	4.7%	0.699
D	15	50.0%	0.368
E	5	2.9%	0.605
F	25	0.3%	0.844
G	10	0.4%	0.674
H	15	6.3%	0.687
I	20	4.0%	0.756
J	5	1.3%	0.614
K	10	3.4%	0.656
L	25	6.9%	0.781
M	25	15.0%	0.703
N	15	0.1%	0.733
O	20	1.5%	0.777
P	10	1.3%	0.668

This work has some limitations that will be the subject of future work. The authors plan to enhance the simulation so that it accounts for parts shared across repairs. As such, the inter-relationship among parts' inventory policies will be studied. Finally, the impacts of expediting shipments of backlogged parts will be evaluated.

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Optimal Strategy in Decision Making for the Estimation of Population Variance Using Auxiliary Parameters

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ABSTRACT

In this study, we suggest a new structured ratio estimator by combining the ratio and the exponential ratio estimator for elevated estimation of the population variance of the study variable using the known auxiliary parameters. The properties of the sampling techniques, mainly bias and the Mean Squared Error (MSE) of the suggested estimator, are derived for the first order of approximation. The characterizing constants of the proposed estimator are optimized through the method of maxima and minima so that the MSE of the suggested estimator is minimum. The introduced estimator is theoretically and empirically compared with the competing estimators using real as well as simulated data sets. Through the numerical study, the most efficient estimator is recommended for practical use in different areas of application, including business and management.

KEYWORDS: Study Variable, Auxiliary Variable, Bias, MSE, Percentage Relative Efficiency (PRE).

INTRODUCTION

Variation is instinctive and it may be observed everywhere in nature. Even two similar objects have variations. It is vital and beneficial for large populations to reduce errors with less time and money spent on planning and decision-making. Rapid policy decision-making necessitates sampling and then estimation of the parameters under consideration. Teplicka (2015) investigated the problem of variance analysis for better firm decision-making, demonstrating that variance analysis is a useful tool for estimating price variations for production factors in producing items. Cohen and Pant (1989) investigated the problem of variance analysis and demonstrated that it is a powerful tool for any organization in achieving its goals because it is critical to understand the impact of variation on financial results and proper management of this variation to meet the organization's goals. Conine and McDonald (2017) demonstrated that variance analysis is highly effective for financial planning of diverse companies by sampling estimates of the parameters for improved decision-making to enhance organizations. Pollono and Pupkevics (2021) worked on the sales variance analysis and demonstrated that it is an effective instrument for boosting an organization's profit. As a result, variance plays a crucial role in business and other significant decisions, and its estimation and analysis are critical for making outstanding decisions. Many researchers have shown their interest through their work in elevated estimation of population variance (σ_y^2) of the main variable (Y) using information on the parameters of the auxiliary variable (X). Some of the considerable works include Isaki (1983), Upadhyaya and Singh (1999), Singh and Singh (2001), Singh and Singh (2003), Kadilar and Cingi (2006), Shabbir and Gupta (2007), Singh *et al.* (2008), Singh and Solanki (2012), Subramani and Kumarpandiyan (2013), Khan and Shabbir (2013), Maqbool and Javaid (2017), Yadav *et al.* (2019), Gulzar *et al.* (2020), Shahzad *et al.* (2021) and Sharma *et al.* (2022).

In this paper, we consider a new estimator for improved estimation of σ_y^2 using known parameters of X, which is motivated by several authors in the literature. As a result, we may be able to estimate population variance closer to the true population variance, allowing for more effective policy formation. We study the suggested estimator's various features and compare them to competing estimators theoretically and empirically to assess its efficiency over competing estimators. The manuscript is organized into several sections, including a review of existing estimators that use auxiliary information, the suggested estimator, theoretical efficiency comparison, empirical investigation, results, discussion, and a conclusion.

REVIEW OF EXISTING ESTIMATORS

In this section, different estimators of σ_y^2 has been presented along with their variance/MSEs for the approximation of degree one. Table 1 below shows different estimators of σ_y^2 under consideration with their MSEs.

Table 1: Estimators by different authors and their MSE

S. No.	Author(s)	Variance/MSE
1.	Anonymous for sample variance	$V(t_0) = \gamma S_y^4(\lambda_{40}-1)$
2.	Isaki (1983)	$MSE(t_R) = \gamma S_y^4[(\lambda_{40}-1)+(\lambda_{04}-1)-2(\lambda_{22}-1)]$
3.	Upadhyaya and Singh (1999)	$MSE(t_1) = \gamma S_y^4[(\lambda_{40}-1)+R_1^2(\lambda_{04}-1)-2R_1(\lambda_{22}-1)]$
4.	Kadilar and Cingi (2006)	$MSE(t_i) = \gamma S_y^4[(\lambda_{40}-1)+R_i^2(\lambda_{04}-1)-2R_i(\lambda_{22}-1)]$, $i=2,3,4$
5.	Subramani and Kumarpandiyan (2012a)	$MSE(t_5) = \gamma S_y^4[(\lambda_{40}-1)+R_5^2(\lambda_{04}-1)-2R_5(\lambda_{22}-1)]$
6.	Subramani and Kumarpandiyan (2012b)	$MSE(t_i) = \gamma S_y^4[(\lambda_{40}-1)+R_i^2(\lambda_{04}-1)-2R_i(\lambda_{22}-1)]$, $i=6,7,\ldots,10$
7.	Subramani and Kumarpandiyan (2013)	$MSE(t_{11}) = \gamma S_y^4[(\lambda_{40}-1)+R_{11}^2(\lambda_{04}-1)-2R_{11}(\lambda_{22}-1)]$
8.	Khan and Shabbir (2013)	$MSE(t_{12}) = \gamma S_y^4[(\lambda_{40}-1)+R_{12}^2(\lambda_{04}-1)-2R_{12}(\lambda_{22}-1)]$
9.	Maqbool and Javaid (2017)	$MSE(t_{13}) = \gamma S_y^4[(\lambda_{40}-1)+R_{13}^2(\lambda_{04}-1)-2R_{13}(\lambda_{22}-1)]$
10.	Khalil *et al.* (2018)	$MSE(t_i) = \gamma S_y^4[(\lambda_{40}-1)+R_i^2(\lambda_{04}-1)-2R_i(\lambda_{22}-1)]$, $i=14,15,16$
11.	Yadav *et al.* (2019)	$MSE(t_{17}) = \gamma S_y^4[(\lambda_{40}-1)+R_{17}^2(\lambda_{04}-1)-2R_{17}(\lambda_{22}-1)]$

12.	Sharma *et al.* (2022)	$MSE_{\min}(t_{18}) = S_y^4\left[1-\frac{A^2}{B}\right]$, where $A = 1+\gamma R_{17}^2(\lambda_{04}-1)-\gamma R_{17}(\lambda_{22}-1)$ and $B = 1+\gamma(\lambda_{40}-1)+3\gamma R_{17}^2(\lambda_{04}-1)-4\gamma R_{17}(\lambda_{22}-1)$

Where, $\gamma = \frac{1-f}{n}$, $f = \frac{n}{N}$, $\lambda_{rs} = \frac{\mu_{rs}}{\mu_{20}^{r/2}\mu_{20}^{s/2}}$, $\mu_{rs} = \frac{1}{N-1}\sum_{i=1}^{N}(Y_i-\bar{Y})^r(X_i-\bar{X})^s$, $R_1 = \frac{S_x^2}{S_x^2+\beta_2}$, $R_2 = \frac{S_x^2}{S_x^2+C_x}$, $R_3 = \frac{S_x^2\beta_2}{S_x^2\beta_2+C_x}$, $R_4 = \frac{S_x^2C_x}{S_x^2C_x+\beta_2}$, $R_5 = \frac{S_x^2}{S_x^2+M_d}$, $R_6 = \frac{S_x^2}{S_x^2+Q_1}$, $R_7 = \frac{S_x^2}{S_x^2+Q_3}$, $R_8 = \frac{S_x^2}{S_x^2+Q_r}$, $R_9 = \frac{S_x^2}{S_x^2+Q_d}$, $R_{10} = \frac{S_x^2}{S_x^2+Q_a}$, $R_{11} = \frac{S_x^2C_x}{S_x^2C_x+M_d}$, $R_{12} = \frac{S_x^2\rho_{yx}}{S_x^2\rho_{yx}+Q_3}$, $R_{13} = \frac{S_x^2}{S_x^2+(TM+Q_a)}$, $R_{14} = \frac{S_x^2}{S_x^2+C_xS_x}$, $R_{15} = \frac{S_x^2}{S_x^2+C_x\bar{X}}$, $R_{16} = \frac{S_x^2}{S_x^2+C_xM_d}$, $R_{17} = \frac{S_x^2}{S_x^2+(TM+Q_3)}$

PROPOSED ESTIMATOR

Under this section, a generalized ratio-cum-exponential ratio type estimator of σ_y^2 utilizing the known parameters of X have been introduced, and we have studied the bias and MSE for the approximation of order one. The estimator, bias, and MSE of the suggested estimator, respectively, are given as,

$$t_p = \kappa_1 s_y^2\left(\frac{S_x^2+(TM+Q_3)}{s_x^2+(TM+Q_3)}\right)+\kappa_2 s_y^2\exp\left(\frac{S_x^2-s_x^2}{S_x^2+s_x^2}\right)$$

$$B(t_p) = S_y^2[\kappa_1\{1-\gamma R_{17}(\lambda_{22}-1)+\gamma R_{17}^2(\lambda_{04}-1)\}+\kappa_2\{1-\frac{1}{2}\gamma(\lambda_{22}-1)+\frac{3}{8}\gamma(\lambda_{04}-1)\}-1]$$

$$MSE_{\min}(t_p) = S_y^4\left[1+\frac{L}{M^2}\right]$$

Where,

$$L = \begin{Bmatrix} 2(PT-SR)+2(QS-RT)-2(PT-SR)(QS-RT)R \\ -(QS-RT)^2P-(PT-SR)^2Q \end{Bmatrix}$$

$M = (PQ-R^2)$ and

$$P = 1+\gamma[(\lambda_{40}-1)+3R_{17}^2(\lambda_{04}-1)-4R_{17}(\lambda_{22}-1)]$$

$$Q = 1+\gamma[(\lambda_{40}-1)+(\lambda_{04}-1)-2(\lambda_{22}-1)]$$

$$R = 1 + \gamma[(\lambda_{40} - 1) + (R_{17}^2 + R_{17} + \frac{3}{8})(\lambda_{04} - 1) - (\lambda_{22} - 1)]$$

$$S = 1 + \gamma[R_{17}^2(\lambda_{04} - 1) - R_{17}(\lambda_{22} - 1)]$$

$$T = 1 + \gamma[\frac{3}{8}(\lambda_{04} - 1) - \frac{1}{2}(\lambda_{22} - 1)]$$

EMPIRICAL STUDY

In this section, we have compared different estimators under comparison and have calculated the variance and MSE of these estimators. The parameters of the population under consideration are presented in Table 2.

Table 2: Parameters of the Natural Population
$N = 80$, $n = 20$, $\bar{Y} = 51.8264$, $\bar{X} = 11.2646$, $S_y = 19.3549$, $C_y = 0.3542$ $S_x = 8.4563$, $C_x = 0.7507$, $\rho_{yx} = 19.3549$, $\lambda_{40} = 2.2667$, $\lambda_{40} = 2.8664$, $\lambda_{22} = 2.2209$, $Q_1 = 5.1500$, $Q_3 = 16.975$, $Q_d = 5.9125$, $Q_a = 11.0625$, $TM = 9.3180$, $M_d = 7.5750$

The MSEs of the introduced and the estimators in competition, and their percentage relative efficiency (PRE) with respect to sample variance estimator t_0 under a simple random sampling scheme are presented in Table 3.

Table 3: MSE and PRE of different estimators

Estimator	MSE	PRE	Estimator	MSE	PRE
t_0	5393.89	100.00	t_{10}	3133.33	172.15
t_R	3925.16	137.42	t_{11}	2467.88	218.56
t_1	3658.41	147.44	t_{12}	2878.56	187.38
t_2	3850.16	140.10	t_{13}	2820.06	191.27
t_3	3898.56	138.36	t_{14}	2547.21	211.76
t_4	3580.83	150.63	t_{15}	2450.18	220.14
t_5	4157.95	129.72	t_{16}	2580.75	209.00
t_6	3480.55	154.97	t_{17}	2040.12	264.39
t_7	2908.65	185.44	t_{18}	1986.22	271.57
t_8	3098.41	174.09	t_p	**1779.64**	**303.09**
t_9	3427.19	157.39			

CONCLUSION

In this study, we have introduced a new ratio-cum-exponential ratio type estimator to estimate σ_y^2 utilizing the known parameters of X . The bias and MSE of the introduced estimator are studied for the approximation of order one. The suggested estimator is compared with the competing estimators of σ_y^2 using and without using auxiliary information. From Table 3, it may be observed that the introduced estimator has the minimum MSE among the class of estimators in competition. Thus, the introduced estimator may be utilized for the enhanced estimation of σ_y^2 in different areas of applications.

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(A complete list of references is available upon request.)

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Optimization of ERP Data Collection Process Using Discrete Event Simulation

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ABSTRACT

Business systems software, such as Enterprise Resource Planning (ERP), offer more capability for tracking and reporting data than ever before. The cost of additional data collection processes is often overlooked or difficult to predict. Utilizing discrete event simulation (DES) to optimize the placement and quantity of data collection points in a manufacturing environment, this project integrates an ERP data collection process in a DES model of the overall production environment. The results of the simulation are used as inputs to conduct a cost-benefit analysis that identifies the most cost-effective solution.

KEYWORDS: Industry 4.0, Digital Transformation, Electronics Manufacturing Service, labor costs, Lean Manufacturing, Discrete Event Simulation

INTRODUCTION

Industry 4.0 has touted the benefits of interconnected manufacturing plants for a number of years. Access to real time data from embedded machines, inspection and quality, inventory and kitting, maintenance technicians, and throughput yields, is likely to benefit a company's efficiency and productivity in ways that were not previously possible. These benefits would be particularly useful for flexible manufacturing firms, such as contract manufacturers, which experience more frequent setups, higher product mixes, and dynamically changing schedules (Weber, 2021). Despite the apparent benefits, only 24 percent of manufacturers have implemented Industry 4.0 or "Smart Manufacturing", but an additional 53 percent plan to implement smart manufacturing in the next 3 years (Plex Systems & LNS Research, 2020).

The barriers to smart manufacturing implementation are similar to the challenges faced when implementing Lean Manufacturing. Traditionally, organizations would make the decision to implement Lean Manufacturing "based on a combination of faith in lean manufacturing philosophy, the reported experiences of others who have previously adopted these principles, and general rules of thumb on anticipated benefits" (Detty & Yingling, 2000). In their 2000 case study, Detty and Yingling attempted to demonstrate the benefits of using discrete event simulation (DES) to illustrate the specific benefits of Lean Manufacturing. They hypothesized that DES could be used to quantify the impact of lean principles during the planning stage, prior to implementation, specifically continuous flow, just-in-time inventory management, quality at the source, and level production scheduling (Detty & Yingling, 2000). The authors created models of the current state and proposed future lean state. Statistics were gathered on various key performance indicators (KPIs) including system flow time, order lead times, time between departures, and resource utilization among several others. After running two series of simulations, the authors demonstrated quantifiable improvements in every metric being evaluated. One of the greatest benefits to using DES was that the impact to the overall system as a whole could be evaluated, instead of isolating the benefits for each principle, making the proposed improvements more relatable to management (Detty & Yingling, 2000). As a logical next step, a manufacturer could utilize the modeling techniques described in this case study, to optimize their assembly processes for lean manufacturing, then add the smart manufacturing elements to the model (e.g., data collection points) and quantify the impact of implementing a smart manufacturing system and ensure it does not negatively impact lean manufacturing initiatives.

A case study by Ingemansson, et al (2005) attempted to demonstrate the benefits of using automatically collected machine data to feed a DES model for bottle neck analysis. In their methodology, production disturbances were automatically logged and provided to a DES model of the production environment. This allowed engineers to evaluate the cause of the bottle neck within the model, simulate a proposed correction, and simulate the results in compressed time. In the case study evaluated by the authors, they observed an improvement in availability of 6 percent over the course of a year.

One observation made by the authors was that in cases where automatic data collection was not possible, manual entry and classification of production disturbances was required in a “semi-automatic” manner. This required employees to enter the data into a computer by interacting with a data collection terminal and manually selecting the disturbance category from a predetermined list (Ingemansson, et al, 2005). There is a higher risk of error with this approach as employees may vary in how they categorize disturbances. There is also a risk that inefficiencies in the data entry process could result in less than optimal or even reduced efficiency than before intervention. The impact of the data entry on productivity should be incorporated in the model.

One of the greatest barriers to digital transformation of manufacturing operations is the high cost of the technology required to converge powerful digital systems, manufacturing equipment, and employees. These costs come in two forms: (1) The non-recurring cost of hardware such as mobile and stationary workstations as well as one time software fees. (2) The recurring cost of software licensing. Software systems are the heart of these transformations.

In a study by Krenczyk, et al (2018), the authors proposed a method of integrating ERP and DES software by automatically downloading data from the ERP system to the DES software. Using a neutral data storage format, specifically XML, data from the ERP system can be transformed into program code that is interpreted by the DES software. The method outlined in their research allows for rapid creation of simulation models that could be used by production management to quickly understand production flow and constraints given real, up-to-date data (Krenczyk, et al, 2018). The challenge with such a process is that data entered into the ERP system must be current and accurate. Legacy ERP and/or MES systems are often transactional in nature and not capable of processing and reporting live data in a manner that would be useful to manufacturing managers. Firms must make a substantial investment in implementing new systems that will receive data from the floor and transform it into a usable format for sales, quality, operations, and supply chain utilization.

The challenge of data collection is not only one of cost but also of lost efficiency. For example, in order to track employee productivity, employees must inform the system when they start or stop work on a particular work order. The time spent traveling to and interacting with a data collection point is non-value-added time that manufacturers may not have experienced prior to digital transformation. The most efficient solution would be to provide employees with mobile devices that would allow them to enter data into the system regardless of their physical location

(Moallen, 2020). This would likely be the highest cost solution as each employee would require a mobile computer which may also require a separate software license. Stationary workstations would have lower up-front costs, but the proper number and location of workstations is critical. Too few and the impact to productivity may be high as employees travel further and spend more time waiting to access the workstation. Too many and the company may be paying recurring cost for under-utilized resources.

Without proper planning and care when deciding on data collection methods for use in smart manufacturing systems, organizations run the risk of overspending on underutilized data collection points or increasing the amount of non-value-added time in the production process potentially negating any improvement to productivity expected in the digital transformation. Discrete event simulation (DES) may be an effective tool that will help companies “right-size” the number and location of data collection points on their manufacturing floors and/or stock rooms.

This project proposes to use DES modeling to optimize the placement and quantity of data collection points in a manufacturing environment by integrating the data collection process in a model of the overall production process in an electronics manufacturing service. The processes involving interaction with these workstations will be mapped in flowcharts and real-world delay and travel times collected and used in the simulation. With this model, alternate strategies for the placement and quantity of the data terminals will be proposed. The amount of direct labor being spent on terminal interaction will be provided by the simulation output and a cost-benefit analysis will be performed to identify the most cost-effective solution.

THEORETICAL DEVELOPMENT/MODEL

To create an accurate model, a case study was performed on a small electronics manufacturing service (EMS) provider located in the Midwest United States. Data was collected from direct observation of their operations and interviews of employees. This manufacturer had recently undergone an ERP transition to a digital system and implemented shop floor data collection via static terminals. This manufacturer utilizes a setup that is typical of small to medium EMS providers. For this study, some of the processes performed by this manufacturer were not included. The scope was limited to 3 value streams that make up five of the work centers and a total of 14 employees. These value streams include Surface Mount Technology (two identical work centers with two employees each), Wave Solder (one work center with four employees), and Selective Solder (two identical work centers with three employees each). They work a single 8-hour shift, 5 days per week.

Model Development

The main intention of this research is to optimize the process of direct labor employees entering data into an ERP system. It is important to perform this process as efficiently as possible as it involves using direct labor to perform a non-value-added task therefore contributing directly to overhead cost. Discrete event simulation is a proven tool for performing process optimization as DES models provide the means to change different conditions and see the results in the model (Ingemansson, et al, 2005). To develop an accurate simulation of the ERP data entry process on the manufacturing floor, a good conceptual model is needed to demonstrate the steps in the process. For the subject electronic manufacturing service, the high-level conceptual model is shown in Figure 1 and consists of the following steps: (1) Work orders are created in the ERP system. (2) The ERP system will dispatch the work order to one of five work centers. (3) The work center will perform the work required by the work order. (4) The work order is complete.

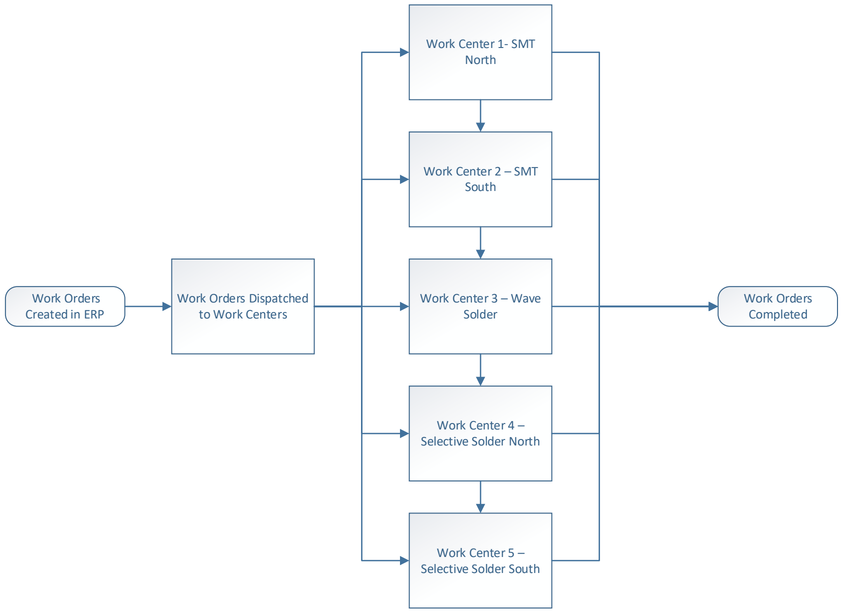

Figure 1: Conceptual Model

From this conceptual model, a more detailed process flow can be created, illustrating the process steps involved when each work center's operators clock in and out of the work orders. The process is broken down into a series of discrete events and decisions that are made by the operators involved. These steps are illustrated in Figure 2.

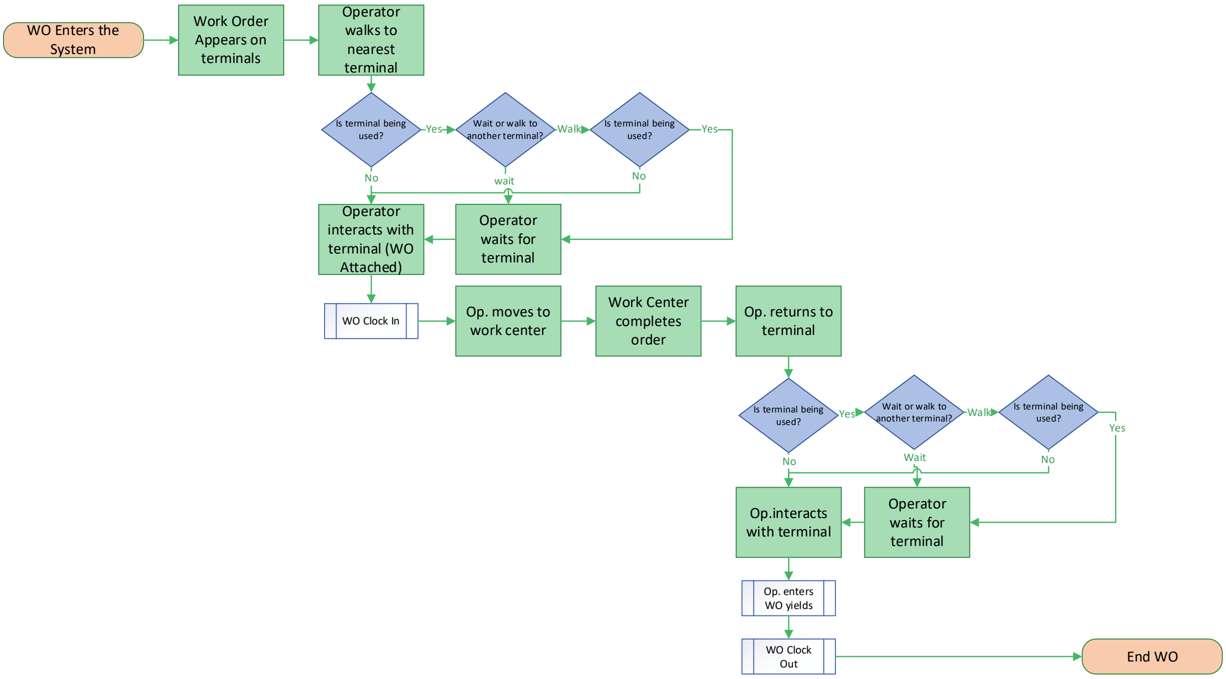

Figure 2: Process Flow Chart

From these process steps, a DES model can be created using the AnyLogic software platform and adapted to simulate different scenarios and predict the amount of time direct labor employees will spend traveling to, waiting on, and interacting with the ERP Terminals.

The simulation will have several benefits over a simple estimation of the terminal interaction time. For instance, the simulation can also account for the distance traveled from work center to terminal allowing the location of the terminal to be a process optimization variable. Additionally, the simulation can account for human behavior elements such as the amount of time operators will wait before walking to another terminal and the varying amounts of time each person will interact with the terminal. Data to incorporate these factors was obtained by directly observing the process being performed by the subject EMS.

Model Input Data

To ensure the validity of the model, input data was obtained from the electronic manufacturing service provider that was subject of the case study. From their operations, the location and space requirements for the work centers and terminals was obtained and used for the current state model. Total square footage of the shop floor where the five work centers are included is approximately 14,400 square feet.

Sample data was obtained for the time spent interacting with the ERP terminals both at clock-in and clock-out as well as work order run times. A survey of employees revealed clock-in times ranging from 30 seconds to 120 seconds with most clock-in interactions taking around 60 seconds. Clock-out times ranged from 15 to 60 seconds. Clock-in times appeared to take longer due to employees scanning though a list of work orders to find the one they were assigned to complete. Clocking out only required employees to scan their ID badges and enter the number of units completed. The distribution of this data was incorporated into the model.

The shift schedule is also accounted for in the model. This study focused on their first shift, which is run five days per week, from 7:30 AM to 4:00 PM with a 30-minute break at 11:30 AM. At the start of each shift, the employees must clock-into a work order and clock-out at the 11:30 AM break and clock back in at 12:00 PM. They will also clock out of the work order at the end of the shift. Employees must clock out of the work order at 11:30 AM and 4:00 PM even if the work order is not complete. These are the times when the demand on the ERP terminals will be highest as every employee will be attempting to use them at the same time. This shift schedule is accounted for in the model.

Labor cost information was not obtained from the subject company. Instead, it was estimated from data provided by the Bureau of Labor Statistics for the region (U.S. Bureau of Labor Statistics, 2020). Hardware cost was estimated from the requirements advertised by several ERP providers. Annual software license fees were also estimated from rates advertised by ERP providers with a customer profile similar to the subject company.

Model Logic

In the DES model, work orders are defined as the primary agent entering and moving through the system. As described in the conceptual model, work orders are created in the system and dispatched to one of the five work centers. Based on data collected from the subject manufacturer, each work center has, approximately, an even distribution of work orders dispatched to each work center. The work order agent will then seize the operator resource for that work center. Seizing this resource will trigger the start of the operators' task to clock into the work order. The operators from that work center will move to a queue location adjacent to a terminal. If the terminal is available, the operator will seize it and move up to the terminal. If another operator is currently interacting with the terminal, they will wait until it is available. If an operator waits for an excessive amount of time, they will move to another terminal and repeat the process of waiting for the terminal to become available or moving to a third terminal and waiting.

When determining which terminal to send the operator resources to in the simulation, an assumption had to be made that the operators will always first attempt to use the nearest terminal. This is an accurate assumption as employee training by the subject company instructs new employees in this way. However, if an employee chooses to move to another terminal, they will usually choose the next closest terminal but observation of the process in real life revealed that is not always the case. Approximately 30% of the time, employees would arbitrarily move to the farther terminal. This probability is incorporated into the simulation at this step in the process, again, making DES a more accurate representation of actual conditions than simple averages of the total process time.

Each work center has a required number of operators to seize before the work order can be run. Each operator must perform the clock-in task before the work order agent can move to the run order step in the simulation. Once this is done, a delay block will simulate the time spent running the order through the work center. After the delay is complete, the work order agent will release the operator resources. This will trigger the clock-out task for the operators which mirrors the clock-in process.

Figure 3 shows the model logic for one work center, “SMT North Line.” The same process is repeated for the other four work centers.

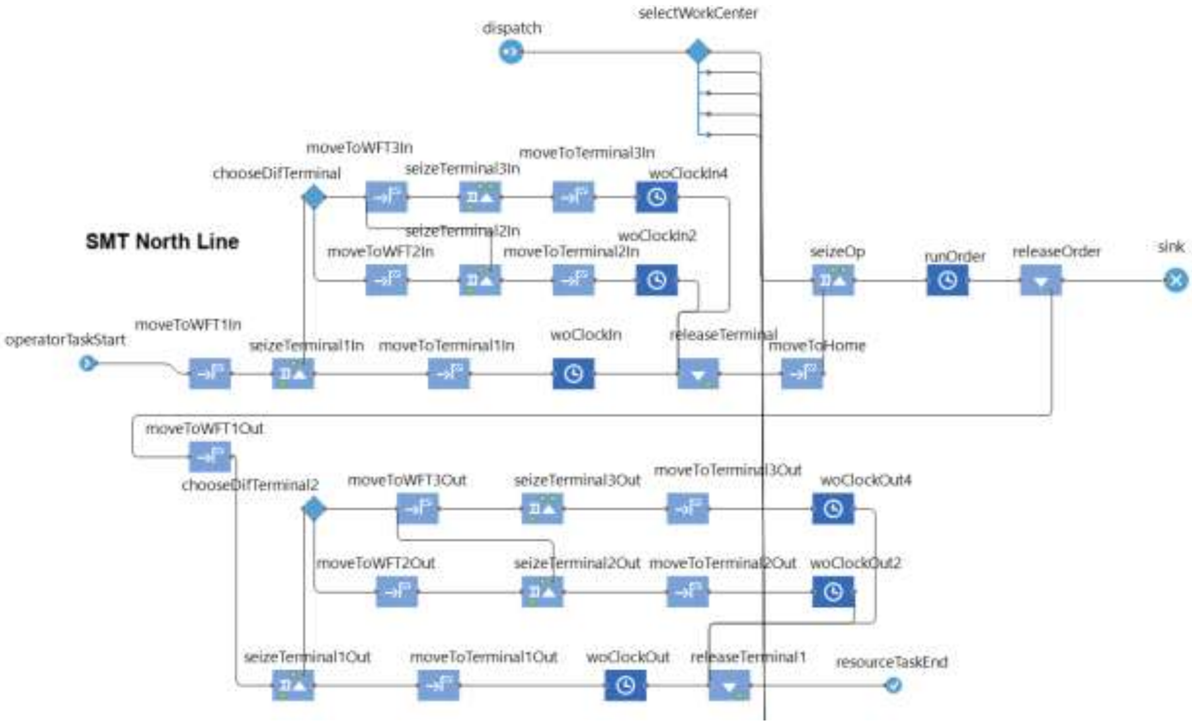

Figure 3: Model Logic – SMT North Line Work Center

PROPSED SIMULATION MODELS

To evaluate the effectiveness of DES to aid in cost reduction during ERP implementation, 4 different models will be created of the production environment to simulate the interactions employees have with ERP data entry terminals. The simulation will provide estimates of the labor time spent interacting with the terminals and when combined with the hardware and software costs, the true cost can be determined.

The four models will consist of a pre-intervention current state model that will be used as a baseline for comparing three post-intervention models. The post intervention models will be compared to the current state in an attempt to identify the most cost-effective improvement.

Pre-Intervention Current State

To find the most cost-effective approach, four different scenarios will be simulated. A pre-intervention, current state model (see Figure 4) that will act as a control. In this model, three terminals are placed at locations convenient due to the availability of power and ethernet. Each terminal is placed so that there is one terminal per process but can be shared by the five work centers.

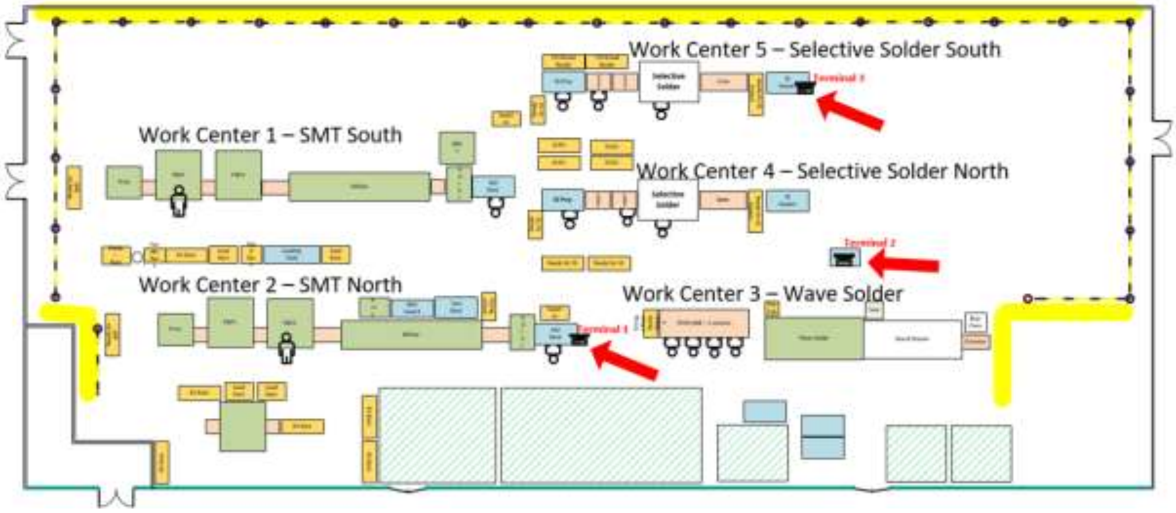

Figure 4: Pre-Intervention Current State – Three Terminals

Post-Intervention Scenario # 1

The first post-intervention model will simulate the use of mobile computers that would be issued to each employee (see Figure 5). This would eliminate the need for stationary terminals thus eliminating any transportation time walking to the terminal and waiting time if the terminal is occupied. This scenario would be most efficient, having the lowest labor cost but highest upfront investment in hardware and the highest annual recurring cost in software licenses. The high cost in hard dollars for this option may be too restrictive for smaller manufacturers who have likely invested a large amount of capital in the ERP implementation already.

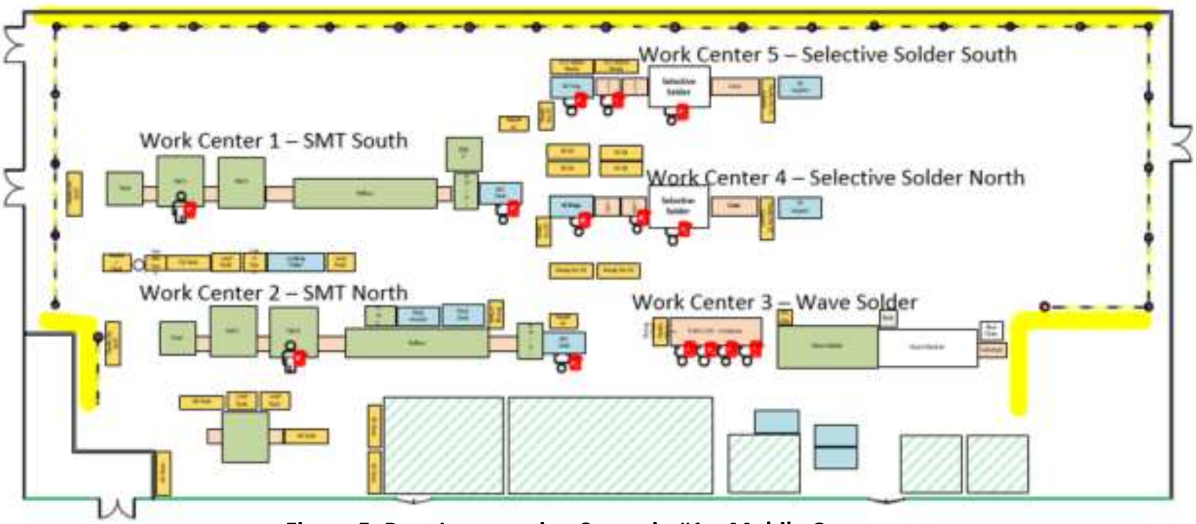

Figure 5: Post-Intervention Scenario #1 – Mobile Computers

Post Intervention Scenario # 2

The second proposed scenario simulates the lowest capital investment and lowest recurring cost by placing a single terminal in a central location (see Figure 6). This approach may be attractive to small manufacturers as it would have the lowest upfront cost but will likely have the highest labor cost as employees will spend more time traveling and waiting for use of the terminal. The lost productivity may become exceedingly costly overtime.

Figure 6: Post-Intervention Scenario #2 – Single Terminal

Post-Intervention Scenario # 3

The third scenario will attempt to minimize the upfront and recurring costs but still attempt to minimize travel and waiting times by placing a terminal near each work center (see Figure 7). This will require a higher upfront and annual cost than the current state but not nearly as high as the mobile computer option. The location of each terminal will need to be carefully chosen to minimize the travel time. The utilization results of the pre-intervention model will provide guidance on the proper number of terminals. The goal will be to have equal utilization at each terminal.

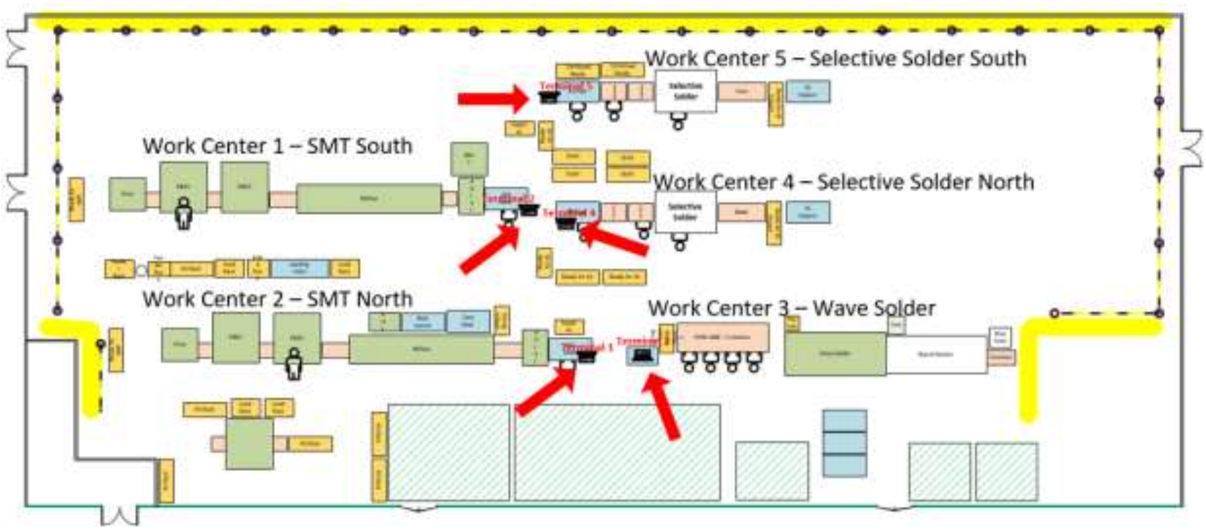

Figure 7: Post-Intervention Scenario # 3 – Terminal at Each Work Center

The predicted outcomes of these scenarios are summarized in Table 1:

Table 1: Prediction Table

Post-Intervention Scenario 1	Mobile Computers	Highest Efficiency	Highest Cost
Post-Intervention Scenario 2	Single Terminal	Lowest Efficiency	Lowest Cost
Post-Intervention Scenario 3	Terminal at each Work Center	Higher Efficiency	Higher Cost

Additional Post-Intervention Scenario

Since the different work centers have varying numbers of operators, there is a potential that some terminals in scenario # 3 will experience congestion and thus cause operators to attempt to use other terminals, contributing to waste. If this is apparent in the results, then a fourth scenario will be run to balance the number of employees per terminal by placing an additional terminal at each point of congestion. The cost of this will also be evaluated in the cost-benefit analysis.

DATA ANALYSIS METHODOLOGY

The simulation will be run for one month of simulated time. Within the simulation data are generated for the clock-in and clock-out times at each work center and collected in datasets. Clock-in time is recorded from the moment the clock-in task is triggered by the work order to the time the operator has returned to their home work center. Clock-out times are recorded from the moment the operators have finished the work order and begin to move to the terminal to the moment they have finished the wrap-up task and step away from the terminal. This total time spent walking to and interacting with the terminals will be referred to as “terminal time.” The terminal time data from each post intervention scenario will be analyzed both cumulatively and by each work center and compared to the pre-intervention data. Additionally, the terminal utilization rates will also be captured. The utilization data will be used to determine the effective placement of terminals in Post-Intervention Scenario 3.

COST ANALYSIS METHODOLOGY

For each proposed scenario, a Cost-Benefit Analysis will be done to determine which option is the most cost effective. To conduct this analysis, both the direct cost of the terminals (or mobile computers) and the annual software license fees and the indirect costs of the labor spent interacting with the terminal must be considered. The benefit-cost ratio (BCR) of the net present value of the anticipated labor savings (when compared to the current state) over the net present value of the direct cost of the terminal hardware and annual fees will be evaluated with the following formula:

$$\frac{\sum NPV\ of\ Benefits}{\sum NPV\ of\ Anticipated\ Costs} \tag{1}$$

The cost of the hardware will be considered a present value. The annual fee will be considered a present value for the current year and discounted at an interest rate of 8% for every year after the current year for five years. The NPV of the proposed labor savings will also be discounted at a rate of 8% per year. The post-intervention scenario with the highest ratio will provide the most cost benefit to the company.

Every terminal will require a software license from the software provider. The cost of this license is $1,100 per terminal, per year. For scenarios that require terminals, the upfront hardware cost of each terminal is summarized in Table 2:

Table 2: Terminal Hardware Cost

PC	$670
22-inch Monitor	$170
ID Card Reader	$160
PC Cart	$110
Total Hardware Cost	**$1,110**

For Post-Intervention Scenario 1, we will assume a mobile computer cost of $700 (see Table 3):

Table 3: Mobile Computer Hardware Cost

Mobile Computer	$700

ANALYTICAL RESULTS

Each scenario was modeled in AnyLogic and ran for one month of model time. Terminal time data was collected, and descriptive statistics were generated from the times. These statistics are summarized in Table 4:

Table 4: Descriptive Statistics

	Current State	PIS1-Mobile Comps.	PIS2-One Terminal	PIS3-Five Terminals
Total Terminal Time (minutes)	4,565.29	1,417.42	7,000.73	2,628.41
Count	1,602	1,624	1,464	1,632
Mean (minutes)	2.85	0.87	4.78	2.19
Min (minutes)	0.54	0.26	0.55	0.47
Max (minutes)	10.08	1.96	15.27	6.33
Sigma	1.55	0.38	2.87	1.03
Time Difference from Current State (min)	0.00	-3,147.87	2,435.44	-1,936.88

Pre-Intervention Current State Results

The simulation of the pre-intervention state produced a total monthly terminal interaction time of 4,565.29 minutes or an average of 2.85 minutes per interaction, including travel and wait times. 283 work orders were completed in one month with this scenario. This was comparable to all other scenarios except for scenario # 2, which only completed 266 work orders.

This simulation also revealed that terminal 1 was chosen 40% of the time, terminal 2 chosen 31% of the time and terminal 3 was chosen 29% of the time. It makes sense that terminal 1 would be utilized more often as it is the preferred terminal for both SMT lines and the Wave lines, being shared by 8 of 14 employees. This produced more waiting and thus more employees exiting the queue to use another terminal. In fact, the simulation showed 339 instances of employees leaving the terminal one queue compared to 95 instances for terminal 2 and 59 instances for terminal 3. This would be an area that is identified by the simulation as an area for improvement. These data from this simulation will be used as the control for post invention comparison.

Post Intervention Scenario # 1 Results

This model simulated a scenario where mobile computers are used by the operators instead of terminals. The simulation showed a clear improvement in the total time spent clocking-in and out of work orders at 975.22 minutes and an average clock-in/out time of 0.88 minutes, a difference of 2,036.95 person minutes per month or a 78.67% improvement. As each employee would be issued a mobile computer, there is no utilization data to compare to.

Post Intervention Scenario # 2 Results

This model simulated a single terminal, somewhat centrally located, that would be used by all five work centers. This scenario would likely be considered by companies looking to reduce their upfront costs when implementing a new ERP system or by companies looking to reduce the annual recurring cost of the software licenses.

The results of the simulation showed a total terminal time of 7,000.73 minutes, an average of 4.78 minutes per interaction. A 53.35% increase over the current state. This scenario appears to represent the opposite extreme compared to Post Intervention Scenario # 1.

Another observation from the simulation is that it took almost 15 minutes at the start of the shift for all employees to clock in.

As expected, this was the least efficient option but with fewer terminals, there will be a lower recurring cost. Whether or not this is enough to offset the reduced productivity will be discussed in the cost-benefit-analysis.

In this case, only 266 work orders were completed with this scenario (compared to 283 in the current state). This would indicate that the additional terminal time would have a significant impact to productivity potentially impacting on-time-delivery and lead time.

Post Intervention Scenario # 3 Results

In this scenario, a terminal was placed adjacent to each work center, attempting to minimize the distance to the terminal and the number of employees sharing the terminal thus reducing the wait time. The simulation showed a total terminal time of 2,628.41 minutes over the course of one month. A savings of 13.86 person-hours per month.

The utilization data shows that terminal 4 is the most utilized and has the most timeouts (see Figure 8). This is likely due to the fact that its proximity to the SMT South work center causes it to be shared by SMT operators when terminal 2 is occupied. This imbalance warrants the investigation of a fourth scenario.

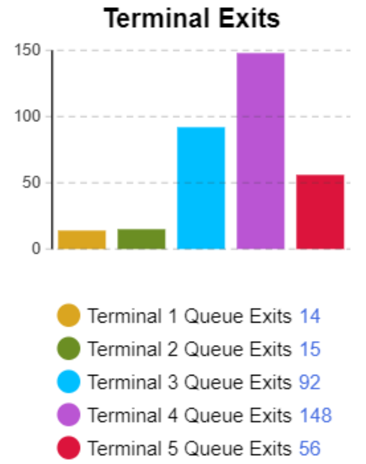

Figure 8: Post Intervention Scenario # 3 Timeouts by Terminal

Post Intervention Scenario # 4

This scenario utilizes the same strategy as scenario # 3 but places an additional terminal next to the Wave Solder work center and an additional terminal between the north and south Selective Solder work centers for a total of seven terminals (see Figure 9). At 14 employees, this provides one terminal for every two employees.

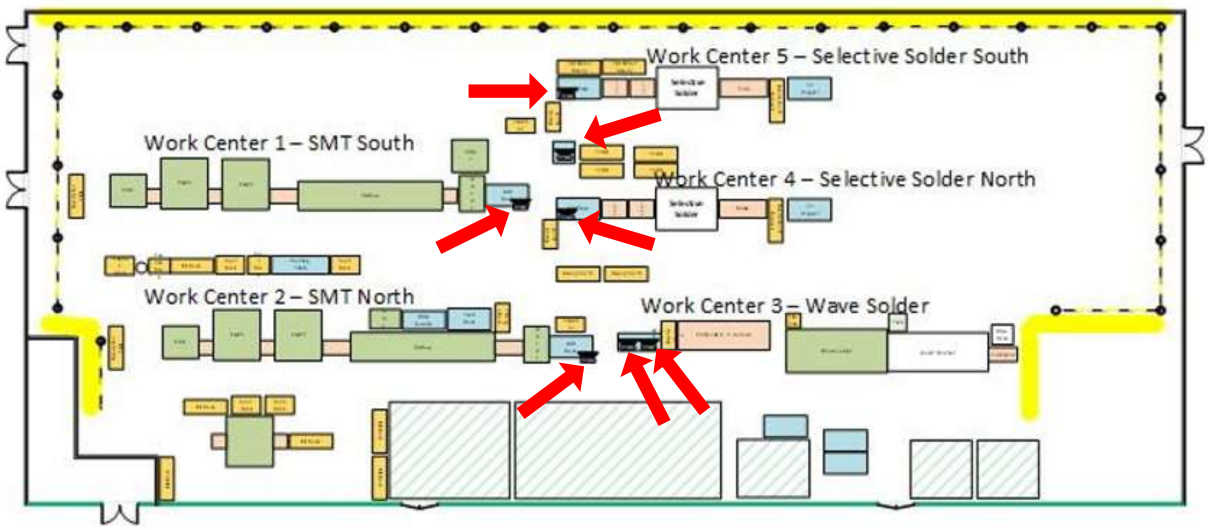

Figure 9: Post-Intervention Scenario # 4 – Seven Terminals

The results of this simulation (see Table 5) show an average terminal time of 1.95 minutes an improvement over the 2.85-minute mean terminal time in the current state and 2.19-minute mean time in scenario # 3. The same number of work orders were completed in one month as was completed in scenario # 3. The terminal time results table has been updated to include the results of post-intervention scenario # 4:

Table 5: Descriptive Statistics (including Scenario # 4)

	Current State	PIS1-Mobile Comps.	PIS2-One Terminal	PIS3-Five Terminals	PIS4-Seven Terminals
Total Time (minutes)	4,565.29	1,417.42	7,000.73	2,628.41	2,340.77
Count	1,602	1,624	1,464	1,632	1,632
Mean (minutes)	2.85	0.87	4.78	2.19	1.95
Min (minutes)	0.54	0.26	0.55	0.47	0.34
Max (minutes)	10.08	1.96	15.27	6.33	8.02
Sigma	1.55	0.38	2.87	1.03	0.97
Time Difference from Current State (min)	0.00	-3,147.87	2,435.44	-1,936.88	-2,224.52

Although still less efficient than the mobile computers simulated in scenario # 1, both scenarios # 3 and 4 are likely to have a lower cost than scenario number 1. The cost-benefit-analysis will reveal if this improvement in efficiency is worth the cost of additional terminals.

Histogram data

Within the simulation the data is collected into histogram datasets and displayed in real time. The actual terminal interaction time is modeled using a triangular distribution. This is a common technique used in fuzzy logic applications where historical data is not easily obtained. If no other factors were influencing the terminal time, then one would expect the histogram to take the shape of the triangular distribution which is true of scenario # 1 where there is no transportation to a static terminal and therefore no waiting. Most results are clustered near the mode with fewer results at each extreme. In this case there is a slight right skew as the mode is closer to the minimum value than the maximum (see Figure 10).

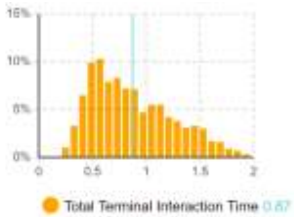

Figure 10: Scenario # 1 Histogram

With all other scenarios, the right skew of the distribution becomes more pronounced with the distribution taking a more exponential shape (see Figure 11). In fact, the skewness of the distribution is a good visual representation of how much wait and transportation time is affecting the results.

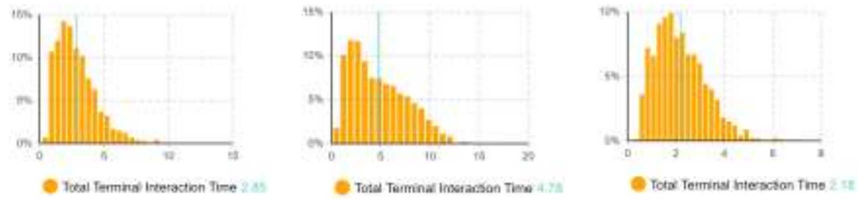

Figure 11: Current State and Scenarios # 2 & 3 Histogram

COST-BENEFIT-ANALYSIS

From the labor data produced by the simulations, we can calculate the potential cost or savings compared to the current state by multiplying the time difference by the labor burden rate. For this case, we used a burden rate of $17 per hour. This rate was obtained by taking the average wage for entry level assembly jobs in Illinois and adding a 30% burden to cover estimated payroll tax and benefits (U.S. Bureau of Labor Statistics, 2020).

Table 6 shows the costs and benefits of the current state and each post-intervention scenario:

Table 6: Cost Analysis Table

	Current State	**PIS1-Mobile Comps.**	**PIS2-One Terminal**	**PIS3-Five Terminals**	**PIS4-Seven Terminals**
Monthly Labor Cost	$1,293.50	$401.60	$1,983.54	$744.72	$663.22
Annual Labor Cost	$15,522.00	$4,819.24	$23,802.49	$8,936.61	$7,958.62
Estimated Annual Labor Savings (Cost)	**$0.00**	**$10,702.76**	**($8,280.49)**	**$6,585.39**	**$7,563.38**
NRE Cost	$3,330.00	$9,800.00	$1,100.00	$5,550.00	$7,770.00
Annual Recurring Cost	$3,300	$15,400	$1,100	$5,500	$7,700
Additional Investment Cost (Year 0)	**$0.00**	**$25,200.00**	**$0.00**	**$7,720.00**	**$12,140.00**
Additional Recurring Cost	**$0.00**	**$12,100**	**($2,200)**	**$2,200**	**$4,400.00**

In a cost benefit analysis, cash flows are categorized as either benefits or costs. Therefore, negative labor savings would be considered a cost and negative costs are categorized as benefits. The higher the ratio number, the greater the benefit of the proposed solution. A ratio of 1 indicates a neutral cost-benefit. Less than 1 indicates the proposed solution would be a loss.

In addition to cost factors, carefully chosen intervals for analysis are important. For this study, 5 years is a reasonable interval. The upfront non-recurring expense (NRE) for these scenarios, particularly scenario # 1, would take time to remunerate with the anticipated labor savings. Beyond 5 years, it is likely that new hardware would be needed or other system changes, whose costs are currently unknown, would be required. Additionally, because we are discounting future dollars, there is a diminishing return as we look further out in time.

Table 7 shows the results of the 5-year cost-benefit-analysis. The present value (PV) dollars of all associated costs and benefits are shown for each year.

Table 7: Cost-Benefit Analysis

5 Year Cost-Benefit Analysis					
	Current State	PIS1-Mobile Comps.	PIS2-One Terminal	PIS3-Five Terminals	PIS4-Seven Terminals
NPV Benefits					
Year 0	$0.00	$0.00	$0.00	$0.00	$0.00
Year 1	$0.00	$9,909.96	$2,037.04	$6,097.59	$7,003.13
Year 2	$0.00	$9,175.89	$1,886.15	$5,645.91	$6,484.38
Year 3	$0.00	$8,496.20	$1,746.43	$5,227.70	$6,004.05
Year 4	$0.00	$7,866.85	$1,617.07	$4,840.46	$5,559.31
Year 5	$0.00	$7,284.12	$1,497.28	$4,481.91	$5,147.51
NPV Benefits	$0.00	$42,733.02	$8,783.96	$26,293.56	$30,198.38
NPV Costs					
Year 0	$0.00	$25,200.00	$0.00	$7,720.00	$12,140.00
Year 1	$0.00	$11,203.70	$7,667.12	$2,037.04	$4,074.07
Year 2	$0.00	$10,373.80	$7,099.18	$1,886.15	$3,772.29
Year 3	$0.00	$9,605.37	$6,573.32	$1,746.43	$3,492.86
Year 4	$0.00	$8,893.86	$6,086.41	$1,617.07	$3,234.13
Year 5	$0.00	$8,235.06	$5,635.56	$1,497.28	$2,994.57
NPV Costs	$0.00	$73,511.79	$33,061.58	$16,503.96	$29,707.92
Benefit-Cost Ratio	**1**	**0.58**	**0.27**	**1.59**	**1.02**

The results of the CBA show post-intervention-scenario # 3 as the most cost-effective investment. For every dollar spent the company would receive $1.59 back. Scenarios 1 and 2 show that they would be a loss for the company and scenario 4 would be nearly cost neutral when compared to the current state and not worth undertaking.

Despite being the most efficient, the cost of the mobile computer hardware and software licensing is too prohibitive for this to be an advisable direction but if costs could be negotiated down, then this would be an ideal future state.

The single terminal demonstrated in scenario 2 has the least benefit by far. This is important to understand as many organizations may only look at the upfront and recurring cost of the hardware and software not considering the productivity cost, resulting in significant losses overtime.

Scenario 4 showed some improvement in efficiency over scenario 5 by relieving some of the congestion at certain terminals but the cost of the additional terminals negates the benefits.

CONCLUSION AND LIMITATIONS

The capabilities of new business systems, such as the latest ERP and MES systems, to capture and report data are vastly improving. It is easy for business owners to imagine the benefits of having up to the minute visibility on their operations. This data could be instrumental in making decisions that will improve profitability. What is often overlooked, or difficult to predict, is the cost associated with certain aspects of the implementation, such as data collection processes. This study demonstrated that discrete event simulation, when combined with cost-benefit analysis, can be an effective tool for anticipating and evaluating the impact of these additional non-value-added tasks required of direct labor employees. In this case, the additional time required to clock in and out of each work order, a task required of the ERP system for tracking direct labor.

This study showed that a DES model could be developed to simulate the current state of a production environment that has already implemented a new ERP system and incurred the additional labor of interacting with terminals but with a valid modeling technique, it could certainly be used prior to implementation to predict the impact to productivity by process changes required for the ERP system to operate at its full capability.

DES allowed us to evaluate the direct labor cost of multiple scenarios to identify the most efficient state. In this case, the results showed that mobile computers would provide the maximum efficiency but when analyzed through cost-benefit analysis, this costs of implementing this option would outweigh the benefits to improved efficiency. In fact, our analysis showed that the company would lose $0.42 for every dollar spent. However, in our study, we only looked at the direct labor cost applied to each employee’s time. Mobile computers may also reduce errors in data entry that could result in additional downtime or indirect labor to correct it. Mobile computers may also offer other benefits like providing information directly to each employee in real-time, such as schedule updates and deviations. The benefits of which are not fully explored for the purpose of this study but could certainly be incorporated by a company into the cost benefit analysis if the data is available.

The input data assumed in this model was largely gathered by informally surveying employees at the case study manufacturer. For the purpose of this study, this approach is adequate for demonstrating the use of DES as a source of data for cost-benefit-analysis and did not require a thorough validation of the model to real world data. Should DES modeling be used in a real-world setting, it is important that real world pre-invention data be collected and compared to the current state model in order to validate the model and ensure post-intervention data is an accurate representation of labor times. A common method of validation would be to calculate the confidence intervals of the mean for the desired simulation response variable and identify if the real world mean falls within this range (Petty, 2012).

The total time spent interacting with the terminals provided a convenient KPI to compare the different proposed solutions and is sufficient for predicting the cost of the non-value-added direct labor for the cost-benefit analysis. In practice, it may be useful to breakdown the components of the total terminal time to better understand the amount of time employees are waiting, traveling, and interacting with the terminals. Doing so could provide additional insight that may aid in optimization efforts.

This study effectively showed the hazard of focusing on a single metric as a measure of improvement and “over-improving.” If we simply looked at reducing the recurring cost of the software licenses, then scenario 2 would have been selected, but the DES demonstrated the impact to direct labor and when costed at the labor burden rate, the loss over time would be significant and achieving maximum efficiency, scenario number 1 would have been selected but this would likely come at a loss for the company as well due to the high cost of hardware and software licenses required for every employee. Focusing on evenly balancing the utilization of stationary terminals appeared to be an improvement over scenario 3 but the cost of two additional terminals would negate any benefit to additional productivity to the point it was almost cost neutral when compared to the current state. In fact, even though there was an improvement in the total terminal time, no additional work orders were completed. This would not be a worthwhile endeavor.

Ultimately, scenario 3 would produce the most benefit to the company with the least cost. By using DES and cost-benefit-analysis, we can make that determination without having to disrupt operations or expend capital.

There are many direct and indirect costs associated with ERP implementation that result from changes to existing processes or new processes that are required to fully utilize the capabilities of the system. This paper focuses on the costs associated with one such process, data collection from the shop floor. However, this model, and discrete event simulation in general may also be adapted for analysis of the costs associated with other changes in the manufacturing environment related to ERP implementation.

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Optimization of Production Planning for Coffee Supply Chains: A Case Study

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ABSTRACT

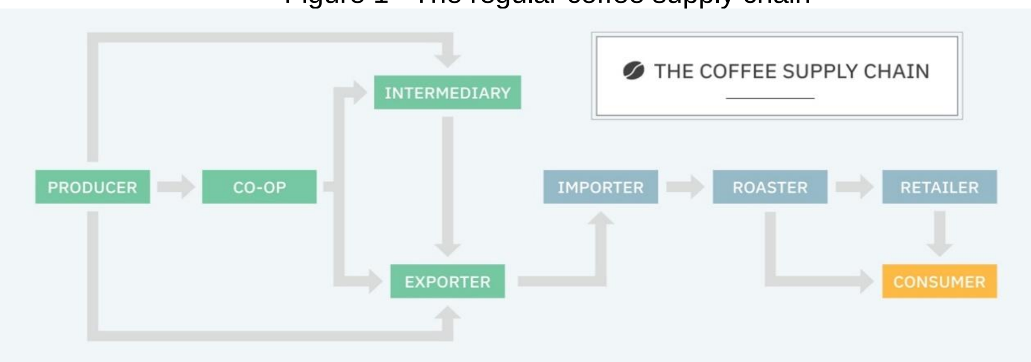
The growing trend of coffee consumption calls for the rise of the coffee industry. Due to the complexity and variety of coffee supply chains, we develop an optimization model based on a case study for coffee smallholder growers in Yunnan, China, to illustrate the methodology on how to improve efficiency in coffee production planning. Given the conditions of increasing coffee planting and processing costs and uncertain international procurement prices of coffee beans, we apply Modern Portfolio Theory to generate an optimal product portfolio of specialty and commercial coffee by maximizing the expected return of the product portfolio.

KEYWORDS: Coffee Supply Chains, Production Planning, Portfolio Optimization

INTRODUCTION

In the regular coffee supply chains (Figure 1), there are four major stakeholders (Candelo et al., 2018) from the upper end to the roasters: (1) the producers, most of whom are small farmers and family plantation owners and are the origin of the extraction of 70% of coffee beans globally (Graebu et al., 2016), (2) the first and second level traders who buy green coffee beans from the local farmers, (3) the coffee exporters who collect and export or sell to domestic roasters, and (4) the roasters who reprocess/roast coffee beans to meet the market demand.

Figure 1 The regular coffee supply chain



Source: https://www.ibm.com/blogs/blockchain/2018/08/brewing-blockchain-tracing-ethically-sourced-coffee/

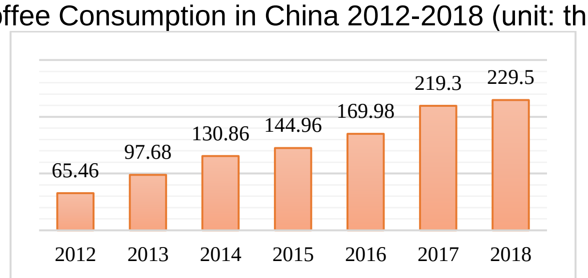
Coffee supply chains are buyer-driven commodity chains (Borrella et al., 2015) in which the lead firms are importers and roasters, who govern the supply chain in a hand-off way, maintaining dominance and capturing most of the gains. For the case in Yunnan, China, in the upstream of the supply chain, the coffee growers sell the green coffee at a regular price of 17RMB/kg and attain only 1% of the total value compared to the price of around 1600RMB/kg when coffee is consumed in coffee shops. Therefore, with such unique characteristics in the configuration of relationships among the stakeholders, the business has been criticized for a long time for the issues of sustainability and social responsibility.

The major concern is for the smallholder farmers, which could explain that many reports and studies suggest that the current coffee supply chain is vulnerable because of the dilemma both from the natural environment and the squeeze from the upper-end of the supply chain. The low-power smallholder farmers are facing numerous threats, who rely on large corporations within unstable markets and are exposed to severe climate change issues. They often have difficulties in trading with first-level traders who always tend to cut the price down and underestimate the quality of the coffee beans. This situation could lead to severe unsustainable decisions and consequently, the farmers would switch to other more profitable crops. Therefore, it’s a global topic for the whole coffee industry to empower smallholder farmers and understand their common interests in coffee supply chain improvement.

Coffee Industry in China

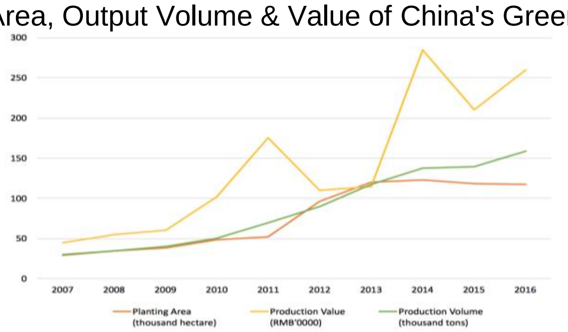
Although China remains a predominantly tea-drinking country, evidence indicates an awakening taste for coffee. The total consumption volume of China increased dramatically from 2012 to 2018 (Figure 2), which led it to No.7 in coffee consumption in Asia (Huang, 2017). China is currently the 12th biggest coffee producer in the world (Huang, 2017). The changes in the planting area, production volume, and production value of China’s coffee between 2007 and 2016 are shown in Figure 3, which indicates an increasing trend.

Figure 2 Coffee Consumption in China 2012-2018 (unit: thousand tons)



Source: CBNData, Report of coffee consumption trend of China 2018

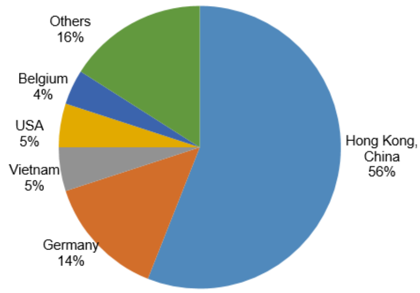
Figure 3 Planting Area, Output Volume & Value of China's Green Coffee 2007-2016



Source: Data from the website of Ministry of Agriculture and Rural Affairs of China

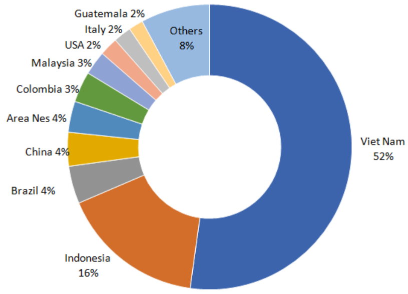
In terms of China's coffee exports and imports, Hong Kong and Vietnam are the leading importer and exporter respectively for China. For the year 2017 alone, China exported to 50 countries worldwide, 84% of these shipments went to just five destinations (Figure 4). Hong Kong is the biggest destination accounting for 56% of the total exports, where the coffee is likely processed and re-exported. Chinese coffee market is predominantly composed of instant coffee, which is shown by the origin of coffee imports (Figure 5) where Robusta is the prominent variety produced by Vietnam and is the regular blending ingredient for instant coffee.

Figure 4: Major destinations of coffee exports by China (2017)



Source: ITC calculation based on General Customs Administration of China statistics.

Figure 5: Origin of coffee imports by China (Average of 2013-2017)



Sources: ITC calculations based on General Customs Administration of China statistics since January 2017

All the facts show that China's coffee market is of great potential for a high level of market value in near future. However, China's domestic coffee producers suffer from the fluctuation of international procurement prices. Seeking more measures to stabilize and improve the coffee supply will not only bring in more benefits to the coffee growers but contribute to the sustained development of the whole coffee supply chain.

The Concept of Specialty Coffee and the Grading of Green Coffee Beans

The Specialty Coffee Association of America (SCAA) defines specialty coffee in its green stage as coffee that is free of primary defects, is properly sized and dried, presents no faults or taints in the cup and has distinctive attributes (Rhinehart, 2009). The specialty coffee industry is on robust growth. According to the latest market research, the global specialty coffee shops market is expected to accelerate at a CAGR of over 10% during the forecast period from 2017 to 2021 (Tolessa et al., 2016). The rising consumption of coffee is one of the key factors triggering the growth of the market. The new wave of specialty coffee with a cupping score higher than 85/100

(Poltronieri & Rossi, 2016), is sending a hopeful signal that through careful coffee production planning and controlled fermentation processes, coffee producers would generate higher revenue by assuring high standard of quality and high added value for the coffee experience sector.

The purpose of grading is to define the quality criteria of a certain lot of green coffee beans thus to facilitate pricing for trading, most of the time for export. Currently physical and cup quality analysis is the key tool for coffee quality assessment. Physical quality of green coffee beans is associated with the presence of defects found in certain coffee batches such as deviations in odor, color, size, and shape of beans (Tolessa et al., 2016). Cup quality characteristics are attributes of coffee that can be distinguished by senses and can be assessed by professional coffee tasters, based on established terminologies for cup quality attributes including (1) fragrance/aroma, (2) flavor, (3) aftertaste, (4) acidity, (5) body, (6) uniformity, (7) balance, (8) clean cup, (9) sweetness, and (10) overall (SCAA, 2015). However, because of the different characteristics of coffee in each coffee origin, there is no one grading system being used for evaluating green coffee beans from different producing countries. Each producing country has developed its own classification and grading system (ICO, 2005).

Coffee Industry in Yunnan

Yunnan now accounts for 95% of China’s coffee production, with half coming from the mist-shrouded landscape. The remaining 5% is made up of very minor Arabica and Robusta harvests along China’s southern seaboard (Schmid, 2016). There are more than 300 thousand coffee smallholders in the region with more than one million grower individuals engaged with coffee planting (Wang et al., 2015). The majority of their coffee beans are purchased by the world's big coffee brands like Nestlé and Starbucks as raw materials. Around 80% of Nestlé’s suppliers in Yunnan are smallholder growers whose plantation is less than 3.33 hectares (Pu et al., 2016).

<u>Coffee Processing Methods</u>

Once the coffee has been picked, processing must begin as quickly as possible to prevent fruit spoilage. Due to different natural resources and local climatic conditions, different producing regions may have their preferences for coffee primary processing. While in Yunnan, we see the most common processing methods are dry-process, wet-process and, honey process.

The dry process, also known as unwashed or natural coffee, is the oldest method of processing coffee. The entire cherry after harvest is first cleaned and then placed in the sun to dry on tables or in thin layers on patios. As the cherries dry, they are raked or turned by hand to ensure even drying and prevent mildew. It may take up to 4 weeks before the cherries are dried to the optimum moisture content, depending on the weather conditions.

The wet process, also known as washed coffee, requires the use of specific equipment and substantial quantities of water. The skin of the sorted cherry and some of the pulp is removed by pressing the fruit by machine in water through a screen. Then it goes through the fermentation process to remove the pulp clinging to it. When the fermentation is complete, the coffee is thoroughly washed with clean water in tanks or special washing machines. The beans must be dried to a water content of about 10% before they are stable.

The honey process is about halfway between a washed coffee and a natural process coffee. During honey processing, coffee is dried with some or all of the mucilage remaining on the parchment encasing the seed. Coffee cherries are picked, sorted, de-pulped, and then moved to dry patios or beds for various periods of time.

Status Quo and Challenges

Due to the continuous low procurement price and the growing production cost over the past recent years, the planting area of coffee in Yunnan has been shrinking for two consecutive years (Huang, 2017). Like many other coffee producers across the world, the procurement price of commercial coffee in Yunnan has been long subject to the New York future price, but the situation is especially tough for Yunnan growers. Because the cost of labor is increasingly high in China and the majority of the coffee growers are smallholders which renders few possibilities for mechanized farming and standardized management. The international price of green coffee beans for January to May of 2017 was 160.36 US cents/lb (Huang, 2017), which is fairly close to the production cost. As low-power stakeholders in the coffee supply chain, coffee farmers have little bargaining power on price. Many coffee farmers are now changing from commercial coffee to specialty varieties that can fetch up to RMB 50 (USD 6-8) per kilo. Specialty coffee beans have a better price but the limited resources of labor and equipment are the bottlenecks restricting yield.

Most of the coffee production in Yunnan is fully washed Catimor, which has some resistance to coffee rust but is generally considered as low-quality commercial coffee and not specialty grade. However, there is a change since 2012. Starbucks has certified 1,200 farms in Yunnan and has been training coffee growers for experimenting with high-value varieties in its farm support center since 2012 (Dahlstrom, 2017). In 2014, Volcafe, one of the world's largest coffee traders, signed a deal with Simao Arabicas Coffee Co. to form Yunnan Volcafe, Ltd. which is now supplying Europe with its specialty grade coffee (Volcafe, 2014). With the influence of the third wave of the coffee supply spreads to China, it is both a challenge and opportunity for Yunnan coffee. The second generation of Yunnan coffee growers attempts to achieve more on their parents' coffee farms for specialty coffee.

Research Motivation and Objective

The coffee industry worldwide has the incentive to experience and apply new practices and management to improve the status of coffee growers. In the macro-environment of coffee procurement, the price getting down and the production cost of coffee surging up, this study aims to help coffee smallholder growers in Yunnan generate higher profit under a certain risk level through an optimal portfolio of specialty and commercial coffee and streamlining their production planning. We apply the modern portfolio theory to analyze the coffee production planning problem of how coffee growers can diversify their product portfolio to minimize risk and maximize expected return.

LITERATURE REVIEW

Our study interacts with several streams of literature that include the efforts to benefit coffee growers in coffee supply chains, production planning of agricultural commodities, and the application of portfolio theory to agricultural planning. From this point of view, our study contributes to the literature by connecting multiple areas of research.

The Efforts to Benefit Coffee Growers in Coffee Supply Chains

Coffee is generally regarded as the pioneering industry for sustainability standards and certification (Reinecke et al., 2012). Despite better farm management practices, increased organization, and improved relations with buyers (SSI Group, 2014), economic factors play a crucial rule when all those sustainability standards are devoted to benefiting the coffee growers.

Past studies have focused on some coffee regions in terms of the sustainability standards' influence on coffee growers. An article (Bacon, 2005) suggests that participation in organic and Fairtrade networks reduces farmers' livelihood vulnerability through research of 228 farmers in Nicaragua measuring the impact of sales on organic and Fairtrade markets. Another research (Barham & Weber, 2012) suggests certification norms that permit improving grower welfare and attracting and maintaining growers by using survey data from coffee growers in Mexico and Peru. These sustainability initiatives set the stage for evolution in multi-stakeholder coffee sully chains (Alvarez et al., 2010).

Additional studies have researched direct trade, which is a relatively new approach popularized by specialty coffee's rise. A recent study analyzes the dominant development discourse of relationship coffee in Indonesia but finds the benefits have been subsequently captured by key individuals in the producer community or cooperative and have little to do with poverty alleviation in the region (Vicol et al., 2018). In terms of direct trade, another study claims to focus on different types of intermediaries which operate with different models and could bring different value distribution along the supply chain (Borrella, et al., 2015).

One more interesting study touched on the online coffee auctions applied in India (Banker & Mitra, 2007) and argues that the online direct selling of commodities by growers is likely to evolve only under a certain set of conditions and only the well-known plantations could get tangible benefits from an online auction. Therefore, the writer urges initiatives that could increase the confidence of the buyer to directly procure from lesser-known growers.

However, most of the literature discuss how to benefit the coffee growers with the help or assistance from a third party or by coordinating with other operators along the coffee supply chain. It is truly necessary to manage the issue from an integrated point of view, but when focusing solely on the one end, it's more secure for the whole coffee supply chain that the origin end could optimize the production planning even under the worst macro-environment. Therefore, if the coffee growers could get to know how to adjust the ratio of the output of different coffee types in response to the estimated trend of the price range, it will substantially reduce the risk of the whole supply chain.

Optimization Methods for the Production Planning of Agricultural Commodities

Production, harvest, storage, and distribution are identified as the four main functional areas of agriculture supply chain (Ahumada & Villalobos, 2009). Planning is an activity that supports decision-making by identifying potential alternatives and making the best decisions according to the objectives of planners (Fleischmann et al., 2005).

Agricultural supply chain could be divided into the supply chain for fresh agricultural commodities and non-perishable agricultural commodities. Since green beans of coffee after primarily processed could be stored for about one year, so we will look into more of the non-perishable agricultural commodities to the reference of the optimization methods of production planning. For agricultural commodity growers of non-perishable commodities, the issues they are concerned about the most are production, harvest, and storage. Decisions made in production include those related to croppings, such as the land to allocate to each crop, the timing of sowing, and the determination of the level of other resources needed to apply in production. The decision made during the harvest includes but is not limited to the timing for collecting the crops from the fields, the relevant labor, equipment, and facilities required for the harvest, and the scheduling of packing and processing (Ahumada & Villalobos, 2009).

The agricultural production process involves plenty of aspects, such as scheduling field tasks, investment analysis, machinery selection, and cost and benefit analysis. There are studies seeking to improve the better production planning decisions of non-perishable agricultural commodities using various modeling approaches. A study on land use planning in agriculture production system considers the optimization of profit to cash expenditure and crop production to land utilization as a fractional objective using multi-objective linear fractional programming (Mishra et al., 2014). Another study develops a validated decision support system that includes scheduling field tasks and analyzing investments with the objective of minimizing costs using a MIP model, which is suited for medium-large farms (Recio et al., 2003). It is the common appeal for all agricultural operators that all the tasks are scheduled in sequence at the lowest possible cost to improve productivity and achieve the best yield from scarce resources. A study applies time windows by a mixed 0-1 programming model to take account of the relations of precedence among each task, and in such a way that each task is done within its time window and with the resources being assigned in a feasible way (Ortuño & Vitorianon, 2011).

The Application of Portfolio Theory to Agricultural Planning

The application of portfolio theory for finding an optimal allocation of agricultural land is popular in the literature. Since the 1950s, agricultural economists have adapted many popular financial portfolio selection rules to the farm manager's land allocation problem. The first application of the portfolio theory to crop planning goes back to Freund whose approach defined the risk of an agricultural enterprise through the variability of its returns, measured by variance (Freund, 1956). This implies the use of quadratic programming for finding the optimal crop patterns. Single index portfolio models are used for farm planning (Collins & Barry, 1986) in the paper. Models for resource allocation in agriculture that are taking into account specific risks are published (Weintraub et al., 2001). Mathematical models that take into account farmers' decisions and climate change are studied (Lewandrowski & Brazee, 1993). Efficient allocation of land in a mean-variance sense is investigated with the use of portfolio theory (Roche & McQuinn, 2004) to examine the potential implications of the land allocation decision of the 2002 EU Commission's proposed mid-term reform of the Common Agricultural Policy (CAP) related to decoupled payments. Applications of portfolio theory to biodiversity conservation are also studied (Figge, 2004). Another study explores the opportunities for the application of Modern Portfolio Theory (MPT) to quantify the benefits of diversification for risk reduction in the context of highly diversified horticultural systems (Paut et al., 2019).

DATA COLLECTION

We explore and collect all the necessary data information first for the procurement price of coffee beans and the coffee production costs before discussing the optimization model.

The Procurement Price of Green Coffee Beans

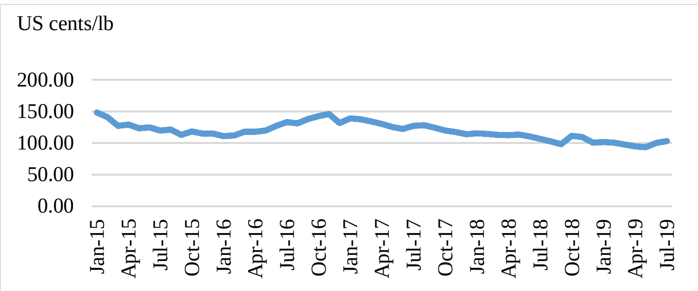
Various factors and causes could be involved in the uncertainty of the agricultural problem, such as weather risk, pest risk, disease risk, and market risk, along with the risks that arise with the machinery efficiency and interaction with technology. With economic globalization, agricultural producers especially non-perishable crop producers are competing with unpredictable competitors with comparative advantages. Therefore, the price namely the market risk is of great significance and may increase over time.

<u>International Coffee Price</u>

Like with other primary commodities, the global coffee market has been defined by high volatility and long-term declining price (SSI Group, 2014). The causes of price volatility include the delay in moving from new planting to production, climatic variability, and speculative trading.

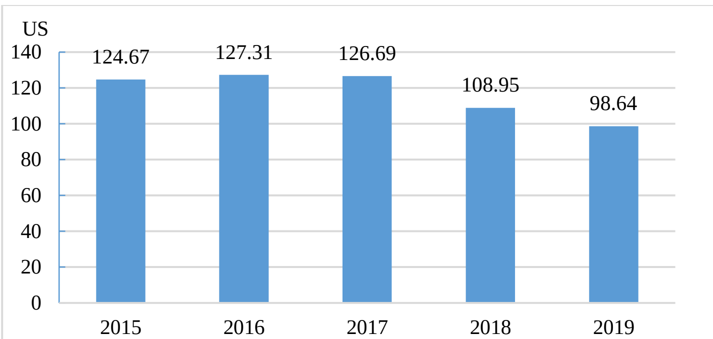
On the subject of managing price volatility, it is observed that while instruments do exist for producers, for example hedging on the futures market, these are not always appropriate and can cause more harm than good. Furthermore, price risk is not the only threat to producers, with issues such as climate risk and other production risks also requiring attention (ICO, 2016). The commercial grade coffee beans in Yunnan refer to the ICO composite indicate price (Figure 6 and Figure 7) while the price of specialty grade beans is negotiated lot by lot according to the actual quality and market demand.

Figure 6 ICO Composite Indicator Price (Monthly Averaged)



Source: Data from ICO http://www.ico.org/coffee_prices.asp?section=Statistics

Figure 7 ICO Composite Indicator Price (Yearly Averaged)



(The statistics of 2019 include the first 7 months.)
Source: Data from ICO http://www.ico.org/coffee_prices.asp?section=Statistics

Procurement Price of Yunnan Coffee

The data of historical procurement price (2014-2019) were retrieved from Mangzhang Farm (Nayun Town, Menglian County, Yunnan Province, China). With a planting area of 512 hectares, the farm produces around 900 tons of green coffee beans on a yearly basis. For the confidential reason, the data used in this study has been adapted rationally.

The Production Cost of Green Coffee Beans in Yunnan

The coffee growers are facing the challenge that the decision of production planning has to be made now without foreseeing the sales and purchases which depend on the yields and demands. It is even worse compared to other agriculture commodities as it takes 3 to 4 years for a coffee tree to be mature enough to bring economic benefits. Moreover, in the coffee industry, planting is the first stage, and the second stage goes to the primary processing that immediately happens after the harvest which involves different processing methods, economic input, and resource assignment. We study several typical plantations in Pu'er to learn about the cost for green coffee beans with different collecting and processing methods. Cash costs per kilogram are the key measures to differentiate specialty coffee beans from commercial coffee beans.

Costs in the Seedling Stage

Since it takes around 4 years for a coffee tree to be mature enough to produce quality coffee cherries, the first four years of input including the one-time spending like buying seedlings, digging trenches, transplanting, and the daily care should be split averagely over its following 30 years' economic life.

Table 1 Cost of Seedling Stage (Input before harvest)

Unit: RMB/per acre

Stage	Item	Specialty Grade	Commercial Grade
One-off Spending on Seedling Stage	Seedling	900	600
	Digging trenches	1300	1300
	Transplanting	150	150
	Backfilling	300	300
Yearly Spending for the year 1-4	Fertilizer	360	240
	Applying fertilizer	300	200
	Weeding	500	400
	Eradicating Pests	300	200
	Daily management	800	500
Total cost of Seedling Stage		11690	8510
Cost split averagely over the economic life (around 30 years)		390	284

Costs in the Maturation Stage

Notably, hand picking and primary processing are the two most labor-intensive processes and affected substantially by the surging cost of labor. According to the statistics of Chinese Social Science Net (Jin & Zhu, 2015), in recent years, the cost of labor in rural China has been increasing around by 10% annually. We could get the yearly spending for the maturation stage as below.

Table 2 Cost of Maturation Stage

Unit: RMB/per acre

Stage	Item	Specialty Wet Process	Specialty Dry Process	Specialty Honey Process	Commercial Grade
Maturation Stage	Fertilizer		300		150
	Daily care		350		200
	Weeding		200		150
	Hand-picking		1000		400
	Primary processing	80	200	250	50
	Packaging		50		10
Yearly Spending for Maturation Stage		1980	2100	2150	960

Table 3 Yearly Spending for Maturation

Unit: RMB/per acre

Year of Production	Specialty Wet Process	Specialty Dry Process	Specialty Honey Process	Commercial Grade
2014-2015	1980	2100	2150	960
2015-2016	2088	2220	2275	1005
2016-2017	2207	2352	2412	1054
2017-2018	2337	2497	2564	1109
2018-2019	2481	2657	2730	1169

The Production Efficiency

As the weather and the adequate water resources in Yunnan are more friendly to wet-processed beans, the output of dry processing and honey processing is lower than the wet method. In addition to the natural condition, the output of specialty coffee beans is much lower than that of commercial grade beans as the defective ones should be strictly picked out and only the qualified part of the yields can meet the standards. Data from Migu Coffee (Pu'er) showed that every production year, around 500kg of coffee cherries are harvested from per acre's land. The output per acre for specialty wet processed beans, specialty dry processed beans, specialty honey processed beans, and commercial beans are 80kg, 50kg, 50kg, and 100kg respectively. The total production cost could be obtained in Table 4 by combining Table 2 and Table 3.

With procurement price and production cost, the unit operating profit “RUNIT” can be formulated as unit procurement price “PUNIT” minus unit production cost “CUNIT” in Eq.1. Next, the production efficiency of each type of coffee namely the profitability index “R%” (Turco et al., 2017) can be computed in Eq.2.

$$R_{UNIT} = P_{UNIT} - C_{UNIT} \tag{1}$$

$$R\% = R_{UNIT} / P_{UNIT} \tag{2}$$

With the probability index presented above, the expected return (mean of the data set) and the risk level (standard deviation of the data set) can be concluded respectively.

Table 4 the Production Cost of Each Type of Green Beans per KG

	Year of Production	***Specialty Wet Process***	***Specialty Dry Process***	***Specialty Honey Process***	***Commercial Grade***
Total Cost (RMB/per acre)	2014-2015	2370	2490	2540	1244
	2015-2016	2478	2610	2665	1289
	2016-2017	2596.8	2742	2802.5	1338.5
	2017-2018	2727.48	2887.2	2953.75	1392.95
	2018-2019	2871.228	3046.92	3120.125	1452.845
Unit Output Volume(kg)		80	50	50	100
Unit Production Cost(RMB/kg)	2014-2015	29.625	49.8	50.8	12.44
	2015-2016	30.975	52.2	53.3	12.89
	2016-2017	32.46	54.84	56.05	13.385
	2017-2018	34.0935	57.744	59.075	13.9295
	2018-2019	35.89035	60.9384	62.4025	14.52845

OPTIMIZATION MODEL

The general problem that the coffee growers are facing is deciding the production quantity of each type of coffee to earn more profits under a certain risk level. It’s a portfolio optimization problem by which we could seek a higher expected return by applying Modern Portfolio Theory (MPT) based on the same or lower risk level. MPT is a mean-variance analysis that assembles a portfolio of assets such that for a given level of risk the expected return is maximized. In other words, in MPT, diversification could lead to a lower risk for an investor and the optimal portfolio could bring a maximum expected return (Markowitz, 1952, 1991, and 2010). The farmer tries to find a product portfolio that maximizes the expected return $\mathbb{E}(R_p)$, which is calculated as the weighted sum of each type of coffee in the portfolio:

$$\mathbb{E}(R_p) = \sum_i w_i \, \mathbb{E}(R_i) \tag{3}$$

w_i represents relative weight or proportion of coffee type i
$\mathbb{E}(R_i)$ represents the expected return of coffee type i
$\sum_i w_i$ equals to 1

The risk of a product portfolio is evaluated mathematically by the standard deviation of the portfolio, σ_p, which is calculated as:

$$\sigma_p = \left(\sum_i \sum_j w_i w_j \sigma_{ij}\right)^{1/2} \quad (4)$$

w_i represents relative weight or proportion of coffee type i
σ_{ij} represents the standard deviation for the coffee type i
When $i = j$, and the co-variance of the coffee types when $i \neq j$

Identification of the Green Coffee Bean Profitability Distribution

Since Markowitz's portfolio model is based on the assumption that the asset profits are normally distributed. It is a prerequisite to test the probability distribution of the profitability index. Hypothesis testing and chi-square tests are applied to check the data. For the specialty grade wet-processed beans, there are 53 records of profitability index (Table 5). We assume that it is distributed normally at a 95% confidence level with a mean of about 4.64 and a standard deviation of 4.59 and develop the following hypothesis test:

H_0: profitability of Specialty wet beans follows $\sim N(4.64,4.59)$
H_1: profitability of Specialty wet beans does not follow $\sim N(4.64,4.59)$

Table 5 R% of Four Types of Green Beans

Year of Production	Specialty Grade			Commercial Grade
Batch No	Wet	Dry	Honey	Washed
2014-15_1	-4.61	7.52	-1.13	20.92
2014-15_2	2.13	4.14	1.03	18.89
2014-15_3	8.03	0.80	8.67	
2014-15_4	7.04	2.56	13.09	
2014-15_5	8.40	2.08	6.17	
2014-15_6	1.28	-4.45	3.97	
2014-15_7	5.20	4.87	0.20	
2014-15_8	-3.73	3.43	7.01	
2014-15_9	8.87	6.99	12.03	
2014-15_10	15.93		6.82	
2014-15_11	5.20			
2015-16_1	1.16	-2.86	9.11	24.44
2015-16_2	2.23	2.39	8.02	23.10
2015-16_3	12.18	-1.95	1.90	
2015-16_4	9.30	-3.06	8.76	
2015-16_5	0.15	1.42	3.44	
2015-16_6	-2.06	6.01	-0.76	
2015-16_7	4.81	8.07	8.75	
2015-16_8	-1.32	-1.87	4.39	
2015-16_9	5.99	4.87		
2015-16_10		8.00		
2016-17_1	8.28	10.07	6.89	18.28
2016-17_2	-1.66	5.35	8.64	16.01
2016-17_3	0.89	1.15	5.42	
2016-17_4	-1.50	3.43	2.74	
2016-17_5	3.99	8.99	1.53	
2016-17_6	9.28	4.59	-0.36	
2016-17_7	2.32	8.37	6.19	
2016-17_8	9.00	4.19	4.11	
2016-17_9	11.89	8.37	2.11	
2016-17_10	1.58	-3.77		
2016-17_11	5.23			
2016-17_12	-0.28			

2016-17_13	13.46			
2017-18_1	4.37	1.78	5.36	19.71
2017-18_2	10.00	-0.67	7.87	15.83
2017-18_3	-0.25	7.39	6.98	15.94
2017-18_4	3.03	6.15	5.22	12.01
2017-18_5	5.82	5.29	5.53	6.07
2017-18_6	12.02	4.27	10.29	12.12
2017-18_7	-3.79	7.98	9.05	12.06
2017-18_8	10.19	3.05		9.19
2017-18_9	4.15	1.70		
2018-2019_1	4.93	3.12	3.63	7.05
2018-2019_2	5.28	1.06	4.83	1.03
2018-2019_3	7.14	-1.36	1.32	6.09
2018-2019_4	6.07	5.89	6.06	-7.14
2018-2019_5	5.50	3.65	3.18	-4.90
2018-2019_6	0.19	2.09	9.27	0.83
2018-2019_7	2.39	1.47	10.15	7.05
2018-2019_8	6.89	4.41	3.97	4.04
2018-2019_9	4.61		1.39	6.03
2018-2019_10	4.29		3.36	1.03
2018-2019_11	4.28			4.10
Mean	**4.64**	**3.41**	**5.37**	**9.99**
Standard deviation	**4.59**	**3.60**	**3.44**	**8.38**

To establish a chi-square test, 11 categories have been created (Table 6) with c=11 and k=10 (degree of freedom). If it is normally distributed as ~N(4.64,4.59), the expected counts of each category can be calculated using Microsoft Excel function (eg. expected counts in categories -3 to -1 would be as [NORMDIST(-3,4.64,4.59,1)-NORMDIST(-1, 4.64,4.59,1)]*53).

Table 6 Distribution Facts of the Profitability of Specialty Wet Coffee Beans

With category range of 2%, Range<	Observed counts	Expected counts	$\frac{(\#\mathbf{Observed} - \#\mathbf{Epected})^2}{\#\mathbf{Expected}}$
-3	3	2.55	0.08
-1	4	3.27	0.16
1	5	5.53	0.05
3	7	7.77	0.08
5	9	9.05	0.00
7	9	8.75	0.01
9	7	7.02	0.00
11	4	4.67	0.10
13	3	2.58	0.07
15	1	1.18	0.03
17	1	0.45	0.68
total	53		1.25

Chi-square $\chi^2=\sum_{i=1}^{c}\left(\frac{(\#\mathrm{Observed}-\#\mathrm{Epected})^2}{\#\mathrm{Expected}}\right)=1.25$

Critical value of chi-square =CHISQ.INV(0.95,10)=18.3

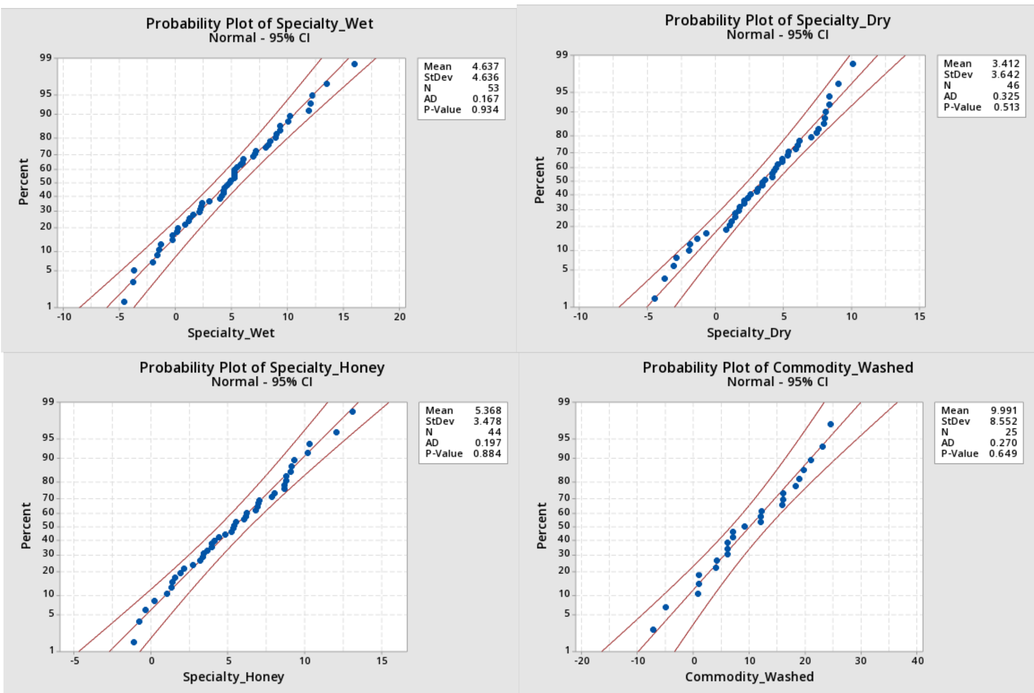
Since $\chi^2=1.25<18.3$, we cannot reject H_0 that the profitability index of specialty grade-wet processed beans is normally distributed. The same processes go to all types of green coffee beans as shown in Table 7.

Table 7 Distribution Facts of the Profitability of Four Types of Coffee Beans

Parameters	***Specialty Grade***			***Commercial Grade***
	Wet	Dry	Honey	Washed
# Observed	53	46	44	25
# Category	11	9	9	9
Degree of freedom	10	8	8	8
Mean	4.64	3.41	5.37	9.99
Standard Deviation	4.59	3.60	3.44	8.38
Chi-square	1.25	1.99	1.27	8.75
Critical Value of Chi-square	18.31	15.5	15.5	18.31

Using the probability plot of Minitab, normal distribution fits the data well with a p-value of 0.934, 0.513, 0.884, and 0.649 respectively for the profitability of four types of green coffee beans (Figure 8).

Figure 8 Probability Plot of the Profitability



The Application of Portfolio Optimization

Given the regular type of green coffee that Yunnan produces, a portfolio composed of 4 individual types could be generated.

Table 8 Mean and Standard Deviation of Profitability Index

Type of green beans	μ_i	σ_i
Specialty_Wet	0.0464	0.0459
Specialty_Dry	0.03414	0.0360
Specialty_Honey	0.0537	0.0344
Commercial_Wet	0.0999	0.0838

The mathematical description of the problem at the maximum portfolio profitability will have the form of Eq.5.

$$\begin{cases} \mathbb{E}(\mathrm{R_p}) = \sum_{i=1}^{4} w_i \times \mu_i \rightarrow max \\ \sigma_p = \sqrt{\sum_{i=1}^{4}\sum_{j=1}^{4} w_i w_j \sigma_{ij}} \leq \min \sigma_i \\ w_i \geq 0 \\ \sum w_i = 1 \end{cases} \tag{5}$$

The first function of the equation set describes the target function, which aims to maximize the overall return of profitability by realigning the structure of the four types of green beans. Secondly, the level of risk of the portfolio is set to be less than or equal to the lowest of the individual levels. The last two restrictions describe the condition of non-negativity and invariability of total production.

On the other hand, the mathematical description of the problem for a less risky portfolio will have as Eq.6.

$$\begin{cases} \sigma_p = \sqrt{\sum_{i=1}^{4}\sum_{j=1}^{4} w_i w_j \sigma_{ij}} \rightarrow min \\ \mathbb{E}(\mathrm{R_p}) = \sum_{i=1}^{4} w_i \times \mu_i \geq \max \mu_i \\ w_i \geq 0 \\ \sum w_i = 1 \end{cases} \tag{6}$$

Using Eq.5 and Eq.6 can be used to calculate the optimal weights of each type of green coffee beans in the optimal product portfolio (Table 9).

Table 9 Portfolio Optimization Weights

	Equal Wt.	Max R_p	Min σ_p
Constraining Variable	None	at σ<=	at μ>=
Value of Constraints	N/a	0.0344	0.0537
		Portfolio Weights	
Specialty-Wet	25%	17.28%	19%
Specialty-Dry	25%	0.00%	31%
Specialty-Honey	25%	25.66%	35%
Commercial_Wet	25%	57.06%	15%
$\sum w_i$	100%	100%	100%
R_p	0.058522868	0.078842081	0.053682877
σ_p	0.020945756	0.034383746	0.019270456

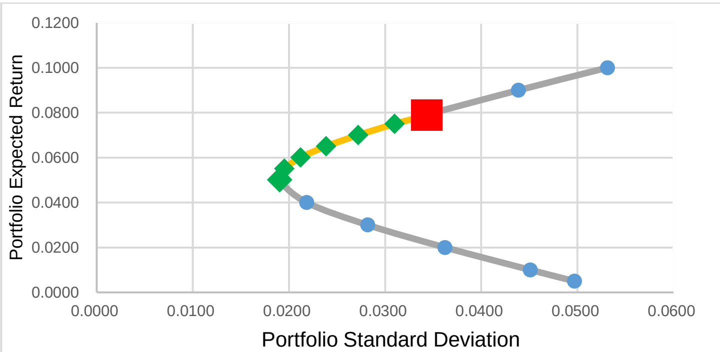
A portfolio with an equally weighted w vector (25% for each type) is used to check the results. We use the Solver to get the expected return of the optimal portfolio as 0.0788, which is much higher than its individual expected return, which indicates that to get the highest earnings, the farmers are suggested to produce 17.28% of wet-processed specialty coffee, 25.66% of honey-processed specialty coffee, and 57.06% of commercial grade coffee.

Table 10 Optimal Product Portfolio

NO.	1	2	3	4	5	6	7
Specialty_Wet	18.28%	18.69%	19.11%	19.52%	19.94%	19.59%	17.28%
Specialty_Dry	36.39%	28.77%	21.16%	13.54%	5.92%	0.00%	0.00%
Specialty_Honey	35.01%	34.55%	34.10%	33.64%	33.18%	31.21%	25.66%
Commercial_Wet	10.32%	17.98%	25.64%	33.30%	40.95%	49.21%	57.06%
σ_p	0.0190	0.0195	0.0212	0.0239	0.0272	0.0310	0.0343
R_p	0.0500	0.0550	0.0600	0.0650	0.0700	0.0750	0.0788

Table 10 shows 7 optimal portfolio sets of four types of coffee production. Each such portfolio obtains maximum profitability at the established risk level. Starting with portfolio No.1, the pair of return and risk climbs to a maximum point of No.7. The efficient frontier (Figure 9) also shows that the coffee smallholder growers will expect a higher return if they are willing to take more risk. Instead, if they seek stability with a lower risk level, then the expected return will be lower.

Figure 9 Portfolio Efficient Frontier



CONCLUSION

This research formulates and applies a portfolio optimization model to optimize the output proportion of specialty and commercial coffee for a certain plantation under the conditions that the labor and material cost for coffee planting and primary processing rise substantially in China and the procurement price of green coffee beans is subjected to the uncertain international procurement price. Modern Portfolio Optimization is applied in the case study to obtain an optimal product portfolio by maximizing the expected return of the product portfolio given a certain financial risk.

The optimal product portfolio generated in this study can be used to guide the coffee growers' decisions on coffee planting and primary processing. The methodology developed in the study can be applied to other coffee supply chains with corresponding modifications.

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Options for connecting decentralized data infrastructure to improve Supply-Chain decision making without giving up individual data property

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ABSTRACT

We present research on the topic of horizontal Supply-Chain data integration. This paper starts with a quick overview on the state of Supply-Chain intercompany communication. We will discuss the state of the connection between Supply-Chain members and the reasons why, especially small and medium businesses, have reservations on sharing data within their Supply-Chain. After that, we will look at existing architectures and concepts for analysis of distributed data. The paper will discuss under which assumptions and conditions the different identified solutions are able to connect the data infrastructure in the Supply-Chain.

KEYWORDS: Supply-Chains, Data-Analysis, Intercompany relations, Data management, Cyber physical systems, Digital business ecosystems, Decision support systems, Data ownership

INTRODUCTION

Supply Chains (SC) have become a regular part of the global economic architecture (Holweg, Disney, Holmström, & Småros, 2005). A SC can be defined as a system of organizations supplying a product or service to a consumer. The problem of managing these SCs has been challenged by organizational activities, but digitalization has brought further technology options to automatize the business layer communication between the different members.

This exchange between SC members is divided in different layers, the information flow and the flow of goods, as presented in Figure 1. The SC management is often managed at the Business layer with support of an Enterprise Resource Planing (ERP) system. The decisions made influence the flow of goods, by creating orders at the operations planning level. Therefore, the usage of automated business connections in SCs have changed the way and speed companies are working together.

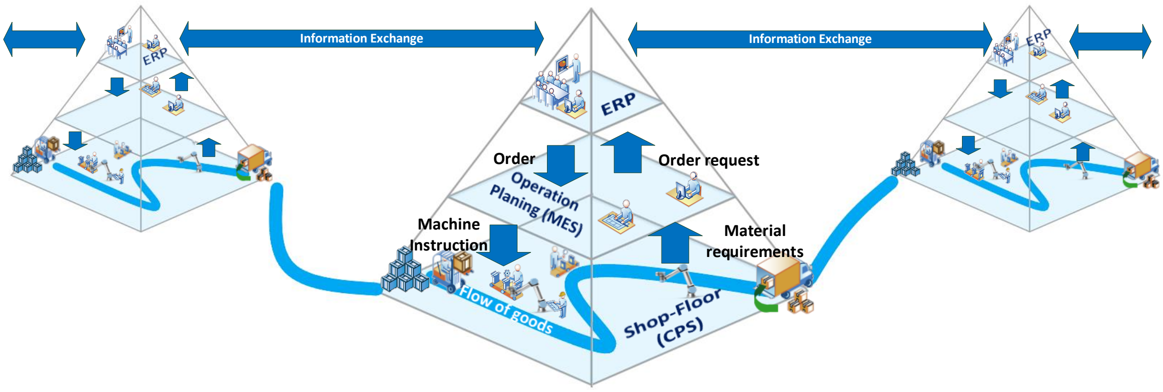

Figure 1 Coordination in a Supply-Chain

In addition, digitalization has enabled the companies to analyze their operations and manufacturing systems to improve their value creation better than any time before (Marmolejo-Saucedo, Hurtado-Hernandez, & Suarez-Valdes, 2020). Machine learning and data analysis yield opportunities to reduce waste, improve timing and quality of the shop floor and logistic systems (Weichert, Link, Stoll, Rüping, Ihlenfeldt, & Wrobel, 2019), while their prices are decreasing and the availability of customizable analytic tools enables even small businesses to use them.

Knowing this, many companies have started to collect data from their shop floor systems to take advantage of the opportunities or to lay the ground to do this in the future. Aware of the value of their data, the companies have become very sceptical at sharing their data with others, like suppliers or customers. By not sharing their shop floor data, they give up many opportunities to improve the overall production efficiency along the value creation inside of SC(Radanliev, Roure, Nurse, Montalvo, & Burnap, 2019).

First of all a major opportunity of the integration is to reduce costs of data generation inside the SC (Alcácer & Cruz-Machado, 2019). Much of the data used by the participants is collected multiple times for different purposes. This results in cost that could be lowered by sharing the data between the members of the SC. The sharing of this data would be a low-level entry in the usage of a supporting data platform, because the shared data is already acquired at the different companies involved. In addition, the companies that are involved in the SC can be seen as members of a community of trust, as they should have a shared interest to improve the results of the group like quality or efficiency.

A second opportunity of connecting SC data is to extract further data through combination of already existing data. By combining of data from different stages of the manufacturing process further relations between incidents appearing in late stages of the manufacturing process and data pattern appearing at earlier stages of the SC (Rong, Hu, Lin, Shi, & Guo, 2015). By gaining this information, it is possible to reduce waste and optimize the overall production system. It could also be possible to consider the quality data of every created part for its further usage.
This poses two questions:

a. which requirements a suitable solution for connecting the distributed information has to meet
b. Are there any existing solutions that meet all these requirements.

This paper will present and discuss the identified existing architectures and concepts.

LITERATURE REVIEW

Requirements and reservations on data exchange

In the beginning, we evaluated the requirements that a suitable solution for companies and organizations has to meet. To get these requirements the authors conducted a structured interview series with experts, executives and representatives from none governmental organizations. The interview results matched the results from a literature review. The interview series was started to get a better understanding of the state of the art of data exchange.

As mentioned the goal of the literature review was to identify the state of data sharing in SC´s. The result of the review shows that many big companies are already take advantage of SC data exchange, for example by connecting Information Systems with their overseas suppliers (M. Wu, Liu, & Yang, 2019) or by directly including them in their own manufacturing systems (Z. Chen & Huang, 2021). Beside this, the current state of intercompany data exchange for small and medium enterprise (SME) in a SC can be considered as fractured and often reduced to the bare minimum. This means, that the data exchange between the companies in SC is often limited to the business communication, which means that the companies interact via orders, invoices or other logistical data elements (Stock & Boyer, 2009).

All this happens on the level of the Enterprise Resource Planning (ERP) system. The Manufacturing Execution System (MES) and the systems on the shop floor are usually not involved in the exchange. They are used to communicate with the suppliers and customers in vertical communication by sending material requirements or by converting customer orders into production orders and later into individual machine orders. The result is that neither the participating companies nor the SC management can access all data that might be available on a certain step inside the SC (Xu & Chen, 2018). Another issue is that the systems, working independently, cannot be as efficient as if they were connected. Therefore, a connection of the divided systems of the different companies could increase the efficiency and dynamic in the SC.

A major reason for the lack of intercompany data exchange, especially in SME, might lay in the fact that many companies calculate the risk of data theft (Colicchia, Creazza, Noè, & Strozzi, 2019). These companies might risk losing control about their intellectual property. In some cases, this could thread the existence of the affected company, because competitors could use the information to improve their own production. Therefore, the fear of many companies of sharing data from their manufacturing systems is justified and understandable. This problem is solvable with trust and legal actions that protect the SC intellectual property. In the interview series, SME executives revealed that some of their methods and intellectual property are the only reason they can compete with other low-price competitors. It should be mentioned that the fear of data theft is not only on third parties that steal the data from outside, but also on some members of the SC, which might try to get advantages from giving access to the data to competitors of their suppliers. This correlates with the results of an interview series on data sharing in SC taken by Södergren and Cartling Wallén (Södergren & Cartling Wallén, 2022). Other studies also found that the trust between companies in an SC is an enabler for sharing the information with each other and a lack of this trust effects the collaboration between the partners (Panahifar, Byrne, Salam, & Heavey, 2018) (Z. Chen, & Huang, 2021) (Abdel-Basset & Mohamed, 2020).

Another issue for SMEs is their lack of technical knowledge to create own platforms and systems to exchange data with other SMEs (S. Wang & Wang, 2020). SMEs often work on a low budget with external technical service providers, which must be able to support the solution of the company to exchange data with a customer or a supplier. The advantages of sharing data rely on the ability to analyze them and understand the results of the analysis. Many SME companies don't have these abilities within their businesses, as our interview partners told us and other studies found out as well (Stentoft, Jensen, Philipsen, & Haug, 2019).

Many SME´s do not collect data from their shop floor or lack the ability to analyze their own infrastructure in a data-driven way. Many of these companies will need to take actions to improve their usage of digitalization to compete on the market.

Therefore, these companies are at a disadvantage compared to others that are able to collect information from their production systems, as data analytics have proven to create value in the shop floor (Wuest, Weimer, Irgens, & Thoben, 2016) (Monostori, Markus, van Brussel, & Westkämpfer, 1996). A survey has shown that the companies are largely using ML and analytics in classic fields like optimizing order scheduling or calculation of costs (Sharp, Ak, & Hedberg, 2018). Beside these trivial tasks, ML is used in predictive maintenance or to analyze quality data. By that it can be taken as proven, that analytics is able to save problems and reduce costs in manufacturing environments of a single company or shop floor. It should be obvious that not being able to use these technologies because of less data generation is a massive disadvantage.

As a SC can be described as a number of shop floors that are connected (Kozlenkova, Hult, Lund, Mena, & Kekec, 2015), it is likely that the same methods that be used to find local optimization can find global optima. Considering this the hypothesis can be made, that a SC can profit from the connection of data the same way as an individual company can profit by optimization of its own manufacturing systems. Therefore, we tried to identify solutions that are able to connect the distributed databases in an SC.

Options for data integration and analysis

To identify possible solutions we conducted a review on existing data analysis strategies and solutions that are working on distributed data sets. The literature review delivers different concepts, which are able to analyze distributed data. The paper will now present the identified solutions and later match them with the identified requirements. First, we will start with Data Spaces as an existing concept for sharing data.

Data Spaces

Data Spaces have been defined by Franklin, Havely and Maier as a next step in the evolution of data integration architectures. (Franklin, Halevy, & Maier, 2005) The evolutionary step is that Data Spaces combine storing of data with services, to combine data from different sources – e.g. companies, research institutes or governmental agencies – to extract information. Key of this approach is the integration of data from different domains and the mapping of their different data elements. Obviously, this part of the Data Space gains the most value for participants.

A Data Space resembles a SC, as it provides data from different sources to fulfill a certain demand. This data sharing allows the whole system to improve its value. Similar to a SC the Data Spaces value depends on the level of compatibility – mapping and matching – between the different (data) suppliers. (Sarma, Dong, & Halevy, 2009)

Therefore, approaches to create a Data Space for business use cases had been started. One of these is the International Data Space (IDS) (Fraunhofer-Gesellschaft, 27.08.2020). The IDS is a system of data providers interacting on a platform. Each participant can be buyer or seller and has the right to negotiate about the rights on the data.

The value gain for the each participants depends on the data available at the platform and the group of other participants inside the platform. By that, the value increases with the number of participants and the volume of shared data. For the further understanding of this, we will provide a short overview of the different roles in the International Data Space architecture.

The IDS main focus is a market place which brings together different roles for the participants and their brought-in data. The roles relevant for this paper are:

- Data Provider
- Data User
- Broker
- Service Provider

The Broker is the key element of the IDS. The company providing the broker function offers two main services to the participants. Firstly, the broker lists and categorizes the data delivered by the data providers.

This service enables the searching companies – data users – to find the data they need. The companies can search based on labeled data or based on the types of data they already have – e.g. a certain type of application or asset. If the system includes a data provider with the needed data, the broker connects the two – or more – companies. As the data can be traded anonymously, it is even possible to buy data from trusted sources without knowledge about the exact company supplying the data.

A service provider intermediates between the entities and to the Data Space provides the process of data sharing. This provider can be part of a whole ecosystem or a service provider. These can for example be Infrastructure services – e.g. data storage, computing power or other infrastructure – that allows participants to be part of the data space without having own hardware.(Shah, Bolton, & Menon, 2020) Beyond this Infrastructure as a Service (IaaS), other providers can add services – e.g. data analysis or searching services – or Software as a Service (SaaS) – e.g. analytics tools or data mining software – via a dedicated App Store.(Rong et al., 2015) To explain how a platform like the IDS realizes the sharing of data between the participants we will show the suggested data model. The system is presented at Figure 2 below. (International Data Space Assoziation)

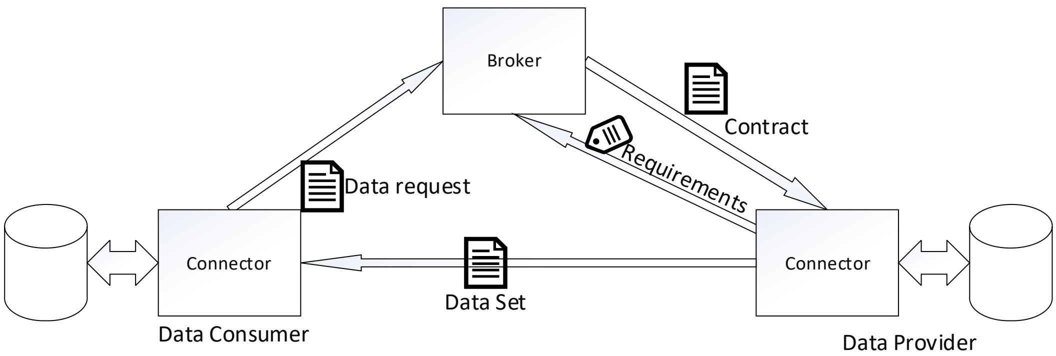

Figure 2: data-distribution (based on International Data Space Assoziation)

As displayed the model consists of data providers and consumers that hold their data in their own physical storage locations. However, these physical Storages do not interact directly with each other. The IDS Connectors operate this function. These Data Space Connectors provide information about the data they could deliver such as identity, functional range, and interaction capabilities in a description file.

Obviously, the connectors are a key component of the whole system, as they deliver the data from the source to the sink. The International Data Space Association suggests to store data as close to the data source as possible. (International Data Space Assoziation) They further suggest that: "Any data preprocessing (e.g., filtering, anonymization, or analysis) should be performed by Internal Connectors. Only data intended for being made available to other participants should be made visible through External Connectors." (Fraunhofer-Gesellschaft, 2020)

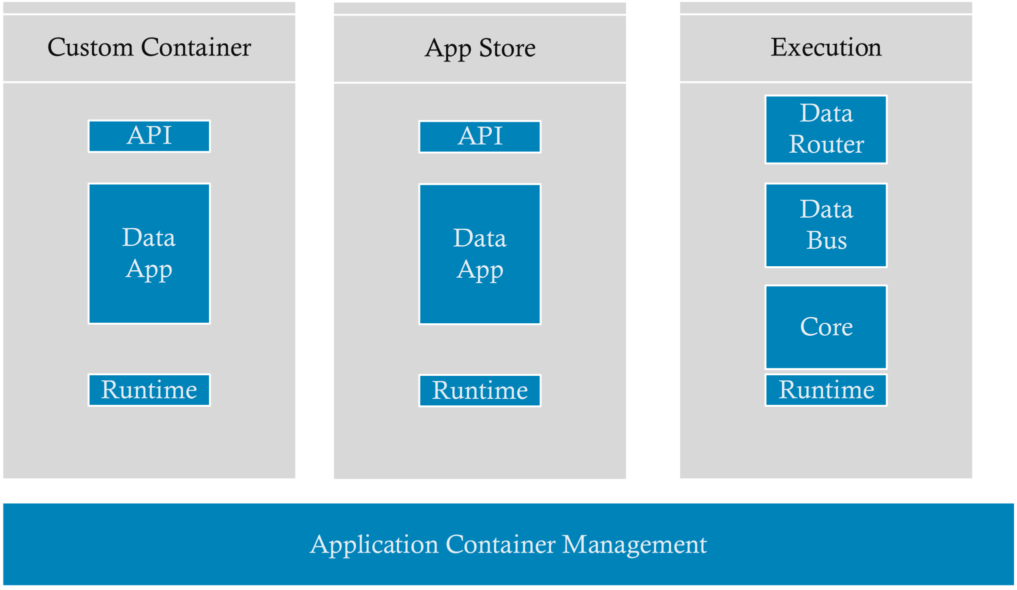

Figure 3: Reference Architecture of an International Data Space Connector (based on International Data Space Assoziation)

The suggested architecture of an IDS Connector is shown in Figure 3. The connector consists of a configuration and an execution part. The configuration part of the reference architecture provides general information about the connector and its represented (data) instances. It also contains information about the network and metadata. The other part of the connector contains the data goods that are encapsulated in container modules – e.g. Docker – that are accessible by an API and managed by a Container Management Module.

The combination of these parts makes it possible to provide an integrated index service – provided by the Broker – that manages the data sources available in the IDS and supports publication and maintenance of associated metadata. This service allows the data suppliers to gain economical value from their data. As this paper focuses on the data connection, we will not investigate in the ways in which companies can monetize their data in the system.

In summation, the IDS delivers a solution to share data between a seller and a buyer. It relies on the will of the seller to give up data ownership and give access to the buyer. Therefore, the IDS does not provide a solution that fulfills the demand of the companies to share information without sharing their raw data. A good concept is the usage of a container-based connector and the usage of a broker service. Therefore, these parts of the IDS technical architecture might be interesting for a solution to share information without sharing data. We will now look at another possible solution, the concept of federated learning.

Federated Learning

Federated Learning is by design a suitable concept for connecting distributed data. It gives methods to create algorithms that work on over different computers or networks distributed datasets. By that, the Federated Learning methods are able to analyze the databases of the members of an SC, without central collection of the individual datasets. Therefore, the Federated Learning is a solution for the kind of problem the paper has described, facing with the data distributed within the SC. The paper will now look how Federated Learning methods are working and which limitations are coming with the use of their methods.

First, it should be clarified, that Federated Learning by itself is not only Machine Learning on a distributed set of data. The different of Federated Learning and Distributed Machine Learning are some assumptions on the data analyzed by the learning model and the goal of the distribution. While the main goal of the Distributed Learning is to reduce the time to analyze homogenous data distributed over a network (X. Wu, Zhang, & Wang, 2020), the main goal of the Federated Learning is not to improve the performance of algorithm. Instead Federated Analytics is used to enable smaller, less performant devices to use pre-trained analytical model to analyze their individual data sets (Q. Yang, Liu, Chen, & Tong, 2019). Therefore, it is obvious that the concept of Federated Learning is not build for SC. Instead, Federated Analytics are used in mobile devices, like smartphones or IoT devices. These devices may not have the same data, but similar data structures. This is not a structural issue of the method, but should be mentioned as there are rare examples of usage beside homogenous IoT devices. One of this is the rare examples is the use of federated learning in the agri-food sector (Durrant, Markovic, Matthews, May, Enright, & Leontidis, 2022). This rare example shows how a SC can use the concept of Federated Learning, but also except the limitation of the method, like Data heterogeneity and indirect information leakage. To understand these limitations we will shortly describe how the Federated Learning works.

To use algorithms on distributed data in step one the machine Learning Model is created on a data sample. In a second step, the model is decomposed in sub models, matching the data elements of the different storages. The different data stores – called nodes – then train the model on their own data. In the fourth and last step the results of the individual models can be transfered to the central application to improve the model.

As it is obvious, a downside of the Federated Learning is that the companies still need to share a certain amount of data to create the starting model. Furthermore, they need to share additional data, to keep the model up to date. As described earlier, some SC members we interviewed are not even willing to share a small sample of data in fear of getting replaceable.

Summed up, the usage of the concept of Federated Learning to connect SC member’s data stores is a possible solution, but comes with the explained limitation. The key limitation for usage in SCs is that there is still a degree of centralization in Federated Learning where a central model uses the output of other devices to build a new model. Considering this, Federated Learning can provide a tool to analyze the distributed, without giving up full data privacy, but still needs to share a certain amount of data.

GAIA-X Federated Catalogue

Another option for sharing information between SC partners might be the usage of GAIA-X, especially the GAIA-X Federated Catalogue. This architecture concept allows the sharing of data elements under usage of a public catalog (GAIA-X: Technical Architecture, 13.07.2021). In the concept, everybody can see the catalog of data available, but can only access data when the access is granted. Therefore, the companies can choose to give permission for sharing data, on an individual level. The GAIA-X foundation guaranties data Sovereignty Services. This means that participants have the capability to full self-determinate their data exchange and sharing. The secure exchange is realized by a function called Data Contract Transaction. This service initiat a handshake between the data provider and the requesting party. The service validates the contract and, if the content is valid and the both parties confirmed the transaction, the Data Contract Service distributes the Data Contract to both companies. After that, the requesting company can access the requested data and may analyze it. Everything is observed by a function called Data Exchange Logging, which enables companies to restrict the usage of their data to a certain amount or for a specific purpose.

Considering this, the authors believe that the model of GAIA-X allows sharing data in a secure and customizable way but still needs to share the data to analyze them inside of the SC. A very interesting part of the solution is the way the catalogue combines data identification and services by a self-description. The value of this for companies that are interested in sharing data has also been examined by Dumss et al (Dumss, Weber, Schwaiger, Sulz, Rosenberger, Bleicher, Grafinger, & Weigold, 2021). They suggest an architecture model that allows a data driven SC to exchange data in a scalable way. They also describe how services can enrich the data generated and how important the self-description is. The research group did not give a suggestion how to secure the data exchange or how to keep the intellectual property of the companies by themselves. This means that the EuProGigant concept, as it is proposed at this point, is not able to protect the data ownership interests of the SC companies.

Therefore, the GAIA-X Foundation provides a reliable, effective and secured solution for sharing data. For companies that are interested in sharing or selling their data the Federated Catalogue is a fitting solution. In the case of an interconnected SC, it might also be a very good communication platform, but is not able to create an information exchange without sharing the data. By that, the opinion of the authors is that the solution does not fulfill the requirement of protecting data ownership.

Commercial Solutions on the Issue

Beside the implementation of any of the concept evaluated in the chapters before the question remains if there is any existing commercial solution to connect SME SCs without giving up their individual data ownership interests. As the number of companies developing solutions for data integration and SC management is rising, the selected existing solutions and products aren´t the whole spectrum of solutions. The authors believe that the range of products analyzed is big enough to display the current state of the art of solutions on the issue of this paper, but it is still possible that some other, not evaluated, solutions or products exist that are solving the companies challenges better.

As one of the commercial solutions, the SAP AG has launched the products Business One and Business ByDesign. The authors were not able to test the software at this point, but tried to evaluate the software on the company's promotional material and reviews of other groups on the software packages.

According to SAP the software Business One is focused on small businesses and is able to deliver a ERP system that does not share much with the main SAP Products S3 and S4 (Schneider, 2018). Business One is available as a cloud and as an on-premise product. Companies can chose to run the software on their own server or use a cloud server hosted by SAP. However, the software can run on the in-memory database HANA and guarantees a good performance. If the company want to save money, it is possible to run the solution on other databases as on-premise version (SAP,2022). The product allows build in analytics and SC automation of business transactions (SAP, 2022). Therefore, we can consider that Business One is a solution that can help small companies to get to the earlier described state of the art of SC communication. It also allows the companies to get analysis of their business decisions, but is not able to solve the issue of intercompany communication. For some businesses, it would still be an improvement of their SC and relation to their customers.

A second product of SAP is SAP Business ByDesign. SAP suggests that Business ByDesign is a product which aims to medium businesses (SAP, 2022). The product is cloud based and provides a customizable ERP system, which can be integrated in a SC (Kurbel & Nowak, 2013). Beside that, the solution is able to create build in analytics, that can create real time dashboards of the company´s situation (Schneider, 2018). In addition to the features of BusinessOne, SAP Business ByDesign delivers the features of SC Management and SC Relationship Management. These functions support the areas of sourcing and purchasing (Schneider, 2018). The benefits of these functions are:

a. Ability of celebrative product development with SC partners
b. Material flow planning between companies
c. Demand forecasting, leading to reduction of inventory
d. Automation of purchase requesting and handling

Like Business One, Business ByDesign did not involve the SC partners manufacturing infrastructure. The solution fits the demand of medium size businesses that want to interact automated with SC partners on the ERP level. As described the solution did not fulfill all requirements that the companies have. Therefore, the solutions of SAP are not able to solve the issue of this paper, but it should be mentioned that SAP Business ByDesign can be customized and by that a solution could be developed which fits all requirements (SAP Business ByDesign Studio: Application Development, 2012).

Now we will look at the solutions of Microsoft. These are Microsoft Dynamics ERP and Microsoft Azure. Like SAP, Microsoft Dynamics is an ERP system that can be integrated as a on-premise or cloud solution. Dynamics delivers functions for integration of warehouses, material flow planning and collaboration with other companies (Microsoft Corporation, 30.05.2022b). The SC management component delivers similar functions to the given by the SAP products. A comparison of the different ERP systems has shown that the different products are matching more and more individual requirements and a suitable solution for one company may not be matching the requirements of the others (Elbahri, Al-Sanjary, Ali, Naif, Ibrahim, & Mohammed, 2019). The review also found that all investigated ERP systems enable the integration of suppliers on the level of business communication. Another study also shows the state of ERP MES integration in Microsoft Dynamics and the lag of a integration of intercompany shop floor data exchange in the solution (Oman, Leskovar, Rosi, & Baggia, 2017). Therefore, Microsoft Dynamics did not solve the issue of this paper, but it realizes the state of the art in SC.

As last commercial solution in this paper, we will discuss the possibility of using Microsoft Azure to connect the companies SC data. Microsoft Azure enables collaboration between companies in a SC with a cloud application that integrates inventory, factory status and logistical data in a twin of the SC elements (Microsoft Corporation, 2022a). The core focus is on using machine learning, optimization algorithms and artificial intelligence on distributed data to improve the decision making inside of the SC. An element called control tower creates a dashboard, which shows this state. The concept of these control towers is that a SC member delivers all relevant data to the gateway and connects them to the data of the other members. The results can be combined with public data, for example weather information (Sunny, Undralla, & Madhusudanan Pillai, 2020). An example for an SC using Microsoft Azure can be found in the agriculture sector (Deepak Vasisht, Zerina Kapetanovic, Jong ho Won, Xinxin Jin, Ranveer Chandra, Ashish Kapoor, Sudipta N. Sinha, Madhusudhan Sudarshan, & Sean Stratman, 2017). These use case show how the connection of different SC data storages can improve the whole SC´s success, but also shows that the members involved must be willing to share their data, as the architecture provides the risk of losing control about the data. It should also be mentioned that the project focus was not on connecting SC members but on connecting singular IoT solutions and product used by different farmers involved (Duggar, 2019). Therefore, the translatability to industrial SC´s may not be given. As a last point of this part, it should be mentioned that Microsoft Azure can be customized and it is able to create individual extension that enable new functions (Pliuhin, Korobka, Karyuk, Pan, & Sukhonos, 2019).

DISCUSSION AND CONCLUSIONS

This paper discusses the state of intercompany data exchange in Supply Chains and elaborates the requirements companies must meet to improve the data exchange between these companies. After the introduction, which describes how companies interact in Supply Chains, the paper described the reservations of companies against the exchange of data. These concern the security of the shared data. Since many companies have become aware of the value of these data, the fear of data theft or abuse is an obstacle for sharing these. Beside this restriction, especially small and medium businesses have to deal with smaller budgets than bigger companies and they also have to deal with a lag of knowledge about data analytics and data management. Therefore, a suitable solution has to deliver a certain amount of security, protection of data ownership and has to be affordable and understandable for the companies or their IT-consultant.

In the following major part, the paper claimed that the current shortcomings of data exchange between companies is also a result of a lag of concepts and products that meet the requirements investigated before. To prove that a literature review on the concepts for data exchange was taken and the most interesting results were presented to show the gaps of the existing concepts and solutions. For the purpose of this paper, only the most famous products and concepts have been presented, but the full literature review featured more than 140 publications on multiple concepts for intercompany data exchange. In addition, as mentioned, a structured interview series has been taken and their results have been compared with other similar interviews, taken by other research groups. The conclusion of this is that further research has to be done and new concepts have to be developed to challenge the issue.

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DECISION SCIENCES INSTITUTE
Organizational Resilience in Higher Education:
Preparation for, Reactions to, and Lessons Learned from Unexpected Events

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ABSTRACT

Unexpected events are a part of business. Organizations must successfully navigate the incidents that seek to threaten their viability and create ways to survive and thrive, despite these events and their effects. This study highlights the importance of lessons that can assist institutions of higher learning better prepare in the future for disruptive events. An existing organizational resilience conceptual model was used to analyze how institutions move through the three phases of organizational resilience as they responded and adjusted over time to the pandemic. A qualitative, exploratory case study approach was employed to examine and provide lessons learned.

KEYWORDS: Managerial decision making, Decision Models, Distributed Decision Making, Strategic Alliances, Process Change, Process Improvement, Framework, Decision Support, Decision Effectiveness

INTRODUCTION

Unexpected events are a normal and inevitable part of the business environment in which organizations exist. Since these types of events are a normalized part of an entity's existence, they can pose a threat to organizations' very being in how they respond to, move through, and carry forward lessons from these unexpected phenomena. To survive and even thrive despite these types of events and their effects, a fundamental challenge for organizations is how to successfully navigate these incidents that seek to threaten their viability, livelihood, and even their continued existence. In other words, being organizationally resilient is necessary to allow entities to manage their way through these disruptive events successfully. This resilient practice may even make the most of disruption by creating a competitive advantage or developing other ways to strengthen the business due to the disruptive experience (Lengnick-Hall et al., 2011). Further, and in contrast to robustness, flexibility, or agility, organizational resilience includes an entity's ability to exit unexpected events stronger due to incorporating the lessons learned into the business's operations (Madni & Jackson, 2009).

Such a disruptive event shocked the world in 2020. The COVID-19 pandemic affected every sector, including institutions of higher education. Many colleges and universities in the United States were grossly unprepared for such a far-reaching event. Strategic and other operational plans became irrelevant once the pandemic's effect caused colleges and universities to quickly make drastic changes to their operations to continue serving their students, keeping safety at the forefront of their decisions while coming to terms with a new operational and learning environment. Higher education institutions had to adjust their delivery of classes in ways that still supported students' successful learning. These institutions required and still require a level of organizational resilience to continue to respond to the ongoing effects of the pandemic in ways that keep them well-positioned to serve their customers and students and position their faculty and staff to do the same while keeping in mind the safety of all. This study explores this disruption and the associated changes and lessons learned during these organizations' response to this worldwide disruptive and unexpected event – the pandemic of COVID-19.

According to research done as recently as 2019, organization resilience is defined as an entity's capability to detect possible risks, deal with these unexpected events adequately, and successfully adjust due to the changes that come by way of these disruptive events (Duchek, 2020). Organizational resilience also includes an adaptation component, which allows the possibility for an entity to emerge from crises more potent than before they encountered the events (Madni & Jackson, 2009). The current body of literature on organizational resilience is relatively new related to its focus on business and management studies (Duchek, 2020). Further, the literature does not cover organizational resilience as it relates to the higher education sector. Therefore, the research gap explored is the extension of organizational resilience in the face of the COVID-19 pandemic to higher education.

Overall, the purpose of this study was to apply an organizational resilience model to the higher education sector to understand these organizations' resilience amid COVID-19 and identify lessons that could be helpful to them that might be carried forward. In this vein, institutions could be better prepared for unexpected events in the future, particularly related to their ability to continue supporting student learning well through these types of events. More specifically, this study addresses the following research questions.

- How did the COVID-19 pandemic impact university operations and activities in the following areas – Administration, Faculty, and Students?
- How can lessons learned be carried forward to better prepare for unexpected events?

LITERATURE REVIEW

Organizational resilience is reasonably new in the areas of organization and management studies. According to Duchek, three primary ideas surfaced in business research from 1998 – to 2015 that recognized organizational resilience as 1) Resistance and Recovery, 2) Adaptation, and 3) Anticipation (Duchek, 2020).

Researchers that have explored organizational resilience as resistance and recovery described resilience as "…a fundamental quality…to respond productively to significant change that disrupts the expected pattern of an event without engaging in an extended period of regressive behavior" (Horne & Orr, 1998). Others defined organizational resilience as "the organization's capacity to absorb the impact and recover from the actual occurrence of an extreme weather event" (Linnenluecke et al., 2012). Moreover, organizational resilience in terms of recovery has been defined as "…bouncing back to a state of normalcy" (Boin & Eeten, 2013). In summary, these researchers believed a focus on dealing effectively with adverse events and then swiftly returning to normal operations was at the heart of organizational resilience (Duchek, 2020).

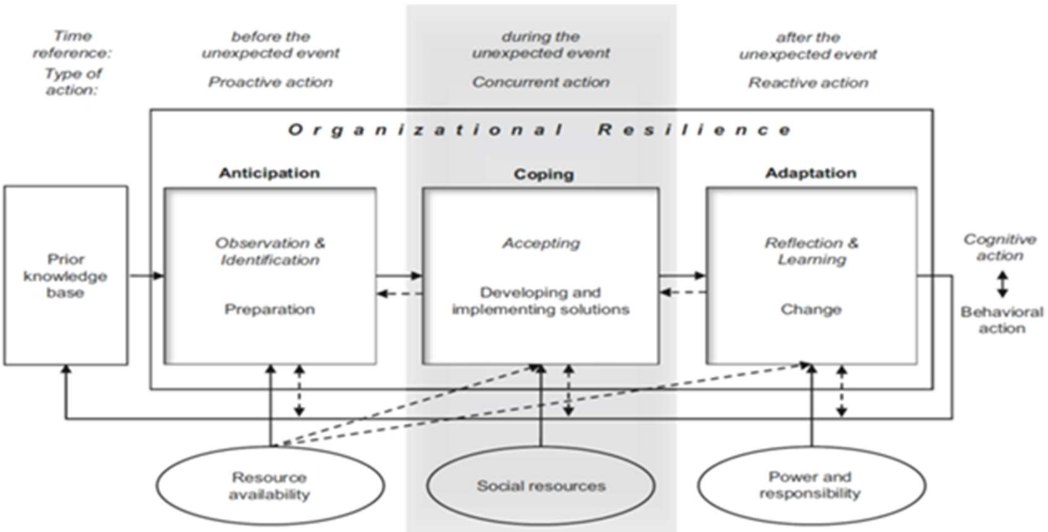
Studies that understood organizational resilience as Adaptation described it as "the capability to self-renew over time through innovation (Reinmoeller & Van Baardwijk, 2005), "the maintenance of positive adjustment under challenging conditions such that the organization emerges from those conditions strengthened and more resourceful (Vogus & Sutcliffe, 2007), and as "…a firm's ability to absorb effectively, develop situation-specific responses to, and ultimately engage in transformative activities to capitalize on disruptive surprises that potentially threaten organization survival" (Lengnick-Hall et al., 2011). For these studies, the focus was organizations possessing abilities that allowed them to "adapt, integrate, and reconfigure internal and external resources and competences to match the requirements of changing conditions (Teece et al., 1997).

Other studies highlighted organizational resilience as Anticipation. Somers understood it to be "…more than mere survival; it involves identifying potential risks and taking proactive steps…to ensure that an organization thrives in the face of adversity" (Somers, 2009). The idea of organizational resilience as Anticipation was also captured as "prevent(ing) budding problems from escalating into a full-blown crisis or breakdown" (Boin & Eeten, 2013). Lastly, other research described organizational resilience as "the incremental capacity of an organization to anticipate and adjust to the environment." (Ortiz-de-Mandojana & Bansal, 2015). For these scholars, the core of the notion of Anticipation is having the capacity within an organization to always be ready for any possible event – being on the offense rather than the defense, which resistance, recovery, and Adaptation all address (Duchek, 2020).

THEORETICAL DEVELOPMENT/MODEL

Duchek outlines a conceptual model that depicts organizational resilience as a process, beginning with Anticipation, flowing to Coping, and then to Adaptation, with organizational capabilities that support each phase as shown below:

Figure 1: A capability-based conceptualization of organizational resilience (Duchek, 2020).



Organizational resilience is defined as "…an organization's ability to anticipate potential threats, to cope effectively with adverse events, and to adapt to changing conditions". Together, these capabilities lay the groundwork for organizations to mature in healthy and beneficial ways in responding to unexpected events.

Theoretical Framing

Duchek believes that organizational resilience is an entity's capability to detect possible risks, deal with these unexpected events adequately, and successfully adjust and distill any lessons due to the changes that come by way of these disruptive events (Duchek, 2020). Further, organization resilience is a process in combination with organizational capabilities that support each phase of the process. The phases are Anticipation, Coping, and Adaptation. All three are separate but interconnected as an organization moves through expectation, realization, and response, then intentional learning from an unexpected event.

Anticipation includes the capabilities of Observation, Identification, and Preparation: Action that supports this phase of organizational resilience are abilities to see the event forming and brace as possible for its realization with the information at hand. Since organizations cannot adequately prepare for the unexpected, an organization building its Anticipation capability needs to act instinctively and make in-the-moment calls.

Coping includes the capabilities of Acceptance, Developing, and Implementing Solutions: Acceptance, creating, and implementing responses to unexpected events are included in this stage of organizational resilience. Organizations need to have the ability to accept and not deny the reality that a disruptive event has occurred so that they are agile enough to craft and implement innovative responses promptly to mitigate further consequences for not swiftly acting.

Adaptation includes the capabilities of Reflection and Learning, and Change: Being intentional on a focus of reflection and cultivating takeaways in ways that lead to organizational change and maturation in resilience is at the heart of this capability. This newly gained knowledge, in turn, acts as an antecedent for Anticipation as it becomes part of an organization's knowledge base and ability to offensively develop its resilience.

Contribution to the Body of Research and Practice

One area that Duchek points out as a possibility for future empirical research was focusing on how entities notice and prepare for, accept, and respond to, and are intentional in understanding and gaining from unexpected events in ways that shore up their organizational resilience capacity (Duchek, 2020). This study includes this focus on addressing a gap in Duchek's work by empirically applying her framework to the higher education sector in the context of the United States, in both a private and public institutions, thus extending the body of research on unexpected events and organization resilience to this sector in support of these institutions as they move through the phases of the resilience model and build their resilience "muscles".

There is also a research gap in studies exploring the sudden move to online teaching modalities, specifically in the context of organizational resilience (Bartusevičienė et al., 2021), which we address. Universities had to quickly switch to an online teaching environment (Oliveira et al., 2021) in order to continue supporting students academically, which, for many institutions and students was an entirely new and different learning environment. (Shaya et al., 2022)

Lastly, we add to the practical body of knowledge to help higher education institutions use lessons highlighted from this study to better plan and prepare for future disruptive events.

RESEARCH METHODOLOGY

For this research, a qualitative, exploratory case study approach was used, examining two large public universities in the Southeastern United States and the actions of their respective employees relative to the onset, actual occurrence, and then longer-term reaction to the pandemic of COVID-19. Per Miles and Huberman, using a multiple case study method adds confidence to the findings and increases the reliability of the study (Miles & Huberman, 1994). Further, our units of analysis from both institutions consist of Administrators, Faculty, and Students.

Qualitative research is used for our study as it is best suited for studies focused on gaining insight into how people understand and give meaning to their lives, experiences, and the world in which they exist (Merriam & Tisdell, 2016). Qualitative research is further explained as follows:

> …an effort to understand situations in their uniqueness as part of a particular context and their interactions. This understanding is an end in itself, so that it is not attempting to predict what may happen in the future necessarily. Still, to understand the nature of that setting – what it means for participants to be in that setting, what their lives are like, what is going on for them, what their meanings are, what the world looks like in that particular setting – and in the analysis to be able to communicate that faithfully to others who are interested in that setting…analysis strives for depth of understanding. (Patton, 1985, p. 1)

In addition to facilitating in-depth analysis, case studies enable holistic investigation of complex social phenomena wherein researchers observe the intrinsic characteristics of real-life events (Yin, 2009). Unlike experiments, case studies do not separate the phenomenon from its actual context by attempting to understand the phenomenon in its natural context (Yin, 2009). This, in turn, facilitates close cooperation between the researcher and the participants while allowing the subjects to express their views (Baxter & Jack, 2008).

Yin explains that questions of "how" and "why" questions indicate the use of a case study approach as an optimal research method as these types of questions are concerned with how organizational activities develop and/or change over time versus the number of instances of changes or activities (Yin, 2018). Case studies extend beyond a narrative account as they are in-depth inquiries into some form of phenomena ''which the analyst believes exhibits (or exhibit) the operation of some identified general theoretical principle'' (Mitchell, 1983).

A primary source of data for a case study is by way of interviews (Yin, 1984). These interviews should be with those knowledgeable about the subject matter and are characterized as critical informants (Mikkelsen, 1995). In this study, interviews with key informants were done with university administrators, faculty, and students from each University.

Further, Yin describes case studies as either exploratory, descriptive, or explanatory. For exploratory case studies, researchers primarily focus on defining another study's research questions and hypotheses (Yin, 2014). Descriptive case studies allow researchers to fully explain in detail and context the focus of the study. The purpose of the explanatory case study is for the researcher to explore and describe causal links for specific matters, events, or phenomena. With this guidance in mind, the exploratory method for our study was chosen.

Our data collection method consisted of semi-structured interviews with leaders from two universities within the following aspects – Administration, Faculty, and Student – that lasted no longer than 60 minutes each. Interview participants were selected from the business schools of each University for the faculty and student categories to narrow the scope of the study further. The interviews included open-ended questions structured around the themes of organizational resilience being explored (Anticipation, Coping, and Adaptation), which helped guide the interviews. The initial questions posed are provided in the Appendix. However, the interview process was adapted as the interviewer moved through the questions, received responses, and then asked follow-up questions or skipped pre-formatted questions as the interview led the dialogue. This method helped the interviewer amend each interview based on the interviewee's expertise and/or experience and permitted the interviewer to examine interesting and unanticipated subject matter that surfaced during interviews.

Each session was conducted by one interviewer, and all data gathered was separately analyzed by each interviewer, with the results of each interviewer's analyses being subsequently compared. This triangulation method was used to help ensure the internal validity of our study. Per Patton (2015), triangulation of interviewers involves having two or more individuals separately analyze the same qualitative data and then evaluate the results afterward. Interviewers used memos and notes to gather as much data as possible, help organize the data, capture any follow-up questions or notes, and flesh out possible codes that surfaced during the interviews. Questions were centered around actions before, during, and after the pandemic and lessons learned that would be taken forward. The interviews were held and recorded via the Zoom video conferencing platform. Participants were not required to have video cameras on during the interview if anonymity was requested. Participants were free to say as much or as little as they wanted. They also reserved the option not to answer any questions or to stop the interview at any time.

Data collection occurred between June 2021 and September 2021. Collectively, the two interviewers conducted thirteen interviews. Given the scope of the study, the nature of the topic, the quality of data, and the study design, this was deemed appropriate and sufficient. Each session was subsequently transcribed using Otter transcription technology. The number of interviews completed by category is shown in Table 1.

Table 1: Interview Completion Matrix

INTERVIEWS	A: ADMINISTRATORS	B: FACULTY	C: STUDENTS
University 1	2	3	2
University 2	2	2	2

The cross-selection of administrators, faculty, and students is representative of the main areas of a university. Additionally, research posits that the more useable data are collected from each person, the fewer participants are needed (Vasileiou, 2018). The level of structure of questions in the interview has been found to influence the richness of data generated, and empirical research shows that open questions, which are asked later in the interview, tend to produce richer data. The structure of the questions within this study follows this architecture allowing for the number of interviews conducted to be sufficient.

RESULTS

The primary purpose of this study was to apply Duchek's organizational resilience model to the higher education sector, and highlight lessons learned that could help these organizations improve their readiness for unexpected events (Duchek, 2020). In analyzing the data, interviews were categorized as either Administrators, Faculty, or Students. Administrators included Information Technology, Budget/Finance, and Communication/Marketing staff. Faculty included both Professors and Department Chairs, and students were at both the undergraduate and graduate levels.

Further, for each category, interview data was organized by organizational resilience phases outlined by Duchek, Anticipation, Coping, and Adaptation (Ducheck, 2020), which are related to Research Question 1, How did the COVID-19 pandemic impact university operations and activities. Upon reviewing the references coded, additional extensions to the model were identified related to Research Question 2, How can lessons learned be carried forward to better prepare for unexpected events.

The transcribed interviews were coded at an initial level within NVivo by each interviewer separately, with all key responses organized based on the research questions and phases of organizational resilience. The results of coding done by each interviewer were then combined. The initial coding resulted in the following concepts presented in table 2.

Table 2: Initial Coding Reference Matrix

THEMATIC CONCEPTS	A: ADMINISTRATORS	B: FACULTY	C: STUDENTS	TOTAL
1. Adaptation	21	25	20	66
2. Administrative Strengths	2	4	0	6
3. Adverse Effects on Faculty	1	12	10	23
4. Adverse Effects on Staff	4	2	0	6
5. Adverse Effects on Students	1	2	24	27
6. Anticipation	7	20	6	33
7. Barriers To Success	0	1	1	2
8. Budget And Finance	6	1	1	8
9. Classroom Management	1	8	0	9
10. Communication	8	7	10	25
11. Consistency	4	1	0	5
12. Coping	16	15	10	41

13. Cross Collaboration	10	1	0	11
14. Decreased Attention Span	0	1	1	2
15. Disconnected From Network	0	2	6	8
16. Flexibility	4	9	5	18
17. Future Uncertainties (Job Insecurity)	1	4	5	10
18. Growth Opportunities	3	6	1	10
19. Hesitancy To Change	1	5	1	7
20. Increased Efficiency	4	1	0	5
21. Infrastructure & Tech Support Needs	8	10	0	18
22. Job Function Changes (Process Adjustments)	6	7	0	13
23. Lack Of Confidence in Self	0	0	1	1
24. Lack Of Planning	1	1	4	6
25. Lessons Learned	8	5	2	15
26. Mental And Emotional Health	0	6	11	17
27. Motivating Students (Engagement)	3	4	3	10
28. Motivation To Change	1	2	2	5
29. Move To Online Learning	6	11	5	22
30. Personal Innovation	0	2	2	4
31. Planning Forward (New Opportunities)	8	5	6	19
32. Professional Development	0	3	0	3
33. Relationship Building	1	1	1	3
34. Resiliency	1	1	1	3
35. Social Anxiety (Health Concerns)	0	4	3	7
36. University Services & Fees	3	1	5	9
37. Visibility And Dependency	4	1	2	7
Total	144	191	149	484

The initial coding was further refined into second-level coding using the phases of organizational resilience and other factors related to extensions of the model. This analysis (presented in Figure 2) resulted in the categorical constructs to enhance the study of the transcribed interviews. Table 3 provides additional information on the files and references aligned with each construct.

Figure 2: Deductive Coding into Constructs

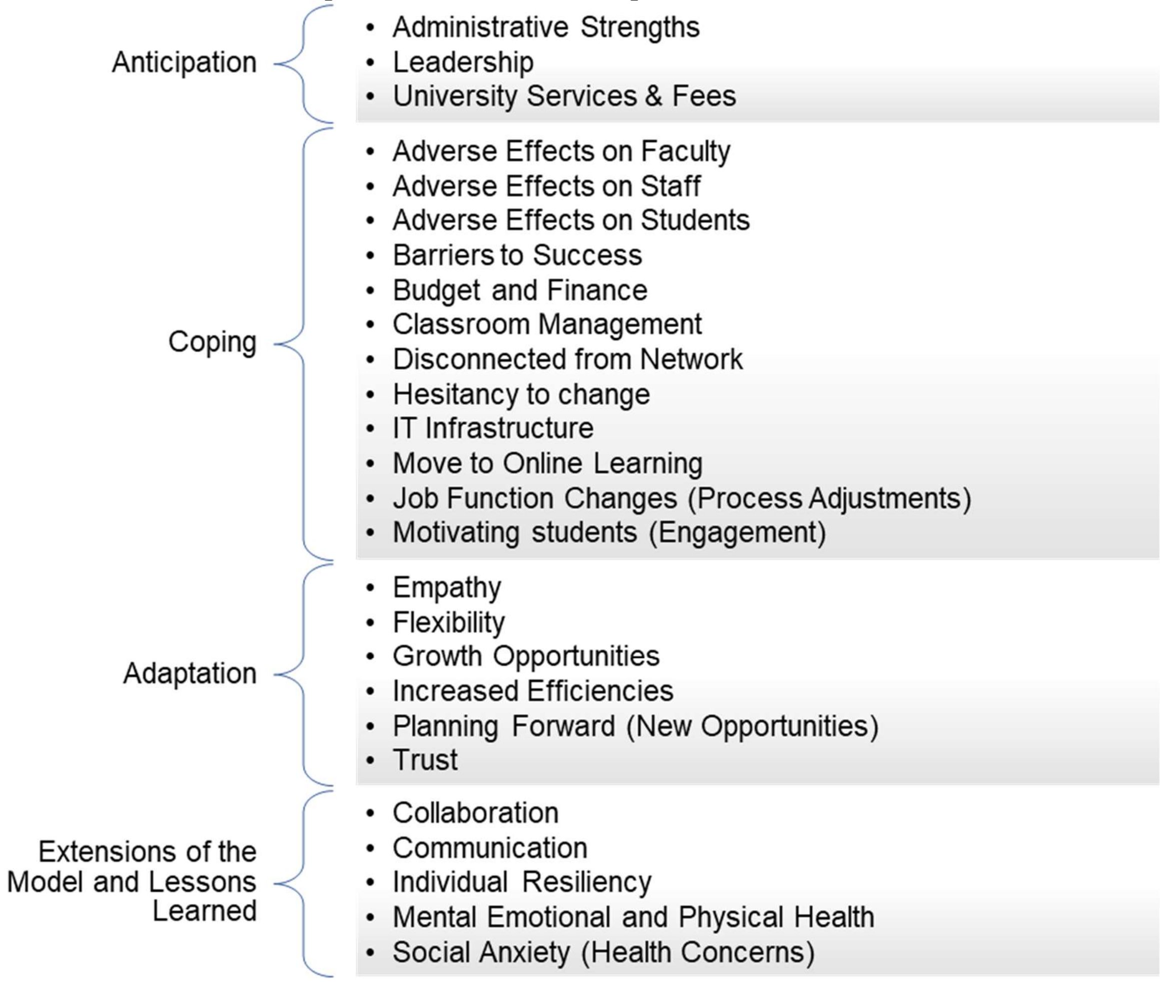


Table 3: Construct Coding Reference Matrix

NAME	FILES	REFERENCES
Anticipation	7	27
Administrative Strengths	3	7
Leadership	5	8
University Services & Fees	2	5
Coping	14	234

Adverse Effects on Faculty	8	30
Adverse Effects on Staff	3	8
Adverse Effects on Students	7	44
Barriers to Success	2	2
Budget and Finance	4	7
Classroom Management	4	7
Disconnected from Network	3	6
Hesitancy to change	5	7
IT Infrastructure	11	55
Move to Online Learning	9	36
Job Function Changes (Process Adjustments)	3	6
Motivating students (Engagement)	3	10
Adaptation	13	129
Empathy	2	3
Flexibility	2	2
Growth Opportunities	4	10
Increased Efficiencies	3	5
Planning Forward (New Opportunities)	7	19
Trust	1	1
Extensions of the Model and Lessons Learned	12	95
Collaboration	4	16
Communication	10	31
Individual Resiliency	3	3
Mental Emotional and Physical Health	8	27
Social Anxiety (Health Concerns)	4	7

Overall, Anticipation had the least amount of references, Coping had the most, and Adaptation was between the two other phases. The quotes referenced speak to the theoretical model framework and additional findings from our data analysis gathered from interviews. Table 4 provides a synopsis of the responses. Excerpts are summarized related to each interviewee's perspective and what they, and thus their organizations, experienced as they moved through each phase of organizational resilience.

Table 4: Interview Quote Synopsis by Category			
NAME	ADMINISTRATORS	FACULTY	STUDENTS
Anticipation	The consensus was that the time to prepare was minimal. However, the preparation period was less hectic due to the upper administration's fast response and decision-making. Constant communication was vital to the preparation period.	The preparation period was approximately two weeks. There was a quick turnaround on the workshops provided to assist faculty. Best practices were not available due to the nature of the disruption. Communication was essential and effective.	Communication was not as effective. Students felt that leadership seemed to waiver and linger in making decisions, making it challenging to prepare. Uncertainty loomed as to what to do for classes and where to live. Students did not feel they had any time to prepare
Coping	Changes were needed to the infrastructure and technology to meet the needs of university constituents better. IT was considered an undervalued department until the disruption hit. Most adjustments were made to work from home and still maintain productivity. Most comments were around communication and technology needs.	The stress of moving to online learning was a significant factor. Some faculty opted for early retirement. Collegiality among faculty was strengthened, as support was needed to implement best practices for teaching online. Concern was raised regarding student engagement and how to motivate them online. More training on these topics would have been helpful in the transition.	Coping is a continual process and will be ongoing for students. A sense of feeling disconnected and unmotivated was heavy. The adverse effect of moving online made some feel isolated. The move was seen as a barrier to success. Access to faculty was lacking, and students did not feel they could get the support they needed. A majority of the communication that was provided did not help support the needs of the students.
Adaptation	Administrators felt that a majority of the tools needed were in place to move forward. Again, the focus was on communication, infrastructure, and technology needs. There is a sense of being well adjusted to the new normal. Moving forward, a hybrid model for	Faculty learned to be more flexible with students and empathized with the current situation. Most are well adjusted to the new normal. However, there is a sense that things need to go back to the pre-covid setup. Comments were made that the online learning environment is not	Empathy and flexibility are vital factors needed to adjust to the new normal. Opportunities to grow in the new environment did not seem clear to students. Attending school was a backup plan for some graduate students who did not feel prepared to face the covid job market or found limited

	working and learning would be ideal. Remote work could also be used as a recruitment tool to attract top faculty and staff to the institution.	conducive to engaging students and ensuring that information is synthesized.	opportunities. As with faculty, a longing for the pre-covid learning environment was expressed.
Extensions of the Model and Lessons Learned	Collaboration across departments was a critical success factor. The decision-making structure was horizontal, which made it more efficient to implement new ideas, activities, and initiatives.	The need to be more flexible with classroom management was a component expressed. Additional training on how to support students emotionally would also be best. Individual resiliency is an additional factor within the organization that could be strengthened.	Additional focus was placed on mental and emotional health needs for continued success. Concerns of social anxiety still loom as students adjust back to face-to-face learning. The need for more collaboration between students and faculty would be ideal moving forward.

DISCUSSION

The organizational resilience conceptual model developed by Duchek provided a framework by which more insight could be gained by examining underlying mechanisms that foster the development of organizational resilience (Duchek, 2020). In conducting the research, these mechanisms were explored through interview analyses to investigate how organizations respond to developments in their environments and how they prepared for unexpected events, accepted problems, and learned from them. Additionally, insight was provided into the determinants of the resilience process. In an examination of the three phases, the following was concluded.

Anticipation

The ability to anticipate events allows an entity to recognize when disruptive events might be forming and start any preparations that might be needed should the event materialize and be realized by the entity.

As within the initial industry of study identified by Duchek, the three phases have some levels of distinction (Duchek, 2020). However, there is much overlap that could be determined by interpretation. In our study and during the COVID-19 pandemic, the overlap was more evident between higher education's Anticipation and Coping phases. Most participants agreed that there was little time for the Anticipation phase. Institutions had little time to see the pandemic coming and brace for its impact. One administrator stated that "…it was less so planning and more so reacting. We call it how we reacted versus how we planned." Due to the state of the entire country not reacting in ways that prompted preparation for the impact of COVID-19, almost all sectors were unprepared for its impact. Another faculty member offered that, at their institution, when the virus was officially recognized in the United States, "…everybody was scrambling at that point, every college university scrambling… So, I can't say that, you know, everything was well defined at that point, but I think we were as engaged in it early as any university…" Further, data indicated that the organizations spent only about two weeks in this phase.

Some key determinants that assisted in success in the Anticipation phase were the existing structure of administrations and consistency and strength of leadership, which supported swift and necessary decision-making. One of the school's presidents "…recognized earlier than a lot of presidents what this was, and so from the beginning, he formed a COVID Task Force". Further, a faculty member offered that there "…was like a chain of command. So, it came down from, you know, a top university-level Board of Governors or whatever to, to the University, and then from the university level, and then trickle down to the school…and the systematic distribution of instructions."

However, due to the transient nature of this phase, there was not adequate time to foresee the pandemic and plan for it as best as possible to utilize resources and institutional capabilities optimally. This was a consistent sentiment across all case classifications. For instance, per Administrators, most planning took place in the Coping phase.

On the other hand, students have substantially no actions associated with organizational planning in the Anticipation or Coping phase.

Anticipating an event also calls for an organization to be already structured in ways that allow it to instinctively react to an unanticipated event and make quick decisions once the event makes an impact. One of the institutions noted that because of systems already in place and "the collaboration across divisions, the low formality, and minimization of bureaucracy to a large degree," they were able to make decisions more quickly in reacting to the effects of the pandemic. In effect, institutions may not always have time to get ready, so, in turn, they need to stay ready and nimble enough to respond to unanticipated events.

As it relates to extending Duchek's organizational resilience model, expanding the definition of Anticipation would allow for additional factors to be considered. One factor could be organizations bolstering their intra-organizational communication. In this phase, where observation and preparation are vital capabilities, robust methods of clear communications would allow for quick dissemination of decisions made as an entity prepares for the possible realization of disruptive events and would assist in gaining trust and buy-in for the implementation of organizational responses to such events among stakeholders.

Coping

A primary component of Coping is accepting the reality that something out of the ordinary has occurred. Further, this phase calls for crafting and implementing solutions to address unexpected events. Given the nature of the pandemic and such a short lead time in preparing for it, the Coping phase was more pronounced within the higher education sector. Coping became an essential factor during the pandemic, and individuals had little space to resist change or maintain the status quo. Per one faculty member, "…we did lose; I'm pretty sure that the pandemic caused us to lose faculty to early retirement. I feel like that, you know, if it weren't for the pandemic, that faculty member would not have retired." Those hesitant to change tended to exit the industry, as indicated by some faculty who chose to retire rather than adjust to new modalities of delivering classes to students. At an organizational level, entities that fail to quickly recognize and respond to an event that disturbs normal operations reap these and other consequences of not doing so.

Given the short window to prepare for the onset of the pandemic in the US, most activities at the outset occurred in the Coping phase. Further, the development of solutions and implementation processes was accelerated because the pandemic reached the US during the Spring semester. Information technology changes moved quickly. One IT administrator felt that "(p)ost COVID…was mayhem, especially in those first few months, everyone needed support… You're trying to help people get their PCs together to take home, setting people up on a VPN access, so the responsibility grew, and the demand grew enormously." Job function and infrastructure support were the primary foci of administrators. Faculty leaned heavily into ramping up their professional development in efforts to support the transition to a fully online learning environment, for instance. Professors needed to swiftly learn new modalities and teaching platforms as their organizations put measures to continue their mission of delivering quality education to students. "…(W)e have about like 50 courses, maybe like, two, three courses out of those 50 were offered online before COVID. Okay, and so then we went from offering about three online courses to…online offerings (of) 100%, which is probably something that wasn't imaginable before the pandemic." These actions required additional support and training above and beyond what was provided to faculty pre-pandemic. "And so, you know, not being accustomed to using a learning management system, not being accustomed to using zoom, you know…those were things that, that were hindrances that could have made the process smoother because we did get …complaints from parents and students around the classes." Some faculty struggled with the need to transition learning online. This difficulty affected the quality of their instruction, and students' learning. "(W)e had to deal with professors not being tech-savvy. So, a lot of their class time was devoted to learning the technology."

Students struggled as well in this new learning atmosphere suddenly thrust upon them. Institutional responses required that "…students would now have to be more so independent than ever". Another student felt that they "…had to put (them)selves in a headspace of like, this is no longer you know, in-person school…and it's going to be a challenge…we just kind of had to get in that mindset and just go from in-person to all online, and it was just kind of like, is a real challenge". Another student shared that "…this is a pandemic. So, to learn during a pandemic, when we've been conditioned for 12 plus years to (an) environment to where the teachers and the desk and we're in this chair, you know, it's hard to adjust to that."

But, albeit imperfect, changes were necessary for all as the institutions moved to swift action to address events beyond their control and in ways that allowed them to continue providing learning environments for their students, support for their instructors, and with everyone's safety in mind.

With their initial changes and responses in play now, the institutions then realized that the pandemic would be with us for longer than most had expected.

Adaptation

The abilities of an organization to reflect, learn and then use those lessons toward change in ways that would better prepare organizations for future disruptive events. These factors are all at the heart of Adaptation.

Adaptation is an ongoing process that involves deep contemplation. When asked, "if you were in charge, what would you do differently moving forward or what would you continue to do moving forward," many participants agreed that change was needed. Institutions that decide to go back to how things were instead of adapting to a “new normal” will see challenges in growth and maybe even student retention moving forward. Organizations learned as they made necessary changes to maintain operations during the pandemic that “people are capable of making changes even on short notice….” And that “…people tend to resist change, not people, organizations, and also if change is necessary, it often takes a long time for people to buy in and to make a change or to adapt to change. But this pandemic obviously provides evidence that this is not always the case….” The most significant change for most higher education institutions was the work involved and the effects of shifting to fully online learning. According to one faculty member, a major lesson for this sector is that “the pandemic proved was that we can get the job done in a remote work environment.” In order words, even institutions, which are traditionally known as slow to change and/or evolve, can do so and do so quickly.

Opportunities for growth and increased efficiencies were also among the determinants for successful Adaptation. A recurring theme in all interviews was the need for entities to improve communication. For instance, an Administrator foresees the need for “…better communication…I see a streamlined, more streamlined process. I see it as using technology to its fullest capacity…” and “…new programs and software coming on, after this stuff in our efficiency, effectiveness, and it’s all because of the pandemic.”

Interestingly, the need for empathy, understanding, and compassion as everyone dealt with major operational changes surfaced in the data; specifically, the need for all to be empathetic with each other as everyone adjusted to major shifts in their normality, both in their academic as well as personal lives. A faculty member noted that “…you have to provide empathy, you have to understand people’s feelings.”

Extensions and Lessons Learned

Our analysis revealed a few unexpected factors in addition to those captured by Duchek’s conceptual model’s definition of the three phases of organizational resilience. This speaks to the need to consider broadening the model’s scope to be more applicable and generalizable across industries. The additional elements incorporate a human capital aspect that supports organizational resilience in that an organization’s resilience is lived out and/or manifested by human actors. These additional factors include collaboration, communication, and mental, emotional, and physical health.

Communication was vital in ensuring everyone had updated information to support continued operations. Some experienced new ways of working in which they could no longer work in siloes. “(The pandemic) forced me to open up communication with my staff as to what I did like there is no more me working in my own bubble because I learned quickly during the pandemic that me working in my bubble and me working at home now meant that everything was now on me…”…the communication level that we had in the office was totally different from the communication levels that we had, that we had to have working from home remotely right…so, I’m learning how to communicate better without fear of being physically present….” Further, the ability to collaborate and make decisions quickly was a factor in the success of institutions’ plans and responses. “…we were having daily briefings there which would kick out its initiatives from that…we have a very, very collaborative culture that has evolved over time that is able to act without a lot of bureaucracy and fanfare, get things done….” “So fast-paced decision-making collaborative environment in a good synchronization of priorities across all of our divisions, I think were key things… assets that we had that helped us get through the pandemic, maybe not as problematic as if we did not have those as assets….”

As a principal constituent in the organization, students' mental and emotional health should be strongly considered while developing and implementing solutions. We suggest that organizational resources should be expanded to address psychological support. Feeling disconnected and isolated adversely affected students' ability to cope and succeed in courses and respective programs. One student noted that they "…became very dependent on people … very emotionally dependent on people." It was stated, "Making more of kind of support around mental health for students who may not be able to reach out to others, they might not have that support group. Building a support group around that would be very beneficial to several students and even faculty as well." This finding is in line with Shaya et al.'s theme of the need for empathetic leadership in times of crisis to support staff as they process and move through the different stages of organizational resilience. (2022)

We propose incorporating these additional factors into the 3 phases as a human resource capability. This would expand Duchek's model and link across all phases.

Organizational resilience is a multi-level concept, and resilience across levels, including individuals, groups, and organizations, depends on the interactions among the different levels. The additional determinants are critical factors for how individuals within an organization can prepare for unexpected events, accept, and manage difficult periods of adjustments and responses to these events, and learn from them in ways that bolster their and, in turn, organizations' resilience.

Overall, the model developed by Duchek helps organizations move through disruptive events. Adding additional extensions to the original definition will make the model more generalizable and more adequately cover business, higher education, and other sectors.

CONCLUSION

In building a resilient organization, it is smart to utilize the experiences and lessons from disruptions as an advantage. Extensions to Duchek's model could encourage a more robust process for organizations to build their resiliency. Further, individual resilience also plays a major role in the success of an organization. Resilient individuals as part of the whole organizational system are integral factors as organizations develop their resilience capacity. Personal characteristics such as confidence, optimism, faith, and belonging contribute to individual resilience (Xiao & Cao, 2017). A combination of psychological factors and accountability are critical for the organizational level, along with adaptive structures, flexibility, social/human capital, and speed and efficiency of decision-making and responses. In essence, as we continue to learn from our failures, we will grow stronger. This is a lesson that can be applied to any person or profession.

This paper contributes to theory by applying Duchek's organizational resilience model in the higher education industry. Practitioner implications include: 1) the need for organizations to consider the budget for and implementation of investments and enhancements of information technology infrastructures in order to have the flexibility to smoothly transition its operations in light of disruptive events, 2) mechanisms for cross-collaboration in order to support quick decision-making and implementation of those decisions, 3,,) flexibility at all levels of the organization, 4) clear, strong organizational-wide communications, and, 5) planning for and attention to addressing the overall health of individuals, particularly as it relates to mental health.

Limitations and Further Research Opportunities

The study was designed as an exploratory case study to focus Duchek's organizational resilience model on the field of higher education. A limitation to this study is that it focused on public universities only and on an event that affected the entire world and possibly will never occur again. Future studies could expand this research to private educational institutions and apply the conceptual model to other types of disruptive events. Future studies could also extend this research and examine the capabilities of resource availability, social resources, and power and responsibility (see conceptual model) for this same sector, higher education, and how these elements affect each stage of the organizational resilience model as higher education institutions move through each phase.

APPENDIX

Interview/Survey Questions

The following semi-structured questions were used to guide the interviews. All questions may not be used depending on the interviewee's responses and/or background. Appropriate follow-up questions will be used as needed depending on the interviewee's responses. All follow-up questions will be along the same scope of questioning listed in this document.

Department/Unit-Level Questions

1. Can you state your organization's name and role at the institution?
2. What is your unit responsible for?
3. What is your current position, and how long have you worked in this position?
4. How long have you been affiliated with the institution?
5. How did you/your unit prepare for COVID-19 "hitting" the US? What were the specific actions that you/your unit took?
6. Once COVID-19 hit, how did you/your unit manage this disruptive event? What were the specific actions that you/your unit took?
7. What factors played a crucial role in your institution's preparations for COVID-19?
8. Anything else you could add as it relates to how you/your unit operated pre-COVID-19 as opposed to post-COVID-19?
9. How did you/your unit adapt over time to COVID-19?
10. What factors played a pivotal role to "normalize" operations post the initial reactions to COVID-19?
11. What specific actions and/or lessons did you learn, and will you or your unit take forward?
12. How do you think those actions/lessons might better prepare you/your unit for future disruptive events?
13. Regarding your institution's actions taken in response to COVID-19, is there anything you would or would not do again?
14. What do you think a "new normal" might look like for you/your unit/your institution?
15. Is there anything else you would like to add overall?

Faculty Questions (Business School)

1. Can you state your organization's name and role at the institution?
2. What is your current position, and how long have you worked in this position?

3. How long have you worked at the institution?
4. How did you prepare for COVID-19 "hitting" the US? What were the specific actions that your unit took?
5. Once COVID-19 hit, how did you manage this disruptive event? What were the specific actions that you took?
6. What factors played a crucial role in your institution's preparations for COVID-19?
7. Anything else you could add as it relates to how you operated pre-COVID-19 as opposed to post-COVID-19?
8. How did you adapt over time to COVID-19?
9. What factors played a pivotal role to "normalize" your work post the initial reactions to COVID-19?
10. What specific actions and/or lessons did you learn, and will you take forward?
11. How do you think those actions/lessons might better prepare you for future disruptive events?
12. Regarding your institution's actions taken in response to COVID-19, is there anything you would or would not do again?
13. What do you think a "new normal" might look like for you/your department/your institution?
14. Is there anything else you would like to add overall?

Student Questions (for both undergraduate and graduate business school students)

1. Can you state the name of your institution?
2. What year are you in your program of study?
3. Once COVID-19 hit, how did you manage this disruptive event? What were the specific actions you had to take?
4. What changed at your institution due to how you attended school pre- and post-COVID-19?
5. How did you adapt over time to COVID-19?
6. How did your school adapt over time to COVID-19?
7. What factors played a pivotal role in school "normalizing" for you post the initial reactions to COVID-19?
8. What specific actions and/or lessons did you learn, and will you take forward?
9. How do you think those actions/lessons might better prepare you for future disruptive events?
10. How do you think those actions/lessons might better prepare your institution for future disruptive events?
11. Regarding your actions taken in response to COVID-19, is there anything you would or would not do again?
12. Regarding your institution's actions in response to COVID-19, is there anything you think should or should not be done again?
13. What might a "new normal" look like for your institution?
14. Is there anything else you would like to add overall?

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DECISION SCIENCES INSTITUTE
Predicting Missed Appointments in Healthcare Using Machine Learning

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ABSTRACT

This study uses a healthcare facility medical appointment dataset with approximately 110k records. By using machine learning (ML) methods, the goal is to build models that can predict patient no-shows, while also determining the essential predictors. Lead time (days between schedule and the appointment) and age were found to be the most important variables. The data is imbalanced with 20% of appointments being missed, causing the models to favor the larger class. Oversampling has significantly improved the predictive performance. AUC score of ~0.70 suggests the viability of ML in identifying appointments that have a high chance of being missed.

KEYWORDS: Patient no-show, Missed appointment, Machine learning, Predictive modeling, Oversampling

INTRODUCTION

A no-show is someone who misses an appointment without calling 24 hours in advance to cancel. Patient no-shows are a huge constraint on healthcare organizations. No-shows can lead to higher healthcare costs since overall supply and demand are not being met. In underserved populations high missed appointment rates are a barrier to those seeking or needing medical care. The appointment slot that goes by unfilled means a missed opportunity for another patient and decreases efficiency in the health care system. No-shows can lead to higher healthcare costs since overall supply and demand is not being met. Many organizations look for ways to improve their overall effectiveness and limit no-shows. In a recent study it was estimated that 67,000 no-shows can cost the healthcare system approximately 7 million dollars (Marbouh et al., 2020). In the US, appointment no-shows can cost the healthcare industry around $150B (billion) each year – as measured in 2013 (Toland, 2013). In underserved populations, high missed appointment rates are more problematic since they are a barrier to those seeking or needing medical care (Mohammadi, Wu, Turkcan, Toscos, & Doebbeling, 2018).

To overcome no-show costs some industries such as the airline industry oversell their seats. However, just overbooking flights or appointments is not always the best customer service strategy either. If they overbook too many seats or appointments, they may not be able to deliver on the service. Being able to predict no-shows could allow offices and hospitals to book extra appointments when applicable without over-promising services they are unable to fulfill.

The dataset used in this study comes from Brazil. Brazil is still a developing country, and the distribution of wealth is highly skewed. About 10% of the population lives below poverty (Roosa Tikkanen, 2020). The healthcare system in Brazil is a public health system and is managed and provided by all levels of government. Public health services are offered to all citizens for free; however nearly 25% of citizens "have private health insurance which circumvent bottlenecks in accessing care" (Roosa Tikkanen, 2020). Missed appointments become even more of an issue in a place like Brazil or other underserved communities where heavy bottlenecks are a deterrent when seeking care or treatment. Thus, being able to predict missed appointments and being able to fill more appointment times mean more people are getting the help they need faster. The goal of this study is to analyze and visualize the data followed by applying machine learning classifiers that can predict appointment no-shows. The features that help reach this goal will also be identified.

The paper will follow with a literature survey, explanation of the dataset, machine learning models and discussion of results, and end with the conclusion sections.

LITERATURE REVIEW

Research has shown that lowering missed appointment rates can improve the clinical efficiency and lead to better health outcomes for the patients among other things (Mohammadi et al., 2018). No-show rates or missed appointment rates range from 10% to 50% across healthcare settings in the world with an average rate of 27% in North America (Mohammadi et al., 2018). In order to better assess these rates, many studies try and understand why the patients do not show up. When addiction, drug abuse or mental health is the treatment there are definite behavioral traits that lead to high no-show rates such as fear or lack of desire. One study focused on “evidence-based behavioral engagement strategies to make patients want to attend their appointments (Molfenter, 2013). Studies have shown that the more welcoming the environment, the lower the no-show rates are. In underserved and underinsured populations, high missed appointment rates are one of the most significant barriers to access care for these populations (Mohammadi et al., 2018). Being able to identify the reasons behind no-shows can help improve the overall rate. Depending on the population being served, there may be specific predictors that differ from other populations.

Other studies have struggled on how to represent patient attendance history. Should it be a rate, or should it be the number of previous no-shows? Should it be only recent attendance history or attendance history over time? The rate of successful appointments could also be an indicator. One study decided that “the patient appointment history variable is the observed proportion of times that a patient will miss the next appointment, based on the sequence of prior attendance (Goffman et al., 2017). Various models have also been used to predict no-show outcomes. Some models that have been tested are logistic regression, multilayer perceptron (neural networks), naïve Bayes classifier and XGBoost (Mohammadi et al., 2018).

THE DATASET

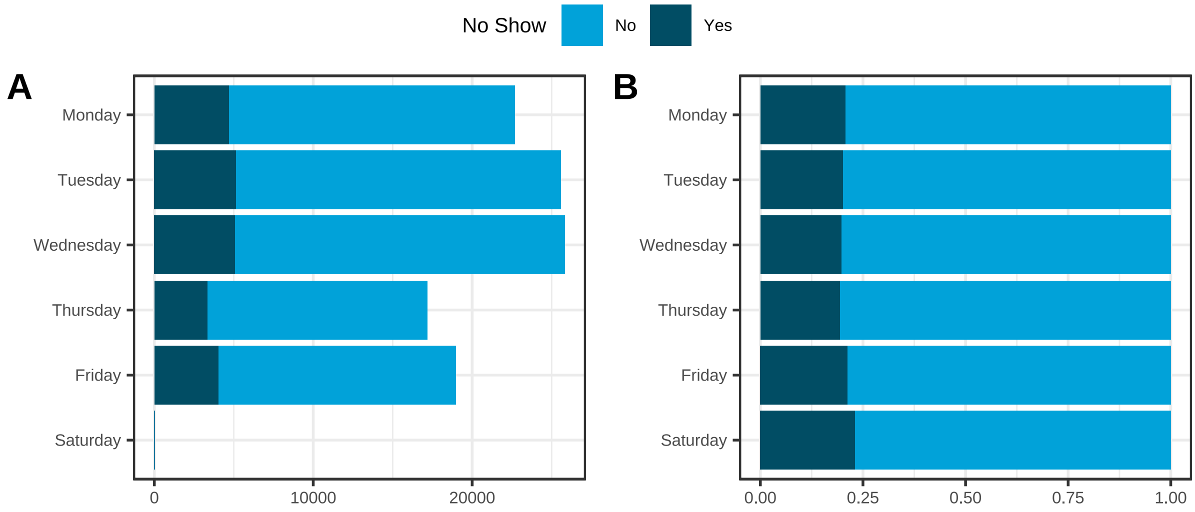
The dataset is obtained from Kaggle (Hoppen, 2016). It contains medical appointments data obtained in Brazil in April through June of 2016. 110,527 medical appointments and its 14 associated variables (characteristics) are present in the data. In this section, both the features in the data and the cleaning/preparation of these features will be explained. The “no_show” variable, which is our outcome variable, shows whether the patient did not go to their appointment (Yes or 1), or whether they went to their appointment (No or 0).

Weekdays

The appointments were mostly held during the weekdays. As can be seen in Figure 1.A, the number of appointments on Saturday is very low and was only held on a single Saturday, on

May 14th, 2016, to be exact. Also, only a few locations provided appointments on Saturday. Saturday also exhibits a larger no-show rate, as can be seen in Figure 1.B. Since we do not have more data throughout the year, this Saturday will be discarded from the analysis to prevent any bias.

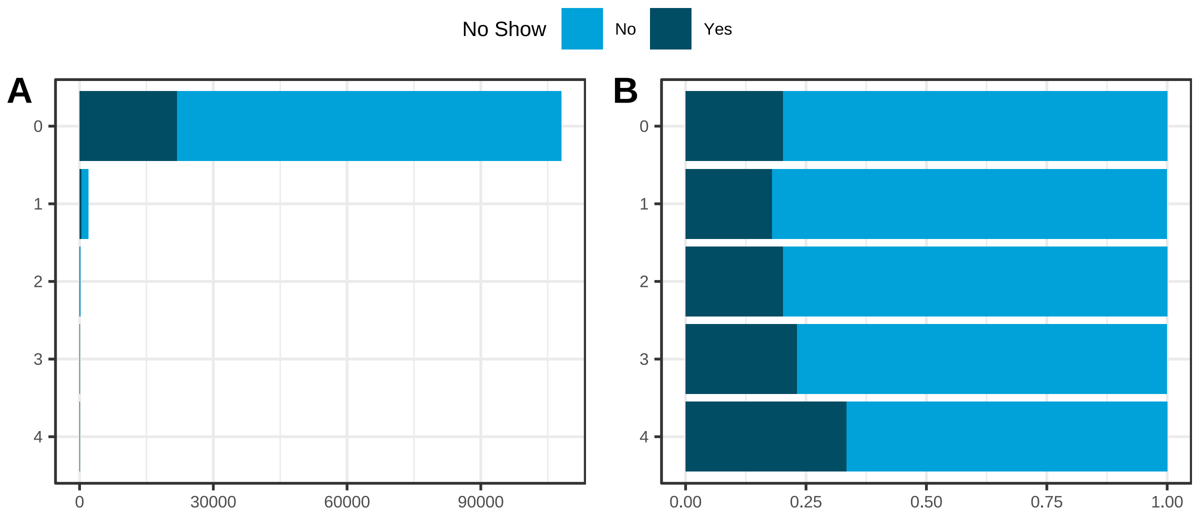
Figure 1: A) Number of appointments each day.
B) Appointment no-show rate. Saturday shows a slightly larger no-show rate



Disability

Disability variable has 5 distinct values, where 0 means no disability, and the values of 1, 2, 3, and 4 represent different types of disabilities. As can be seen in Figure 2.A, there are very few values for types 1, 2, 3, and 4. These values will be all converted to 1. This way, the disability column will represent the presence or absence of disability.

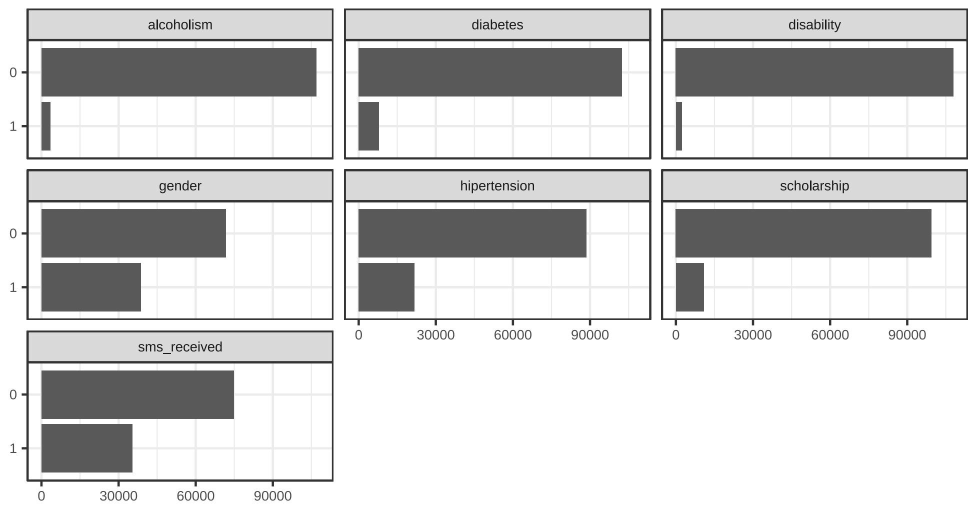
Figure 2: Disability types and the number of counts colored by showing up at the appointment



Categorical Features

The categorical variables in the data and the number of unique values are shown in Figure 3. 0 stands for Female, and 1 stands for Male in the Gender bar plot. In the other bar plots for “disability”, “hypertension”, “diabetes”, “alcoholism”, “scholarship”, and “sms_received” 0 means not present, and 1 means present. Scholarship is defined as some sort of support given to low-income people in Brazil. SMS received signifies whether a reminder was sent to the patient before the appointment or not.

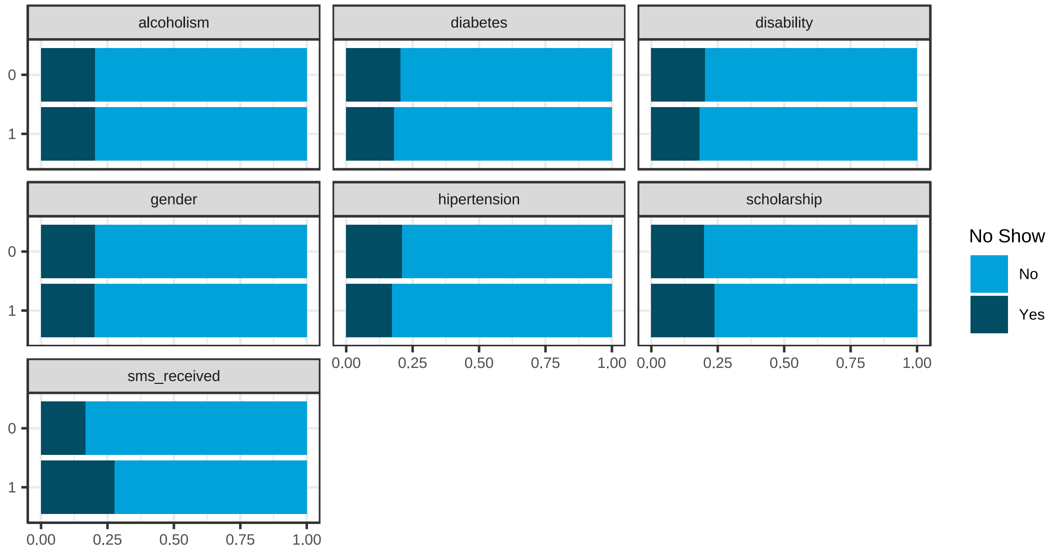
Figure 3: Categorical variables in the data and their corresponding number of entries



The proportion of “no-show” ratios are shown in Figure 4. There isn’t much noticeable difference between the values of the variables. However, it is interesting to see that those who received an SMS have higher rate of not showing up. This result contradicts the intervention proposed by

Goffman et al. (Goffman et al., 2017) where they place reminder calls 24, 48, and 72 hours ahead of the appointment which led to a reduction in missed appointments.

Figure 4: Categorical variables and their "no-show" ratios



Neighborhoods

There are 81 unique neighborhoods in the data. Neighborhood means the place where the hospital is located and not where the patient lives. Vitória is a capital city and receives dozens of patients from other cities (Hoppen, 2016). Some of these neighbors have very few entries. Locations with 100 or a smaller number of entries in the data have been discarded to have a more generalizable model, leaving 74 neighborhoods in the data. Because neighborhood is a categorical variable, the locations will be encoded into dummy variables. However, if one-hot-encoding is used we will need 73 new columns (we will drop the original neighborhood column after transformation). This is an issue high cardinality. Having so many variables will just create more noise, and lead to the "curse of dimensionality". Thus, the remaining 74 unique locations have been binary encoded into 7 columns. In binary encoding we only need k new columns, such that $2^k >= m$, where k corresponds to the new number of columns and m represents the number of unique values in the original variable.

Schedule and Appointment Dates

The data contains schedule and appointment date columns. The time between these two which will be referred to as "lead time" has some potential in terms of distinguishing between appointment show or no-shows. There are more than 40,000 appointments that are set the same day as the appointment, and thus have a value of zero day lead time. Figure 5.A shows the histogram of lead time in days in which all lead times are included. When the lead time is lower, the density of showing up at the appointments are higher. To get a clearer picture, 0 day lead times have been removed and Figure 5.B is obtained. Here we can see that if the lead time is less than 10 days, the density of showing up is higher. Overall, as the number of days between schedule and appointment increases the propensity of not showing up increases. Because of the very long right skew the plots are cut off at 50 days.

Age

As can be seen in Figure 6.A, younger people seem to have higher no-show rate. In Figure 6.B we can see the interaction between age and lead time. The heatmap of lead time vs age is created by binning both variables so as to create discrete values. Each tile shows a combination of lead time and age. Each tile shows the average no-show rate at the current lead time and age values. Here, no-show rate seems to be higher when lead time is longer, and higher when patients are younger.

Figure 5: A) Include all data B) Exclude 0 days (same day appointment) lead time. Plots are cut off at 50 days. Dashed lines show median values.

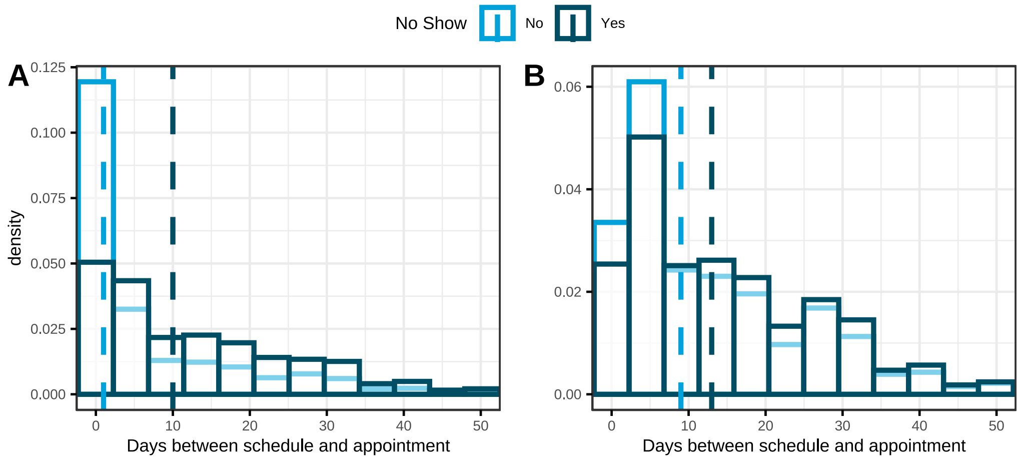
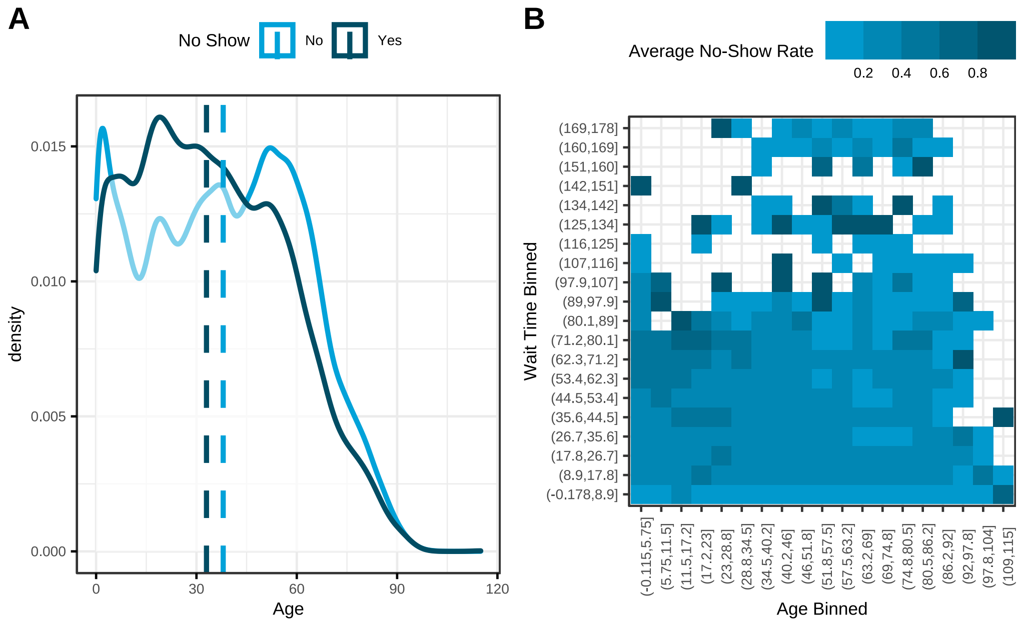


Figure 6: A) Distribution of age. Dashed lines show the median values.
B) Heatmap of lead time vs age. Both variables are binned. Each tile show the average no-show rate at the current lead time and age values.



MACHINE LEARNING MODELS AND RESULTS

Several machine learning classifiers are used to predict no-shows from given data. 10-fold cross validation has been used to train and test the models. The label to be predicted via classification is: 'no-show'. The categorical input variables are: 'gender', 'scholarship', 'hipertension', 'diabetes', 'alcoholism', 'disability', 'sms_received', 'n_1', 'n_2', 'n_3', 'n_4', 'n_5', 'n_6', 'n_7'. Here the variables starting with “n” are the binary encoded neighborhood values. 'days_between' and 'age' are the only real numeric variables. These two numeric values were in the range of 0 – 150 so they are divided by 100 to bring them to the same scale as others.

One challenge here is the class imbalance. Nearly 80% of the data are from “No” no-show class, and only 20% are from “Yes” no-show class. Thus any algorithm will tend to classify “no” more, because simply doing this has higher chance of succeeding. To overcome this problem SMOTE oversampling method is used. This method synthetically creates new data points in the smaller class, thus increasing its presence. The purpose of oversampling is to help the algorithm learn better during training, such that the generalization performance will be better during testing.

The results of the methods using the original data and the oversampled data are shown in Table 1 and Table 2, respectively. The performance metrics abbreviations and their full names are shown in Table 3. The explanations for these metrics can be found on the documentation web-page of scikit-learn (Scikit-learn). We can see that decision tree-based ensemble models performed in general better than the others. We can see a significant improvement when oversampling is used, especially in the recall scores. Recall shows the rate of correctly predicted positive class points, among all the actual positive points. So, recall is a score of how good the model is in terms of identifying the actual positive points. However, the low F1- scores and low precision values indicate the hardness of the problem.

Table 1: Model performance using original data. Models are ordered based on F1 score

Model	Acc.	AUC	Rec.	Prec.	F1	Kappa	MCC
Decision Tree Classifier	0.723	0.575	0.327	0.317	0.322	0.147	0.147
Extra Trees Classifier	0.761	0.678	0.241	0.361	0.289	0.152	0.157
Random Forest Classifier	0.775	0.704	0.200	0.386	0.264	0.146	0.157
K Neighbors Classifier	0.772	0.629	0.164	0.358	0.225	0.113	0.125
Naive Bayes	0.771	0.627	0.126	0.327	0.182	0.079	0.091
Quadratic Discriminant Analysis	0.570	0.549	0.388	0.121	0.179	0.001	0.004
Linear Discriminant Analysis	0.792	0.663	0.030	0.325	0.055	0.022	0.043
Light Gradient Boosting Machine	0.799	0.729	0.020	0.563	0.039	0.025	0.077
Logistic Regression	0.796	0.658	0.014	0.343	0.027	0.011	0.032
Ridge Classifier	0.797	0.000	0.008	0.340	0.016	0.006	0.024
Ada Boost Classifier	0.798	0.717	0.004	0.477	0.008	0.005	0.028
Gradient Boosting Classifier	0.798	0.724	0.004	0.458	0.007	0.004	0.025
SVM - Linear Kernel	0.798	0.000	0.000	0.000	0.000	0.000	0.000
Dummy Classifier	0.798	0.500	0.000	0.000	0.000	0.000	0.000

Table 2: Model performance using oversampled data. Models are ordered based on F1 score

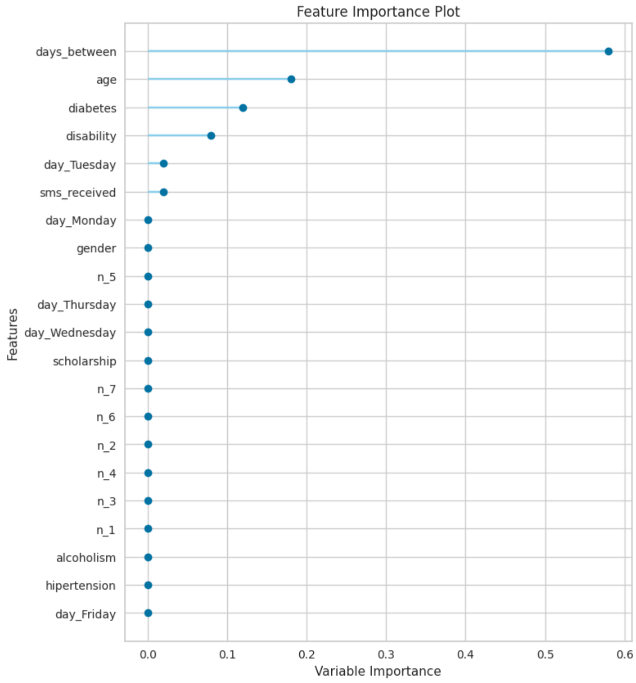
Model	Acc.	AUC	Rec.	Prec.	F1	Kappa	MCC
Ada Boost Classifier	0.623	0.710	0.724	0.313	0.437	0.216	0.259
Gradient Boosting Classifier	0.679	0.713	0.590	0.334	0.426	0.227	0.244
Logistic Regression	0.665	0.661	0.562	0.316	0.405	0.196	0.212
Linear Discriminant Analysis	0.665	0.658	0.560	0.315	0.403	0.195	0.210
Ridge Classifier	0.665	0.000	0.560	0.315	0.403	0.195	0.210
SVM - Linear Kernel	0.647	0.000	0.568	0.302	0.394	0.176	0.194
K Neighbors Classifier	0.666	0.633	0.479	0.298	0.367	0.157	0.165
Random Forest Classifier	0.735	0.706	0.376	0.355	0.365	0.198	0.198
Extra Trees Classifier	0.732	0.686	0.364	0.345	0.354	0.185	0.185
Naive Bayes	0.412	0.622	0.784	0.226	0.350	0.053	0.089
Decision Tree Classifier	0.717	0.578	0.345	0.317	0.330	0.152	0.152
Light Gradient Boosting Machine	0.774	0.718	0.221	0.396	0.283	0.162	0.172
Quadratic Discriminant Analysis	0.458	0.543	0.624	0.207	0.268	0.026	0.038
Dummy Classifier	0.798	0.500	0.000	0.000	0.000	0.000	0.000

Table 3: Performance metrics abbreviations and their full names

Abbreviation	Full Name
Acc.	Accuracy
AUC	Area Under the Curve
Rec.	Recall (Sensitivity)
Prec.	Precision
F1	F1-Score
Kappa	Cohen’s Kappa Statistic
MCC	Matthews Correlation Coefficient

A feature importance graph is given in Figure 7. The "n_#" variables are the binary encoded location variables. Lead time (days_between) and age have been found most important in many of the models tested. Importance is defined as how useful the variable is in terms of distinguishing between the two classes. This is determined based on several factors such as how many times a variable is used in the decision nodes of a tree, at what level they are used, and their contribution to decreasing impurity.

Figure 7: In many of the models lead time and age were found to be important



CONCLUSION

Accurate prediction of no-shows can be beneficial for institutions as they can adapt themselves accordingly. This will lead to great revenue, and also greater customer service. In this paper a data analytics-based approach has been taken to analyze hospital appointment no-shows on a dataset from Brazil. The visual analysis was hinting towards the importance of lead time, which is the number of days between schedule and appointment, and the age variables. Indeed, the machine learning models implemented confirmed our intuition. Because of the imbalance in the data the models predicting the "No" class more than they do the "Yes". Another interesting thing about the data is that those who received a reminder SMS had a higher rate of no-show ratio. This is unintuitive and shows that there might be many more factors at play that are not captured by the data.

By applying oversampling, a significant improvement in the recall score has been obtained across the board. The AUC of ~0.70 is very promising and shows the viability of predictive modeling in this field. However, the F1 and precision scores are not at the desired level. This shows the hardness of the problem. Some potential improvements could be to collect more features. For example, having more socio-economic, demographic, transportation features about the neighborhoods could help in the prediction. Having more info about the type of medical appointment could be helpful. Whether the patients are insured, and other cost related factors based on their visit might also be helpful. We also do not know how far the patients travel and from where they are coming from. The current dataset with the variables studied in this paper is not enough to carry a comprehensive analysis, however even with its limitations it shows that machine learning can be very useful in predicting appointment no-shows.

Such a model can help hospitals and organizations assess the risk of no-shows. By identifying appointments that are in high risk of being missed, the organizations can act accordingly such as placing phone call checks, sending emails, or sending response required SMS messages, etc. It will also allow them to accommodate last-minute or walk-in patients more easily.

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DECISION SCIENCES INSTITUTE

Public Transit Decision Support for Winter Storm Preparation

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ABSTRACT

A system to assist in the allocation of resources in response to upcoming winter storms was created for the Massachusetts Bay Transportation Authority (MBTA). The system provides detailed projections based on the myriad of weather factors that affect road and other conditions. It uses models that were created using machine learning and other analytical approaches. The system includes visualizations that guide MBTA decision makers with magnitudes and timing considerations, all presented by hour. It will be integrated with current storm planning processes, including an overall storm level determination. It was tested successfully in 2021-2022 and full implementation has begun.

KEYWORDS: Decision support, Public sector, Machine learning, Visualizations, Transportation

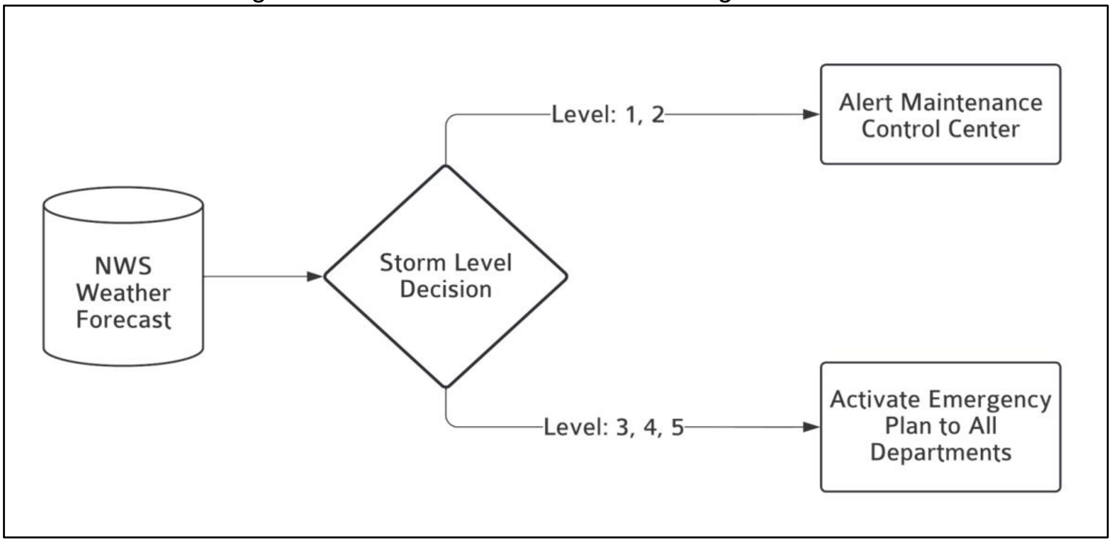
INTRODUCTION

The Massachusetts Bay Transportation Authority (MBTA), which operates the public transportation system in Boston, is typical of public transportation systems around the world. The MBTA system includes 170 bus routes, 5 subway lines spanning 65 miles of track, 13 commuter rail lines spanning 664 miles of track, and 3 ferry lines. It needs to ensure the safety of its passengers that access at MBTA vehicles at 6000 bus stops,140 commuter rail stations, and 148 above and below ground subway stations. Many passengers utilize one of its 44,000 parking spaces. Like many systems in the US, cost control is a vital concern.

New England winter storms pose a particular challenge for the MBTA. Operational effectiveness requires that its physical infrastructure be available for safe operation to protect passengers and employees, and to ensure reliable service. The MBTA has a well-documented snow and ice operations plan to support resource allocation decisions in preparation for upcoming storms.

(see Figure 1). This plan assigns each storm a severity level based on current snow accumulation and predicted upcoming snowfall.

Figure 1: Current MBTA Storm Planning Framework



Individual department managers rely on national weather service (NWS) briefings to schedule storm-related resources (i.e., MBTA labor, equipment, and materials) as well as external snow-removal contractors. These briefings contain information describing the magnitude and timing of weather details using text and meteorological weather maps. Managers make decisions that are also informed by their prior experiences in conjunction with actions planned by local municipalities. They make real time adjustments based on cameras located within their system. They are efficient when taking actions; however, better planning would utilize MBTA resources more effectively, and eliminate or reduce the occurrence of labor shortages.

In Fall 2020, the authors were contacted by City Innovate and asked to propose a modified approach for improving MBTA resource deployment during winter storms. The City Innovate Startup In Residence (STIR) Lab is an applied research group funded by the National Science Foundation. Their mission includes connecting municipalities and academic teams to co-develop and apply research that offer solutions to the critical issues faced by the communities served.

The authors' proposal was accepted by the STIR Labs and work began in January 2021. Initial results were presented at the STIR Lab Summit in May 2021, after which the authors and MBTA personnel continued working independently on the project. Besides the MBTA, other active stakeholders include the Massachusetts Department of Transportation (MassDOT), the Massachusetts Emergency Management Agency (MEMA), and the National Oceanic and Atmospheric Administration (NOAA).

OBJECTIVE

This article describes the creation of a decision support system (DSS) for winter storm planning at the MBTA. The system was designed for use by MBTA planners when winter storms are forecasted. The system would replace the complicated NWS weather briefings with more intuitive decision tools that contain more precise information on where (and when) resource allocation is most critical. Transition to the DSS needs to be integrated in current operating processes where users possess a range of technical abilities. As such, the mathematical and empirical models embedded in the DSS need to favor intuitive visualizations over mathematical complexity.

The system is being implemented carefully in a multi-step manner. First, the authors validated each model based on data collection, statistical testing, and experts' domain knowledge. Second, during the winter of 2021-2022, the authors worked closely with their primary MBTA contacts to evaluate the system's application. For each weather event, they compared the prototype system's visualizations with MBTA managers' actions as they prepared for the storm. Third, the authors are working with MBTA information system technicians to create a fully implemented pilot system for use for winter 2022-2023.

LITERATURE REVIEW

Climate change has and will continue to increase the frequency of severe weather events in Boston (Han et al, 2017), which makes managing a winter maintenance program an increasingly important and complex endeavor. Other cities have created systems to support public transportation resource allocation during winter storms and other inclement weather. Lu & Sun (2020) developed a model to support emergency resource allocation for the Nanjing (China) subway. An after-action review of a major storm in Norway motivated a revision of flooding preparedness (Steen & Morsut, 2020). Others have approached the problem by modifying infrastructure to make roads more robust to changing weather conditions (Doll et al, 2013).

Most winter storm DSS's in the US have focused on clearing snow and ice from roads and highways. The Maintenance Decision Support System (MDSS) provides real-time, hourly snow and ice control timing and locations based on rules for user-defined roadway segments (Steiner et al, 2015; Mahoney et al, 2005). Other efforts include scenario analysis using Monte Carlo simulation to generate random snow events (Li, 2019). This approach can create DSS logic based on limited weather data by generating specific weather events (Li, 2020). Similarly, a rule-based DSS has been proposed to assist managers to make the decisions for plowing and snow disposal of vehicle routing (Perrier et al, 2007). This method is also used for planning of snow removal operations in Japan (Fukuchi et al, 1996).

Researchers have created models to predict overall storm severities (Fay et al, 2020). Sturges et al (2020) provided ten methods for rating the severity of each storm. Examples include a Canadian road system management approach (Matthews et al, 2021) and an approach by Boustead et al (2015) that includes both the minimum and maximum air temperature, and snow amounts. Researchers at the Nebraska Department of Transportation developed a storm classification method that needed to account for a diverse set of road types across the state (Walker et al, 2019).

MBTA planners require a multitude of severity impacts depending on the resource being planned, including the accumulation of snow, freezing rain, ice pellets, and wind, which are known to increase road accidents and travel delays in travel time (Snyder, 2014). Related research has sought to predict the potential for slippery road surfaces more directly. Sass (1997) presented a forecasting heat-budget model for operational forecasting of road conditions in Denmark, that includes temperature, humidity, wind speed, precipitation intensity, surface pressure, cloud cover, cloud base height, and road data. Abdel-Aty et al (2011) analyzed the impact of weather and other conditions on vehicle crashes in Florida.

Density of snow determines its weight and can vary significantly. A typical Snow Water Ratio (SWR) ranges from about 5 to about 25 (Barnwell, 2017). Cox (2005) used a numerical weather prediction model to evaluate the SWR, which they use to determine the forecast snow weight (i.e., its fluffiness). Roebber et al (2003) used a neural network approach to categorize SWR in one of three classes (heavy, average, and light). Meloysund et al (2017) discovered a clear correlation between the observed climate and the measured snow density using multiple regression on weather data in Norway.

The relationship of snow weight to operational factors has been analyzed. Turcotte et al (2007) created a combined snow evolution model and hydrological model based on precipitation, temperature, and snow survey observations in southern Quebec. El Oufir et al (2021) estimated the relationship between snow weight and spectral reflectance using a hybrid snow density estimation model. Seo et al (2008) estimated snowpack temperature profiles using a linear function having the top and bottom temperature, and then used snowpack temperature to estimate the grain size evolution. Koren et al (1999) simulated the total ice content of each soil layer to estimate the infiltration reduction under frozen ground conditions using probabilistic averaging of spatially variable ice content of the soil profile. Kinar and Pomeroy (2015) use Bayesian analysis to measure snow bulk density, which they used to convert snow depth to SWR. Readers interested in additional details on modeling SWR should consult the literature review written by Sturm et al (2010).

Ice accumulation on various surfaces has also been modeled. The Automated Surface Observing System (ASOS) has become the primary surface weather observation system in the US (Sanders and Barjenbruch, 2016). Other ice-related research focuses on road surface temperatures, such as road weather information systems and thermal maps. Because these methods may be inaccurate when frequent temperature changes and coastal winds exist, Covert and Hallstrom (2014) present an alternative method by indirectly estimating road surface temperature using GIS, and by utilizing geographical and meteorological parameters. The model developed by Yang et al (2012) predicts road surface temperature using real-time weather forecasts. To predict road ice formation, Toms et al (2017) separated ice risk into three mechanisms: hoarfrost, freezing fog, and frozen precipitation.

Wind, ice, and other winter weather conditions make power outages problematic for public transportation. Under severe weather, the power outage probability will increase but the magnitude of the increase depends on the existing tree species (D’Amico et al, 2019). Hou et al (2021) developed a prediction algorithm and evaluation method with a focus on the spatial distribution of power outages using meteorological, geographical, and power grid data. Two electric distribution outage prediction models caused by snow and ice storms were developed based on the machine learning approaches random forest and Bayesian additive regression tree (Cerrai et al, 2020).

METHODOLOGY

The challenge faced by the authors was creating models that translate weather forecasts to operationally-relevant meteorological predictions. Because climatologists' research tends to model aggregate effects while meteorologists tend to focus on weather forecasting, the literature review makes it clear that model development needs must be localized to the Boston area. The models required for MBTA decision support need to be created for real time application to show severities on an hourly basis, where many impacts depend on prior conditions. That is, some of the impacts are cumulative (e.g., snow depth impacts) while others are not (e.g., wind impacts).

DSS development requires close cooperation with customers (i.e., the overseers of the system) and users of the DSS. The approach applied by the authors began by interviewing operational leadership, as well as the MBTA risk and emergency management directors. The latter group facilitated meetings with potential system users (department managers and MBTA planners) who make resource allocation decisions. These meetings were designed to educate the authors regarding the tasks required during winter storm preparation and the conditions typically associated with urgency of their deployment. The authors also attended MBTA crisis management meetings while some storms were in progress.

After reviewing relevant literature and learning about the tasks associated with operational meteorology, the authors identified sources of relevant data. The weather data were obtained from NOAA, which is the umbrella organization that includes the NWS. The input variables relevant to this work corresponded to conditions in Boston. These data are provided on an hourly basis by NOAA for both past and future timeframes. Many of these variables are correlated, such as those concerning various forms of temperatures and precipitation. Historical data can be downloaded from the NOAA website on either a daily or hourly basis. For daily values, many variables included the minimum, maximum, and average for each day listed. The input variables consisted of the following:

1. Temperature (dew point, dry bulb, wet bulb, deviation from normal, wind chill)
2. Pressure (sea level, station)
3. Wind (sustained speed, peak speed, direction)
4. Precipitation (rain, snowfall rate, snow depth, sleet)
5. Relative humidity
6. Degree days (heating, cooling)
7. Weather description code
8. Others (fog and smoke index, lightning, flooding, hurricane)

Several data sources were used to generate response variables for predicting severity levels. They included MassDOT, which provided road surface friction indices that measure the level of road traction from a highway in Boston (daily data from 2015-2021). From the City of Boston (COB), the date, time, and weather conditions associated with each vehicle collision were obtained (every collision from 2016-2021). The MBTA provided data with the date, time and details associated with bus collision (every collision from 2013-2022). In some cases, NOAA data were transformed to response variables.

The main effort focused on creating prediction models that translate NOAA weather forecasts to actionable indicators according to each crucial resource allocation decision. When applicable, published models deemed relevant to the MBTA were used. Machine learning methodologies constituted the primary analytical methods for predictive modeling. The models were validated in various ways based on the available information. A variety of visualizations were considered that would provide planners with severities and critical timing information to support their resource allocation decisions.

ANALYSIS

The MBTA operational managers provided critical information by describing their experiences with past storms. They educated the authors' regarding the responsibility of various stakeholders. Although the COB is responsible for plowing and salting streets, the MBTA needs to notify contractors who plow bus stops and park-and-ride lots. Both light and heavy snow are concerning for the MBTA. Fluffy snow can clog a train's engine intake and cause potential damage to train engines. Heavy snow requires more time and resources to plow. Some severities are known to depend on a combination of conditions, such as when rain is followed by a temperature drop resulting in slick road conditions. Table 1 summarizes the actions may be taken by MBTA planners in preparation of a winter storm.

Table 1: Storm Planning Tasks

Tasks	Resources	Description
Clear transmitters	Labor	Eliminate train AVI blockage
Clear tracks	Snow train	Remove snow from rail tracks
Treat platforms	Sand & salt	Prevent passengers from slipping
Clear air intake	Labor	Reduce fluffy snow ingestion in train engines
Move long buses	Buses & labor	Prevent articulated (i.e., long) bus accidents
Shovel bus stops	Labor	Clear entrances to buses from bus stop
Plow parking lots	Labor	Maximize parking space availability
Cut tree branches	Labor & vehicles	Reduce chances of power failures

Operational meteorologists at NOAA perform research that relates weather conditions to potential problems that affect people, traffic, and other activities. But NOAA's research usually does not address day-to-day or hour-by-hour conditions that affect entities like the MBTA. Therefore, models need to be created that are specific to the Boston region and the conditions that affect MBTA operations. In the sections that follow, three models are described that predict the severity and timing of: (1) slick roads, (2) surface & branch ice, and (3) snow density & weight. In each case, the model is described along with its means of validation.

Slick Road Modeling

When unsafe roads are anticipated, the MBTA removes its articulated (i.e., long two-section) buses from service and adjusts some routes that traverse problematic roads (e.g., hills). Three independently derived response data sets were used to create and validate the prediction model for slick (i.e., slippery) roads. They included the COB vehicle crash data, MassDOT road friction index data, and MBTA bus collision data.

The COB vehicle crash data covered 2,145 days from 2016 to 2021. It included the information about the vehicle and occupants while detailing the location, date and time of each collision. It also included the observed road condition. After experimenting with various response variables from the data set, the authors discovered that the most useful response data was obtained by classifying each day as having a slick surface or not. These experiments included the exploration of weather effects on the number of road accidents, the rate of peak hour accidents, and whether or not more than a certain threshold number of accidents occurred on a day. The road surface was listed as slick if the database indicated the road condition as icy, snow covered, or slushy. In the data set, the roads on 14% of the days were classified as slick.

Using the statsmodels module in Python, the significant variables were average dry bulb temperature (p<0.001), precipitation amount (p<0.001), and snowfall amount (p<0.001). The binary logistic regression model is shown in Equation 1, where P_S is the probability of a slick road surface, X_{ADBT} is the average dry bulb temperature (ºF), X_P is the precipitation (inches), and X_{SF} is the snowfall (inches). The accuracy of the model was 87.4%.

$$P_S = \frac{e^{-Y'}}{1+e^{-Y'}}, where\ Y' = -0.774 - 0.031X_{ADBT} + 0.81X_P + 2.95X_{SF} \quad (1)$$

This model was validated in two ways. First, a similar binary logistic regression model was created using MassDOT road friction data, where the indices were transformed into two classes (slippery or not). This analysis resulted in a model with the same significant inputs that generated predictions similar to those generated by Equation 1. Second, an analysis showed model predictions were positively correlated with the frequency of MBTA bus collisions.

Snow Depth, Density & Weight Modeling

During winter storms, the MBTA coordinates activities with the COB and other local municipalities who treat and remove snow from streets. MBTA resource managers react with a multitude of actions that require its resources and those employed by snow-removal contractors. The tasks include clearing snow from bus stops and its own facilities, and plowing park-and-ride parking lots. In addition, the MBTA operates a specially equipped “snow train” that clears snow from subway and rail tracks. All these actions require more time and resources when snow is heavy (i.e., a low SWR). Because fluffy snow (i.e., a high SWR) can be ingested into train engines, preventive action is needed to cover vents when fluffy snow is anticipated.

A variety of models were hypothesized for modeling SWR. They need to differ from published models because of the unique Boston weather conditions. For example, many snowstorms originate from the North Atlantic Ocean; they are commonly referred as nor’easter storms. An analysis of COB weather data indicated a correlation between the wind direction and humidity. This weather phenomenon brings more variation in humidity levels than other locations.

All of the hypothesized models used response data derived from NOAA for Boston from 2000 to 2021. The SWR was calculated as the ratio of the snow fall amount and the equivalent precipitation volume, only for days during which snow occurred. For these data, the 5-number summary for SWR was: 4 (minimum), 10 (Q_1), 12 (Median), 20 (Q_3) and 25 (maximum). This variable is useful but imperfect because some days contain a mix or snow and rain and some days with little snow recorded zero precipitation (hence some manual data cleaning was necessary).

Visualizations highlighted statistical results showing that the relationship of relative humidity and SWR was polynomial for both classes of wind direction (nor'easter or others). The best model for SWR, based on the anova() function in R, was the second-order polynomial regression model shown in Equation 2, where X_{ADBT} is the average daily dry bulb temperature (ºF, p<0.001) and X_{RH} is the relative humidity (%). For RH, both the linear term (p<0.011) and the squared term (p<0.001) were significant.

$$Y_{SWR} = 1.98 - 0.54X_{ADBT} + 0.84X_{RH} - 0.0068X_{RH}^2 \tag{2}$$

The SWR quantification determines the risk of air intake clogging (when sufficient snow has fallen), where higher values represent higher severities. Snow weight depends on both quantity of snow and its SWR. Equation 3 calculates the weight (in pounds) for a one square foot cross-section of snow, which represents about one full shovel. In the prediction model, X_{SF} is the accumulated snowfall amount in inches.

$$Y_W = \frac{5.2X_{SF}}{Y_{SWR}} \tag{3}$$

Surface & Branch Ice Modeling

Ice formulation on subway and bus platforms is particularly dangerous for passengers, and these events can occur under conditions of freezing rain or on wet surfaces after temperatures drop. In addition, ice accumulation on transmitters (called automated vehicle indicators or AVI units) over which a train passes can compromise their detection ability. Finally, ice covered branches (and power lines) can fall, causing street blockages and power outages.

The models developed by Sanders and Barjenbruch (2016) were modified to predict ice accumulation both on flat surfaces and on radial surfaces. Their approach focused on the prediction of the ice amount by volume of precipitation, called its ice liquid ratio (ILR). Unlike other published climate or weather models, the circumstances associated with its accuracy would be present in the COB. Model inputs are temperature, wind speed, and precipitation rate. Gravity effects and the lack of a flat surface cause the ice accumulation on radial services (i.e., branches and power lines) to differ from the ice formed on a flat surface. Typically, a small amount of ice will accumulate on the top of the radial surface and an icicle will form below the radial surface. The result is essentially unitless and therefore is difficult to describe without visualizing the formation of ice.

For the MBTA application, the ILR value is applied to hourly data, and needs to predict ice thickness based on accumulated water on a surface. The accumulated water may include snow, ice, or both (i.e., slush), where the water equivalent in accumulated snow is derived from Equation 2. The starting time for accumulating precipitation is based on assumptions about how long the accumulation will remain relevant (it will not evaporate or dissipate) and is specific to a location's geography (Equation 4).

$$Y_{ICE}(t) = \sum_{i=0}^{t} IRL_i \quad (4)$$

Radial surface ice amounts are equal to flat surface thickness multiplied by a factor, 0.0394, which results in an index whose interpretation is difficult to discern. NOAA considers this index to be dangerous when it exceeds 0.5.

Other Severity Predictions

Other severity predictions were made directly from NOAA from hourly forecasts. Modeling was unnecessary because these factors were more directly associated with the severity of concerns of the MBTA. They included sustained and peak wind speed, which is useful for planning various resource allocations such as cutting branches and maintaining rights of way. In addition, the low visibility index (that includes effects of fog and smoke) is useful for planning resource allocations such as adjusting bus and train schedules, and passenger safety. A future update may include impact of river flooding and/or coastal flooding.

RESULTS

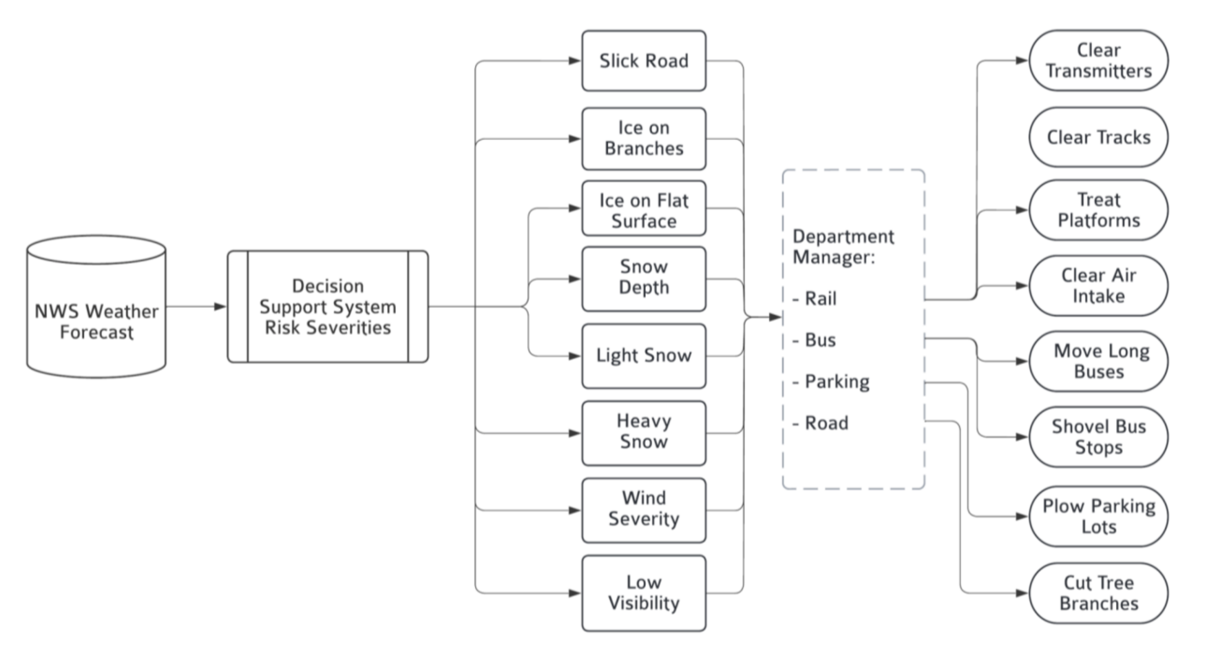
Visualizations were created that converted hourly weather forecast data to the various severity levels associated with the storm planning tasks listed in Table 1 using he models described above. These visualizations were designed to provide initiative yet scientific information to MBTA resource allocation planners when a winter storm was approaching. They were shown to the MBTA contacts who agreed that they would be useful for decision makers and that they represented a significant improvement over the current approach.

The framework of the proposed DSS is displayed in Figure 2. The system is more nuanced than the previous system because it accounts for more conditions that pose risks. It predicts operational severities associated with the myriad of weather factors and their interactions. For example, it predicts the risk of road becoming slippery after a rainstorm followed by a temperature drop. It considers the variety of impacts caused by snow weight – both light snow impacts and heavy snow impacts. It is designed to improve, rather than replace, the current MBTA planning storm planning system.

Visualizations

The DSS shows visualizations for severities when a winter storm is forecasted. They are generated 1-3 days before the day of the storm and correspond to the 24-hour storm period. They show information that helps planners determine the allocation of each resource shown in Table 1. The visualizations include green-yellow-red zones that help MBTA managers appreciate the severity associated with the characteristic that they are viewing. The visualizations assume that no action is taken to mitigate any of the weather impacts. For example, it shows the snow accumulation at bus stops as if no plowing is done during the day. Once action is taken (e.g., bus stops are plowed), the visualizations would be recreated based on current conditions.

Figure 2: Prototype DSS for MBTA Winter Storm Planning



The intuitive color-coding scheme in the DSS includes three zones, representing no action necessary (green) and action required (red), along with a warning zone (yellow), The numerical range for each color zone was determined based on two factors: (1) existing numerical thresholds recommended by the NWS, and/or (2) discussions with the MBTA winter storm operational maintenance and emergency personal. A total of 8 visualizations were included in the prototype system representing the concerns listed in Table 2.

Table 2: Green-Yellow-Red Zones

Severity Risks	Unit	Green	Yellow	Red
Slick road	Probability	0-0.25	0.25-0.5	> 0.5
AVI blockage	Inches	0-0.2	0.2-0.5	> 0.5
Branch ice	Index	0-0.3	0.3-0.5	> 0.5
Snow depth	Inches	0-3	3-7	> 7
Ingestion risk	SWR	0-8	8-12	> 12
Snow weight	Pounds	0-5	5-10	> 10
Wind severity	MPH	0-6	6-31	> 31
Low visibility index	Index	0-1	1-2	> 2

Examples of the visualizations generated by the prototype system just before a major Boston snowstorm on January 29, 2022, are shown below. This storm dropped about 24 inches of relatively light snow in Boston. Although the snow volume was significant, its relatively light weight mitigated the impact that would be present where the snow heavier (although its fluffiness generated a concern for train engine air intake clogging).

Figure 3 shows the slick road severity visualization, which displays the probability of road being slippery. The model (Equation 1) predicted that the road surfaces would become slippery between about 3 and 5 AM. The timing of the salt trucks deployment is critical, because if they leave too early salt can be ineffective and if they leave too late the road can be dangerous.

Figure 3: Slick Road Severity

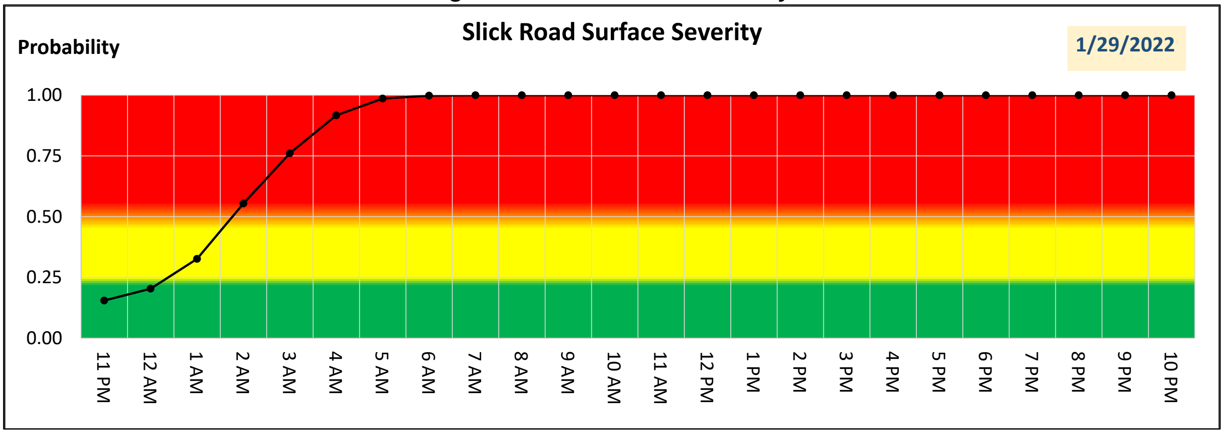


Figure 4 shows the projected ice buildup on ice surfaces as measured in inches. In this case, effective resource allocation to clear AVI's and treat platforms can take place after roads are salted because the danger zone occurs around 1 to 2 PM, which results in more efficient resource utilization. Although a high-volume snow was forecasted, the accumulation of ice was projected to be a concern (but not a major concern) for planners.

Figure 4: Ice of Flat Surface Severity

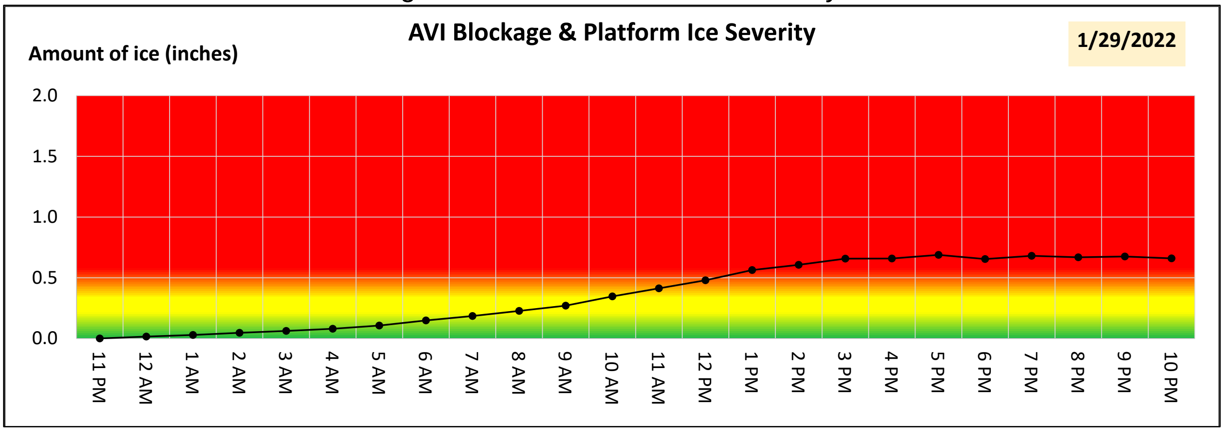


Figure 5 shows the risk of train engine air ingestion caused by fluffy snow, which occurs when SWR are above about 12 and the snow accumulation is above about 4 inches. For this weather event, the action to prevent engine ingestion should take place before 7 AM. In fact, on this date, many MBTA trains experienced instances of engine break down due to snow intake.

Figure 5: Air Intake Clogging Risk Severity

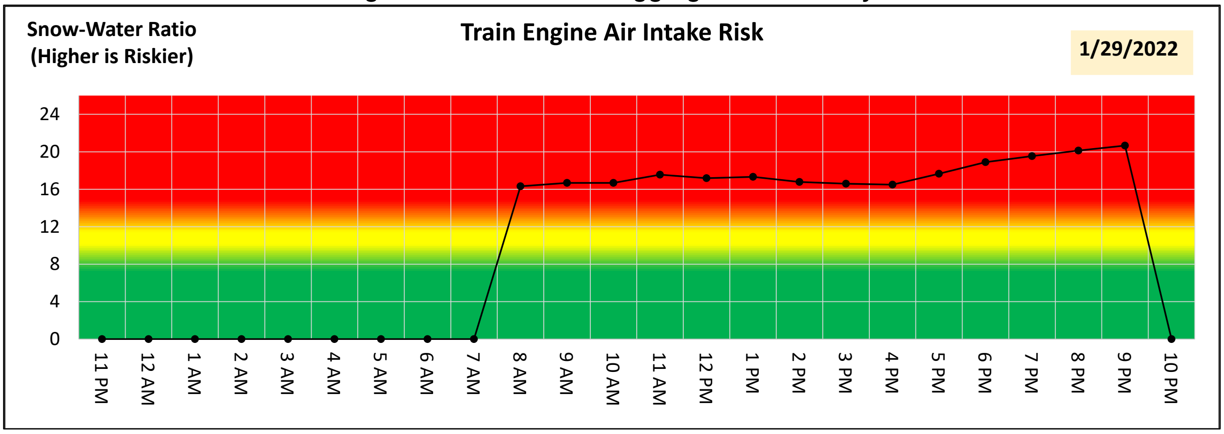
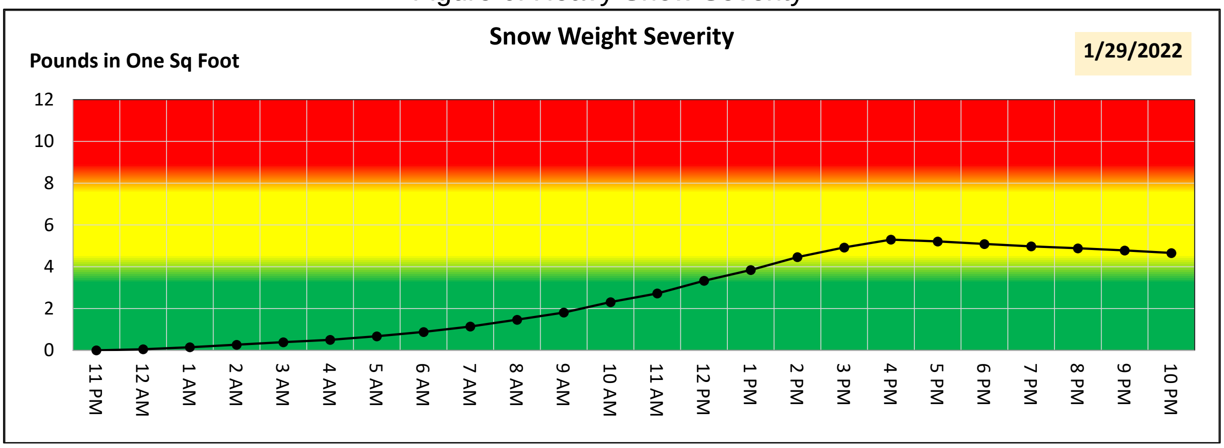


Figure 6 shows severity of snow weight, which is an important factor for resources required to clear bus stops, passenger parking lots, and MBTA facilities. Because the snow was light, the visualization indicates that it can be removed relatively easily. This projection prevents the over-allocation of snow removal contractors and saves MBTA overtime labor.

Figure 6: Heavy Snow Severity



Storm Level Determination

The mobilization of the MBTA storm planning infrastructure will remain because all departments need to be given advanced warning to prepare for an upcoming storm, based on an overall storm level severity indicator. This severity level indicator places personnel on alert and may create a temporary storm help desk. It focuses decision maker attention on the timing and overall impact of the upcoming storm. The severity index detailed below is more comprehensive than the current approach that is based on snow level only. It was developed using five key variables and quantified based on experts' estimation of each storm's potential challenges.

The overall severity index is composed of five dimensions: slick road probability, ice amount on flat surfaces, snow weight, snow depth, and peak wind speed. Each dimension is scored on a 0-

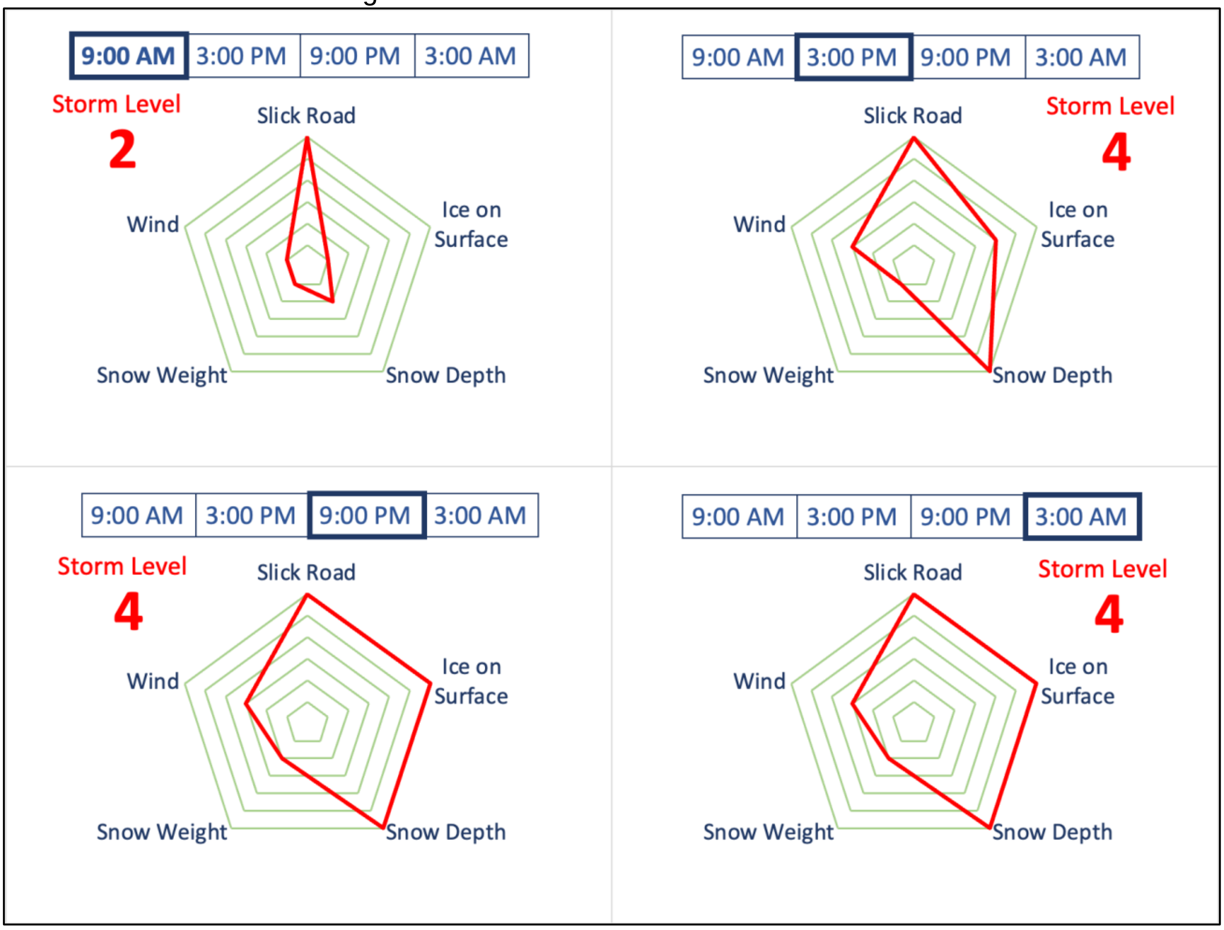
5 scale based on its visualization zone (0 for the green zone, 1 & 2 for the yellow zone, and 3-5 for the red zone). A 2^5 factorial experiment design was created to create the storm level model, with the five severity dimensions were set at two levels each (2 and 5).

Each of the 32 experiment combinations was presented to an expert panel who were asked to rate the overall storm from 0 to 5 scale. The average of these scores was tabulated to represent the response of the experiment. Equation 5 shows the severity index calculation based on the experiment (where $x_1, x_2, x_3, x_4, and\ x_5$ are the levels for slick road, ice of flat surface, snow depth, snow weight, and peak wind speed, respectively), which is rounded for clarity. For example, id $x_1 = 1, x_2 = 2, x_3 = 5, x_4 = 4, and\ x_5 = 2$, the winter storm severity is level 3.

$$Y_{SL} = 0.033 + 0.273x_1 + 0.159x_2 + 0.297x_3 + 0.142x_4 + 0.192x_5 \quad (5)$$

A radar chart was created to display the overall storm severity including the scores for each individual dimension. The chart combines four 6-hour time periods in the 24-hour storm planning horizon. An example is provided in Figure 7.

Figure 7: Overall Storm Level Visualization



Prototype DSS Testing

Prototype testing took place during the winter of 2021-2022. For each approaching storm, the researchers downloaded weather forecasts for the 24-hour storm period. An Excel file was provided to the MBTA project team members. The MBTA team members compared the timing and magnitude of severities generated by the DSS with actions planned by the MBTA operational managers. Communications with the operational managers was undertaken at times, but informally. An after-storm review was also completed for each weather event.

STATUS AND FUTURE WORK

After utilizing the prototype system during the 2021-2022 winter season, the MBTA sponsors were satisfied that the system could bring benefits to MBTA storm planning resource allocation decision makers. They were particularly impressed by its ability to inform managers of specific timing of resource mobilizations. This ability should result in more efficient resource usage and avoid unnecessary allocation of personnel and contractors. It is clear that decision accuracy is improved compared to the existing planning system.

Several activities need to take place for the DSS to become fully operational and user friendly. The system has already been updated to automatically download weather forecasts from the NOAA website and placed into the proper locations in the Excel-based system. This capability requires the implementation of an application programming interface (API) routine. When the refresh function is triggered, all the hourly weather input information and resulting risk predictions will be updated. The API interface needs to be capable of downloading data anywhere from 1 to 4 days in advance of a winter weather event.

The authors are working with MBTA system administrators and technicians to implement the DSS into the MBTA information system framework. A parallel effort is underway to design a process map that shows the MBTA managers and other users how the system would support their decision making. Finally, a short training session is under development.

The main upgrade planned for future versions of the DSS is expanding the targeted area from Boston to other nearby MBTA coverage areas. This capability would be especially important for commuter parking lots that can be located near the ocean or much further inland where the weather can vary. Another consideration is to expand the DSS to year-round extreme weather events, because intense heat waves and flooding risks are more likely to occur in Boston as a result of climate change.

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Purposeful Use of Mobile Internet in US States: Spatial Patterns and Socioeconomic Dimensions

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ABSTRACT

The digital divide in the United States has received renewed attention during the COVID-19 pandemic. As achievement of digital equity remains a high priority, this study examines spatial patterns and socioeconomic determinants of the purposeful use of mobile internet for personal and business needs in US states. Agglomerations of mobile internet use are identified using K-means clustering and differences between clusters are observed. Regression analysis reveals that mobile internet use is associated with age structure, employment in management, business, science, and arts occupations, affordability, and the extent of freedom in US states. Policy implications are discussed based on these findings.

KEYWORDS: Digital divide, Mobile internet, Regression, Clustering

INTRODUCTION

The COVID-19 pandemic has renewed attention to the digital divide in the United States. Over the past two years, the pandemic has highlighted that high speed internet access is a necessity for Americans in all strata of society to communicate with each other, maintain social interactions, remotely participate in educational and professional activities, conduct online shopping, access healthcare, entertainment, amid myriad forms of personal, social, and business-related activities. During the pandemic, restrictions imposed by stay-at-home instructions acted as a driver for mobile internet adoption worldwide. To access information, stay connected, and conduct business and work activities, going online using a mobile cellular device connected to a data plan became imperative; it also provided relief from the monotony of lockdown life.

Globally, 51% of the world's population or 4 billion people used mobile internet by the end of 2020, compared to just over a third of the world population in 2014-15 (GSMA, 2021). In the United States, the base of smartphone users expanded from around 80 million in 2011 to over 220 million at the of the 2021. Since 2015, the proportion of US households that used a mobile data plan grew from 64% or over 80 million households to over 74% or 98 million households at the end of 2021. This growth in the base of smartphone users and mobile data plan users has however not been equitable, with disparities across demographic groups, socioeconomic status, as well as geographic location. For example, 67% of those with family incomes between $25,000-$49,999 are smartphone users compared to 75% of those with family incomes of at least $100,000 in November 2021. A larger gap of over 13% exists between these two groups for mobile data plan use, with 70% of those with family incomes between $25,000-$49,999 compared to over 83% of those with family incomes of at least $100,000 (NTIA, 2022). Similar gaps are also reported in latest NTIA data based on age, gender, education, race and ethnicity, and population density. Globally, the key barriers to mobile internet adoption and use are knowledge and skills, affordability, relevance of content, safety and security, and lack of access to devices, networks, and services (GSMA, 2021).

Despite these barriers, people have used mobile internet for a broad spectrum of online activities. To stay connected with friends and family, mobile internet has been used for instant messaging, making or receiving calls including video calls, and social networking. Mobile internet has enabled people to read the news, search for information online, watch video, play games, listen to music, among various forms of hedonic activities. Mobile internet also enabled users to order, purchase, and sell goods online, access online banking, pay utilities, access mobile money among various forms of business-related activities. Finally, mobile internet has brought health information, job-related information, as well as government services to the fingertips of internet users. Studies have shown that the frequency of engaging in such activities at least once a day, week, or month such increased for every one of these activities from 2019 to 2020 (GSMA, 2021), showing the relevance and necessity of mobile internet spurred by the COVID-19 pandemic.

In this context of purposeful use of mobile internet, it is essential to analyze the disparities and gaps between “individuals, households, businesses and geographic areas at different socio-economic levels with regard both to their opportunities to access information and communication technologies and to their use of the (mobile) Internet for a wide variety of activities (OECD 2011, p.5)”. In recent years, a handful of digital divide studies have started to focus on the use of the internet for various activities and disparities therein (Sarkar, Pick, and Parrish, 2017; Smith, Anderson, and Caiazza, 2018; Warschauer and Matuchniak, 2010). Recently, mobile internet usage and its consequence for digital citizenship in African-American and Latino communities was studied by Mossberger, Tolbert, and Anderson (2017). In this study, the authors found that in the context of dramatic rise in mobile access among African-Americans and Latinos, mobile internet had some positive effects in terms of participation in digital citizenship via online banking, searching for news, jobs, health, and government information online, conducting job-related training, and social networking. GSMA’s survey of mobile internet use among internet users globally is another example of a study focused on mobile internet usage (GSMA, 2021). Apart from a handful of recent studies, there is a gap in prior work in systematic examination of mobile internet based purposeful activities in the United States. This study aims to fill this gap. The objective of this study is to analyze spatial patterns of mobile internet usage for personal and business activities and determine the influences of demographic and socioeconomic factors on mobile internet use.

The research questions are:

1. What are the spatial patterns of mobile internet’s purposeful use for personal and business needs in US states?
2. How is purposeful use of mobile internet clustered in US states and what are the demographic and socioeconomic attributes of such clusters?

3. What are the influences of demographic, occupational, affordability, social capital, innovation, and societal openness factors on mobile internet use in US states?

Analysis of spatial patterns and clusters is essential to understand the influence of geography on the digital divide overall, specifically for mobile internet use. As documented by the NTIA, geography in the form of urban-rural differences in internet adoption and usage has been a consistent part of the digital inequity in the United States. This focus on spatial analysis of mobile internet use is a distinguishing feature of this work. The study is also notable for its analysis of not only traditional demographic and socioeconomic influences on mobile internet use, but also non-traditional factors such as social capital, innovation, and the extent of freedom in US states.

Finally, the study is conducted at the state level for the US. As evidenced from NTIA studies and data over many years, the state unit of analysis provides meaningful insights about the state of the digital divide. This is informative to state-level administrators and also relevant from a public policy perspective, where states have the autonomy to shape their own telecommunications and digital initiatives, priorities, and policy.

The remainder of this paper is organized into sections on literature review of technology use, particularly the internet and its various dimensions in the U.S., conceptual model of purposeful use of mobile internet for personal and business purposes, spatial patterns of mobile internet use, regression findings, policy implications, limitations, and conclusions.

LITERATURE REVIEW

There has been growing attention to research on the digital divide, and recent scholarship has trended towards emphasizing the divide for mobile devices, the divides in purposeful use, and the inequalities in technology use. These themes correspond to a world that is already highly connected in advanced nations, has a new generation of digital natives that have grown up centered on mobile access, and persistence of unequal mobile purposeful use that has become even more visible during the covid-19 pandemic.

Since there is little research that combines all the trends, this review of prior studies considers a number of streams of research that lead up to the present study. The section groups prior US research into subsections as follows: technology use at the state level, technology use at the county level, purposeful use at the county and individual levels, and studies of racial and ethnic differentials on the divide. Literature on theories of the digital divide appears in a subsequent section on theoretical framework.

Technology Use at the state level

At the state level in the US, a study based on data from 2007-2010 was analyzed based on the SATUM theory, which considers geographic patterns and multivariate influences on technology use and is discussed in more detail later on in this paper. The study analyzed eight dependent variables of ICT use, namely desktop/laptop, internet access, broadband adoption, cellphone-only use, high-speed wireless devices, fixed phone use, and facebook and twitter use. Based on the independent variables of demographic, ethnicity, economic, education, innovation, societal openness, and social capital, there were strong positive effects from college education, social capital, and mixed effects for race/ethnicity factors, and the dependent variables were spatially agglomerated, except for social media (Pick, Sarkar, and Johnson, 2015).

A study based on the US Census American Community Survey and centered on the household level in 2018, provided insights that there was nearly full access of households to the internet and a broadband or smartphone presence of 85 percent, while there were substantial differentials by age (inverse), urban versus rural, higher income, and varied means of accessing the internet (Martin, 2021). The study highlights the huge US increases in computer and internet use from 9% in 1984 to near saturation of computer use in 2018.

Technology use at county and individual levels

Research on determinants of technology use at the county and individual levels in the US has revealed considerable geographic agglomeration and determinants of county technology uses (Li, Goodchild, and Xu, 2013; Pick, Sarkar, and Rosales, 2016).

Based on a large US sample of geo-referenced tweets and photos, a study mapped the patterns of use nationwide and conducted a more intensive case study of California examining correlates of social media use (Li, Goodchild, and Xu, 2013). Results showed differing geographic concentration for the two social media entities, with tweets heavily concentrated in urban areas of the northeast, mid-Atlantic and south, whereas high photo density occurred in areas of tourism and technology such as West Coast cities, Lake Tahoe, Yosemite, Austin, Orlando, Ann Arbor, and Boston. Regressions for California indicate tweets are associated with education, income, and graduate study in professional-science-arts, while photos relate to white and Asian ethnicity and graduate study in management, science, and arts.

At the county level, studies based on surveys of counties and government data and similar in design to the present one provide geographic and regression insights into county geographic patterns and determinants of use for ICT use and mobile ICT use. There were generally concentration of high use in the counties of the megalopolis from Boston to Washington, the West Coast, western Colorado and Utah, with low use areas in the mid to lower south, with the exception of the Atlanta metropolitan area and most of Florida (Pick, Sarkar, and Rosales, 2016). Regression analysis indicated determinants of ICT use to be demographic attributes, urban location, service occupation, and mixed findings for ethnicities.

Purposeful Use at County and Individual Levels

As technology uses approach saturation in the US, gaps still loom in the purposeful uses of ICT. For instance, an underserved community may receive broadband throughout from future federal investment, but users in the community may not have the training, education, or financial resources to engage in certain purposeful uses, for example to access scientific journals, financial services, etc. Purposeful technology use in the US has recently become an area of research interest, stimulated by the online needs of covid-19 pandemic. Several examples are examined in this section (Sarkar, Pick, Moss, 2017; Pick, Sarkar, Rosales, 2016; Sarkar, Pick, Rosales, 2018; Delaporte and Bahia, 2021).

Mobile internet use for e-entertainment and e-commerce purposes was studied for US counties, based on the SATUM model. Eight types of such uses studied include using a cellphone to download a game, using a cellphone to access news and information, and using a cell phone to watch a movie. There was much similarity in multivariate findings on determinants of these uses with prominent determinants to be age (inverse), Hispanic ethnicity (inverse), urban residence, service occupation, and higher-level phone bills. Cluster analysis findings mapped indicated high-use clusters in the northeast, west coast, Colorado to Utah corridor, Florida, and Atlanta metro area. Clusters of low use are in the prairie states, Appalachia, and the South. This study of purposeful mobile use in some respects is a pre-cursor to the present study, albeit with an earlier data set and an earlier, less up-to-date group of purposeful uses.

Studies of use of e-entertainment services in US counties (Sarkar, Pick, and Rosales, 2018) and of social media uses in US counties (Pick, Sarkar, and Rosales, 2019) examined specialized purposeful uses, based on the SATUM model, with data drawn from nationwide surveys and government sources. For the e-entertainment purposeful variables, in particular, obtained the latest news, added video to website, watched movie online and ordered iTunes from website, there were fairly consistent determinants including young dependency ratio, education, working age population, service occupations, and Asian ethnicity. Spatial analysis showed distinctive clusters from high to low use, which showed the largest intensities in urban California and the New Jersey to Boston corridor (Sarkar, Pick, and Rosales 2018). For purposeful uses by three major social media types, the important factors are college education, young dependency ratio, working age population service occupation, urban and Asian ethnicity for twitter and LinkedIn and Black and Hispanic ethnicities inverse for Facebook (Pick, Sarkar, and Rosales, 2019). Spatial analysis was performed of national social media distributions of purposeful use by type, with Facebook's national pattern differing in subtle ways from twitter and LinkedIn patterns.

Research on the connected society in low and middle income countries (Delaporte and Baia, 2021) based on extensive surveys by GSMA, included detailed analysis of purposeful uses of the internet, across a sample of middle and low level economies. Generally, the study spanning 198 nations indicates, that although the "coverage gap," i.e. having the mobile internet available, has decreased from 24% to 6% from 2014-2020, the usage gap, i.e. gap in use of mobile services, has remained even at 43%. This underscores the justification in the present study to focus on purposeful uses, which ultimately can close the usage gap. The report (Delaporte and Bahia, 2021) went further and analyzed leading purposeful uses for survey respondents. It consistently found substantial ranges of adoption of services, for example, whereas 79% of mobile internet users looked for information in the search bar or app, only 61% changed settings of data usage limit. In another comparison, 78% of users of mobile internet weekly in 2020 used instant messaging but only 17% percent used mobile banking weekly (Delaporte and Bahia, 2021). Although the study is rich in purposeful use applications in middle and low income countries, it did not examine the geographic aspects.

Influence of Racial and Ethnic Differences on digital divides

Many prior digital divide studies of the US have included race and ethnicity variables, but only a few have drilled down to try to gain deeper and detailed understanding of why the differences exist (Mossberger et al., 2017; Choi et al., 2022). In a survey study of individuals in Chicago in 2013, the findings showed that the mobile internet use is strongly associated with political and economic activities online, with the largest effects of African-American and Latino respondents, particularly for Latino respondents who live in Latino neighborhoods. Using multilevel analysis, the study confirmed that mobile access led to 75-80 percent increases in the probabillity of the number of economic and civic activities for Latinos and 40-45 percent increase for Blacks (Mossberger et al., 2017). Examining many aspects of the mobile enhancements, the study went on to make policy recommendations. Another study examined whether older population in urban and rural areas varied in internet use by racial and ethnic group (Choi et al., 2022). The study found that older Black and Hispanic individuals had lower odds of using the internet, and further that rural living lowered the probability of internet use for Blacks more than for Whites. It suggests targeted programs to reduce the digital divide especially of older Black people living in rural areas. These relatively rare studies can inform the interpretation of racial and ethnic internet use differentials and can be helpful in for explaining findings in the present study.

CONCEPTUAL MODEL OF PURPOSEFUL USE OF MOBILE INTERNET

The digital divide on the theoretical side has had a number of conceptual frameworks developed, but there is not presently a standard framework. Among the conceptual models that were considered for the present study are Adoption-Diffusion Theory (Rogers, 1962), Van Dijk's theories (Van Dijk, 2005, 2021), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), and Spatially Aware Technology Utilization Theory (SATUM) (Pick and Sarkar, 2016). The SATUM theory seems most applicable for the present study and its research questions. Among its pluses are that the conceptual model was developed specifically for quantitative digital divide research, and it posits to analyze, for Internet and ICT dependent variables, the combined associations on the dependent variables of a variety of independent variables including demographic, occupational, economic, educational, innovation, affordability, freedom, and social capital influences. It also includes geographical mapping, cluster analysis, the results of which can be spatially rendered, and spatial autocorrelation. It is more adaptable than some of the other theories, such as Adoption-Diffusion and van Dijk's, to make use of data for governmental spatial units of analysis (Pick and Sarkar, 2016). Hence, it is adopted for the present research.

The remainder of this section justifies the independent variables based on induction from prior studies or reasoning by the investigators. This process of inducing from the literature and reasoning to formulate factors to include in the model is justified for an exploratory study, such as the present one (Stebbins, 2001). The model factors are conceptualized in Figure 1. The dependent variables are grouped into two groups – mobile internet for personal use and mobile internet for business use.

The model justification is given next for these independent variables and dependent variables.

Justification for independent variables

Demographic variables

- Median Age

  This variable has been utilized frequently in digital divide research and generally found to have inverse effect (Lenhart et al, 2010; Pick, Sarkar, and Rosales, 2016; Sarkar, Pick, and Moss, 2017; Pick, Sarkar, and Rosales, 2019; Martin, 2021)

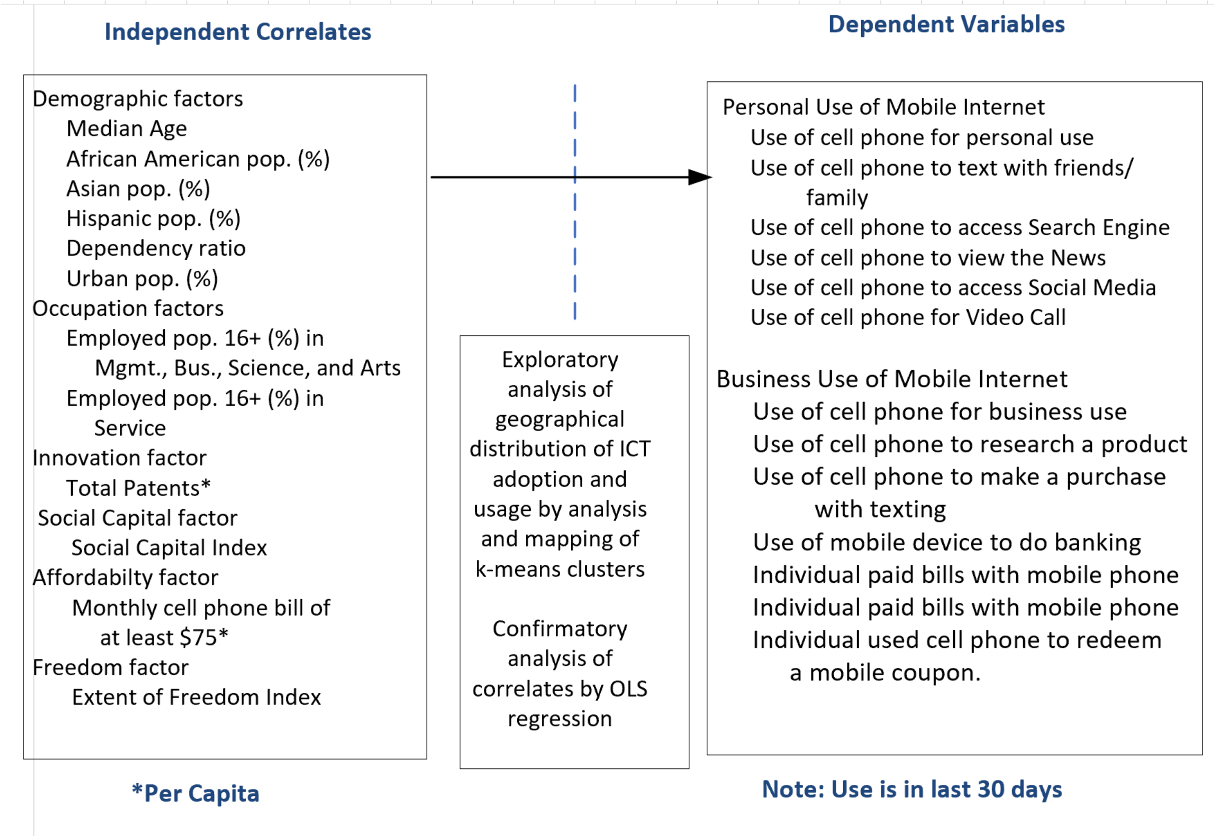
- % of Pop. that identifies as African-American
- % of Pop. that identifies as Asian
- % of Pop. that identifies as Hispanic or Latino

  Two or three of these race and ethnic variables have been included in studies and often been significant in the findings (Pick, Sarkar, and Rosales, 2016; Sarkar, Pick, and Moss, 2017; Mossberger et al., 2017; Pick, Sarkar, and Rosales, 2019; Martin, 2021; Choi et al., 2022). Generally Asian is a positive correlate. African American and Hispanic/Latino variables are usually mixed in direction of effect.

- Age Dependency Ratio, % of Pop under 19 and over 65

  Dependency ratio for young age only has appeared in several studies and been an important factor (Pick, Sarkar, and Rosales, 2016; Sarkar, Pick, and Rosales, 2017; Pick, Sarkar, and Rosales, 2019). Since younger population is a larger part of the full dependency ratio, we expect the variable will remain a positive factor.

Figure 1. Conceptual Model based on SATUM, with posited constructs



- % of Urban Pop.

  Urban has consistently been a positive factor in multiple literature studies, including the following (Pick, Sarkar, and Johnson; 2015; Pick, Sarkar, and Rosales, 2016; Sarkar, Pick, and Rosales, 2017; Sarkar, Pick, and Moss, 2017; Martin, 2021; Choi et al., 2022).

Occupational variables

- Percent of the Employed Pop Age 16+ in the Management, Business, Science, and Arts Occupations

The combination of workforce in these "creative" jobs with higher tech cities has been put forward and justified by research on the creative class by Richard Florida (Florida, 2012). Variables for scientific and technical services workforce have been studied in the U.S. and sometimes found to be significant positive correlates of technology use (Azari and Pick, 2005).

- Percent of the Employed Pop Age 16+ in Service Occupations

  Employment in service occupations has occasionally been included in the literature, and often has positive and significant effects when included (Pick, Sarkar, and Rosales, 2016; Sarkar, Pick, and Rosales, 2017; Sarkar, Pick, and Moss, 2017; Pick, Sarkar, and Rosales, 2019). It can be reasoned that service occupations include job requirements for computer skills and use, often intensive use.

Innovation variable: Total Patents (divided by the Total Pop. of the State)

Innovation is reasoned to stimulate technology and computer use both in technology companies, universities and research centers, but also for communities interacting with these technology hubs.

Social Capital variable: Index of Social Capital

Social capital has been an important variable in some U.S. digital divide studies. It represents the linkages and ties within a population through physical and communication means. It was a major factor in a survey sample of technology use by individuals in the US (Chen, 2013), as well as in a nationwide study of the decisions of people to go online, including from influences of peers (Agarwal, Animesh, and Prasad, 2009).

Affordability variable: Monthly Cell Bill is at least $75

Affordability has been shown sometimes to impact adoption of technology and tends to be more influential in developing countries or economically weaker segments of developed nations. We reason that pricing of internet services can have an inverse influence on individuals, especially in lower income households.

Freedom variable: Extent of freedom in US states

Freedom has been shown to be important in a limited number of studies that perceived it to be an essential aspect of technology use. It was seen the Arab Spring, an opening in many Arab countries in 2010 and 2022, in which feelings of freedom were associated with increased internet communications. It was also shown to be important in Africa for a study of 51 countries (Pick and Sarkar, 2015, chapter 9), in which freedom was represented by the proxy of laws related to ICT. As variables for freedom in the US at the state have strengthened and as internet freedom has become a political issue, it is essential to include a variable for it.

<u>Justification for Dependent Variables</u>

These dependent variables are not individually justified by literature since there is very little prior quantitative and geographical research on purposeful use of indicators to inform this study. The justification for including them goes back to the saturation in recent years in simple use of technologies in the US and the need to spring forward and conduct research on purposeful use and impacts (van Dijk, 2020). The need to segue to purposeful use was initiated by some research a decade ago (e.g., Warschauer and Matuchniak, 2010) and today given the rising needs of purposeful use during the covid-19 pandemic (McClain et al., 2021), we feel justified in reasoning that purposeful use is becoming the new digital divide in the US. This justifies the exploratory inclusion of the following set of purposeful personal uses and purposeful business uses of mobile internet.

Personal Use of Mobile Internet

- Individual uses Cell Phone for personal use
- Individual used cell phone to text message friends/family in last month
- Individual used cell phone to access a search engine in last month
- Individual has viewed the News on cell phone in last month
- Individual used cell phone to access Social Media in the last month
- Individual used cell phone for video call last 30 days

Business Use of Mobile Internet

- Individual used cell phone for business use
- Individual used cell phone to research product last 30 days
- Individual used cell phone to make purchase w/ text in last month
- Individual used mobile device to do banking in last 12 months
- Individual paid bills with mobile phone in last 12 months
- Individual used cell phone to redeem a mobile coupon in last month

METHODOLOGY

The methodology of the study is comprised of several steps. First, the dataset was put together and thoroughly vetted for completeness and accuracy. Descriptive statistics were computed for all 12 dependent indicators of purposeful mobile internet use, as well as 12 independent variables for a sample of n = 49 (lower-48 states plus the District of Columbia). Bivariate correlations were then computed for each pair of independent variables as a preliminary screening for multicollinearity. During this step, it was determined that a variable such as median household income, often associated with disparities in internet adoption and usage, was strongly positively correlated with management, business, science, and arts occupations (Pearson Correlation Coefficient of.846, significant at the .001 level). Similarly, median household income and proportion of population with Bachelors education was strongly correlated. During this screening process, several such variables were eliminated.

Next, to discern spatial patterns of mobile internet use, each of the 12 dependent indicators of purposeful use for personal and business needs were mapped using a Geographical Information System (GIS). GIS mapping is descriptive, yet it can provide valuable insights about spatial distributions of mobile internet usage and point to similarities and differences between states and well as between the variables themselves. Due to file-size limitations, only 2 of the dependent variable maps are provided later in this manuscript. Other maps are available upon request.

Following descriptive mapping, K-means clustering, an unsupervised data mining method is deployed to determine two separate clusters of mobile internet use for personal purposes and for business purposes. One reason for applying k-means is its computational efficiency, compared to other clustering techniques such as hierarchical clustering. In each case, k-means is applied for 6 dependent indicators of personal and business use of mobile internet, with k=5 and k=6. K=6 resulted in more meaningful clusters for both sets of dependent variables – personal and business use of mobile internet. For each set, states are assigned based on the levels of mobile internet use, from high to moderate to low. Cluster centers are used to determine the ratio of mobile internet use between the highest and lowest use clusters. This ratio, while descriptive, is indicative of the extent of disparity in mobile internet use. Each cluster is subsequently characterized based on the demographic, occupational, affordability, social capital, and extent of freedom attributes. Similarities and differences are observed between the clusters based on these attributes. The clusters are also mapped; k-means maps of personal and business use of mobile internet reveal agglomerations of mobile internet activity. These agglomerations are illuminating since they point to the possibility of spatial bias – a pitfall of any geographically referenced phenomenon such as spatial patterns of mobile internet activity.

Finally, Ordinary Least Squares (OLS) regressions are employed to test posited associations between the 12 dependent variables and 12 independent variables. OLS regressions were conducted in stepwise fashion allowing in variables with significance levels of equal or less than 0.05. The Variance Inflation Factor (VIF) was also computed for each regression as an additional test of multicollinearity, and a cutoff of 5.0 for VIFs was used (Myers, 1990). Each of the 12 OLS regressions had a VIF lower than 5.0 and no multicollinearity problems were detected.

Overall, the study's methodology is comprised of geographic mapping of the dependent variables to examine patterns of mobile internet activity; k-means clustering of two sets of dependent variables to determine clusters of personal and business use of mobile internet; and OLS regressions to analyze influences of independent demographic and socioeconomic variables on mobile internet use in US states.

DATA

Data used for the study's dependent and independent variables were collected from a variety of sources. Data on all 12 dependent indicators of mobile internet use for personal and business purposes was sourced from Esri's 2021 Market Potential database (Esri, 2021) which measures the likely demand for products and services among US consumers as well as consumer attitudes on spending, media consumption and usage, internet activities, cell phones and service, health, and the environment. Market potential is estimated by Esri based on data collected from various surveys such as the MRI Survey of the American Consumer and Doublebase 2020 Survey from MRI-Simmons which integrates information from four consumer surveys. It is important to note that due to the time period of data collection and sampling for the Doublebase 2020 Survey, Esri's 2021 Market Potential database documents changes in consumer demand and behavior due to the COVID-19 pandemic.

The 12 dependent variables include six indicators of mobile internet use for personal purposes and six indicators for business purposes. They are listed in Table 1. The personal use indicators include using cell phone use by individuals to text message friends and family, access a search engine, viewing the news, accessing social media, and making video calls. Using mobile internet for video calling and chatting are among the newest variables in Esri's 2021 Market

Potential database documenting shifts in consumer preferences due to COVID. Indicators of mobile internet use for business purposes by individuals include using a cell phone to research products online, making purchases online, conducting online banking and bill payment, and finally using a cell phone to redeem mobile coupons. Broadly speaking, these indicators of mobile commerce (m-commerce) became prevalent during the COVID-19 pandemic when consumers were confined to their homes and used the internet to not only maintain social and professional connections, but also to research information online about products and services and subsequently purchase them.

Data on 7 out of the 12 independent variables are sourced from the U.S. Census Bureau's American Community Survey. 5-year estimates (2016-2020) centered on 2018 were used for these 8 independent variables. These estimates includes data collected between January 1, 2016 and December 31, 2020. According to the U.S. Census Bureau, 5-year estimates are the most reliable, based on the largest sample size of about 3.5 million addresses with survey information collected annually. Data on urban population per capita was sourced from the U.S. Census Bureau's 2010 Census. While it would have been ideal to capture urban population data from the 2020 Census, it is unfortunately still unavailable. Data on patents issued to residents in U.S. states in 2021 were sourced from the Performance and Accountability Report of the U.S. Patent and Trademark Office (USPTO) and was used as an indicator of innovation is U.S. states. Data on freedom in U.S. states for 2018 was obtained from the Cato Institute's Freedom in the 50 states project report (Ruger and Sorens, 2021). Data on social capital in the U.S. states were obtained from a report commissioned by the Joint Economic Committee of the U.S. Congress (US Senate, 2018). The state-level index is comprised of four sub-indices that focus on family unity, family interaction, social support, community health, institutional health, collective efficacy, and philanthropic health. Additional details about the social capital index and its research design methodology can be found in the report (US Senate, 2018). Finally, data on monthly cellphone bill exceeding $75 in U.S. households was compiled at the state level from Esri's 2021 Market Potential database (Esri, 2021), the same database that supplied the study's dependent variables.

All 12 dependent variables and some of the independent variable estimates were normalized based on 2018 population (the mid-point of the 2016-2020 ACS 5-year survey) in U.S. states. This also ensures time simultaneity since the dependent variables are for the year 2021. Finally, complete data on the 12 dependent variables as well as 12 independent variables were available for the lower-48 contiguous states plus the District of Columbia. Therefore, Alaska and Hawaii are excluded from the study and the sample size is n = 49. The study's codebook and descriptive statistics for each variable are in Table 1.

Table 1: Variable definitions and descriptive statistics

Variable Code	Description	N	Minimum	Maximum	Mean	Std. Deviation
(Dependent Variables)	Individual uses Cell Phone for personal use	49	0.5307	0.6102	0.5648	0.0165
	Individual used cell phone to text message friends/family	49	0.5709	0.6562	0.6144	0.0180
	Individual used cell phone to access a search engine	49	0.4272	0.5597	0.4899	0.0246

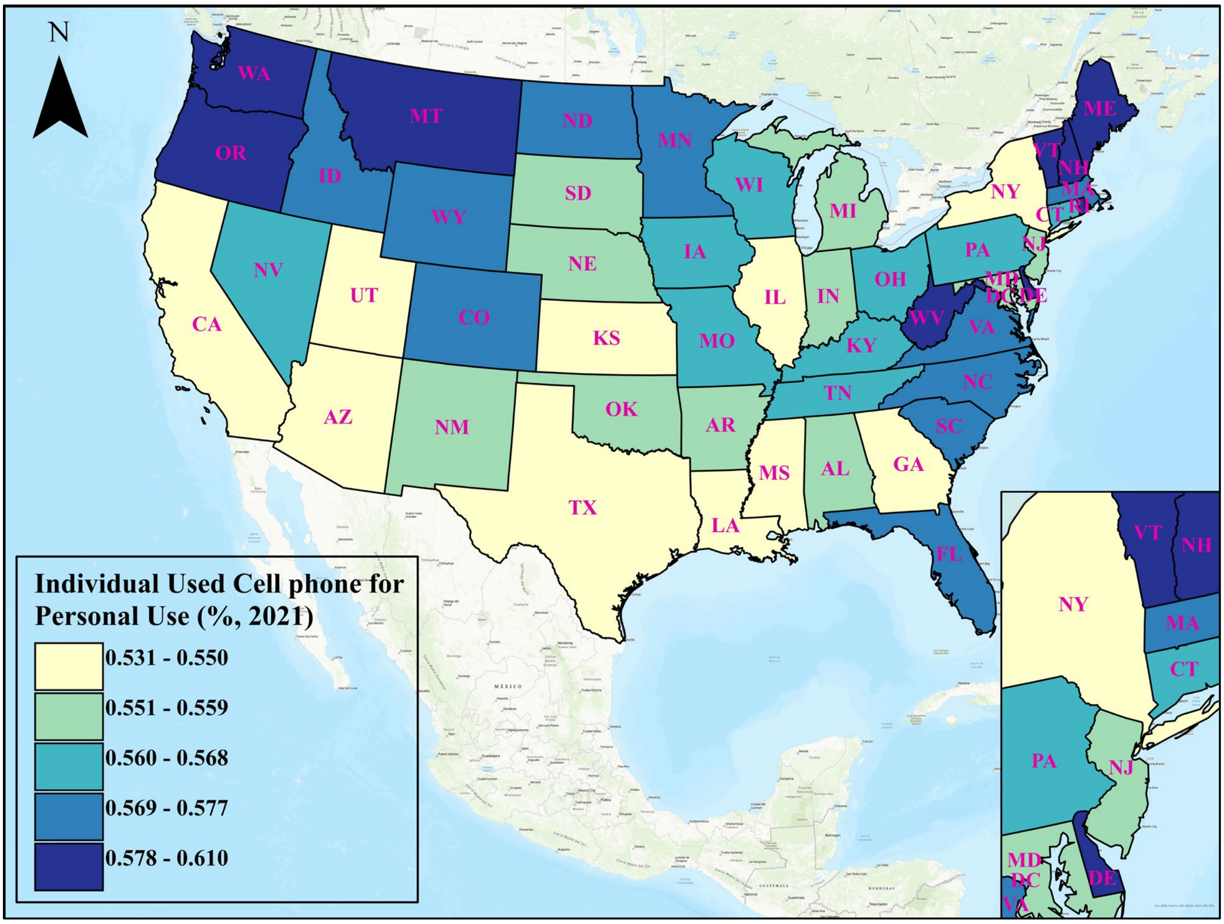
Mobile Internet: Personal Use	Individual has viewed the News on cell phone	49	0.3528	0.4751	0.4044	0.0261
	Individual used cell phone to access Social Media	49	0.3580	0.4413	0.3916	0.0145
	Individual used cell phone for video call	49	0.2403	0.3485	0.2738	0.0170
Dependent Variables Mobile Internet: Business Use	Individual uses Cell Phone for business use	49	0.1257	0.1742	0.1511	0.0102
	Individual Used Cell Phone to Research Product	49	0.3201	0.4122	0.3652	0.0187
	Individual used cell phone to make purchase w/ text	49	0.2600	0.3438	0.2986	0.0159
	Individual used mobile device to do banking	49	0.2171	0.3004	0.2586	0.0179
	Individual paid bills with mobile phone	49	0.1736	0.2136	0.1908	0.0085
	Individual used cell phone to redeem a mobile coupon	49	0.1414	0.1917	0.1581	0.0105
Independent Variables						
Demographic	Median Age	49	31.1000	44.8000	38.6224	2.3717
	% of Population that identifies as African-American	49	0.0056	0.4539	0.1159	0.1064
	% of Population that identifies as Asian	49	0.0079	0.1483	0.0359	0.0278
	% of Population that identifies as Hispanic or Latino	49	0.0159	0.4920	0.1219	0.1049
	Age Dependency Ratio, % of Pop under 19 and over 65	49	0.4975	0.7850	0.7086	0.0472
	% of Urban Population	49	0.3870	1.0000	0.7390	0.1490
Occupation	Percent of the Employed Pop 16+ in the Management, Business, Science, and Arts Occupations	49	0.1381	0.3565	0.1911	0.0359
	Percent of the Employed Pop 16+ in Service Occupations	49	0.0699	0.1182	0.0827	0.0076
Innovation	Total Patents divided by the Total Population of the State	49	0.0001	0.0024	0.0008	0.0005
Social Capital	Social Capital index	49	0.0001	4.2333	2.1514	1.0178
Affordability	Monthly Cell Bill is >$75	49	0.5248	0.6164	0.5699	0.0199
Freedom	Index of freedom	49	0.0000	1.3810	0.9083	0.2606

SPATIAL PATTERNS AND CLUSTERS OF MOBILE INTERNET USE

The dependent indicators of personal and business use of mobile internet were mapped using a Geographical Information System (GIS). GIS mapping while descriptive offers useful visual cues about spatial patterns and arrangements of spatially referenced phenomena. In this case, mapping shows agglomerations of high and low use of mobile internet for both personal and business use.

In 2021, personal use of mobile internet varied between 53% to 61% of the population in US states, with states in the Northeast and Pacific Northwest leading the nation (Figure 2). Surprisingly, West Virginia (WV) in the Appalachian region is a leading state in mobile internet use for personal purposes. Due to the remoteness of the region and infrastructural malaise, WV has often been a laggard in internet access and use (NTIA, 2022). Personal use of mobile internet was also found to be reasonably high in states along with Atlantic Coast, a handful of prairie states, and also in the Rocky Mountain state of Colorado. Conversely, mobile internet use for personal purposes was low in the South and Southwest in states such as Texas, Louisiana, Mississippi, Georgia, and also in California and Arizona. Low-moderate levels of use was also found in some states in the Midwest and also in the South.

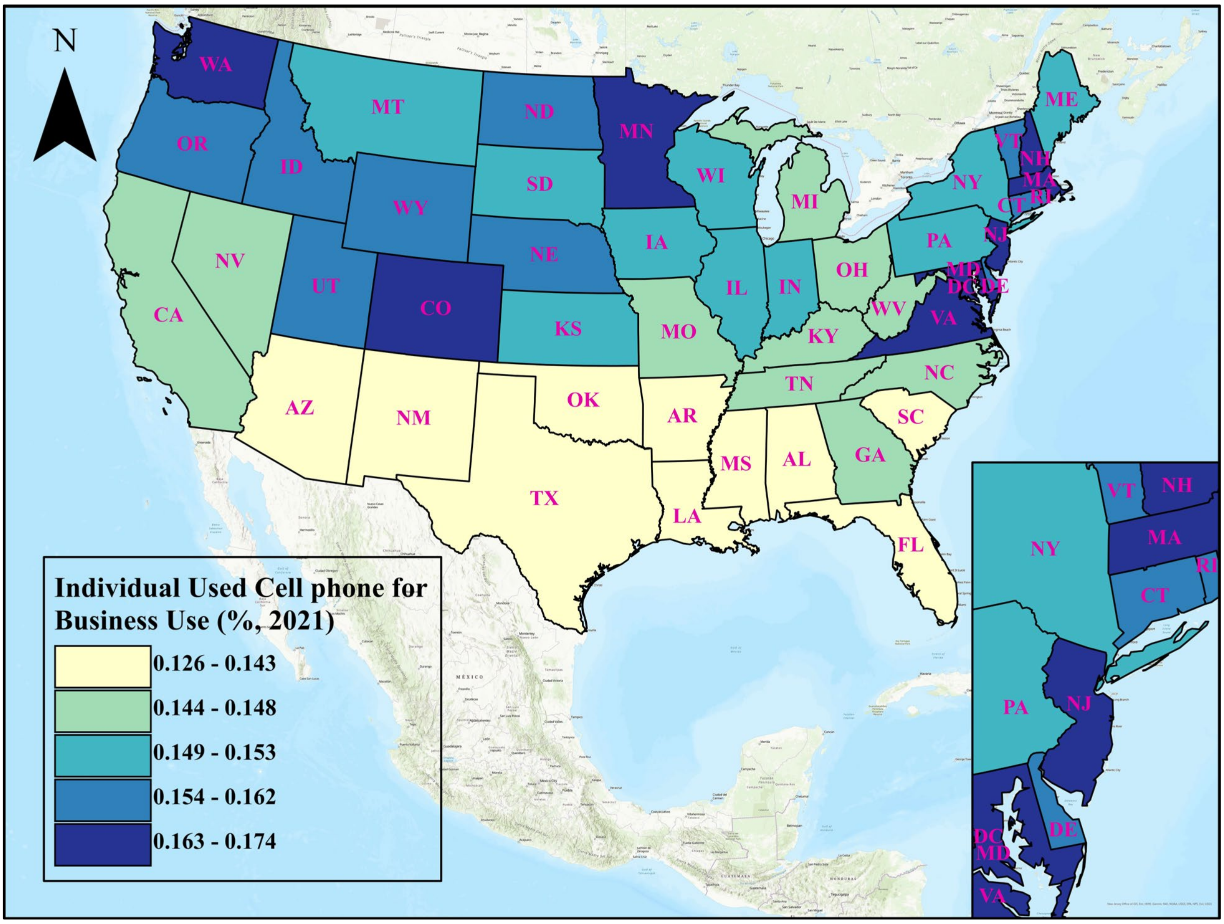
Figure 2 Spatial patterns of mobile internet use for personal purposes in US states, 2021



For mobile internet use for business purposes (shown in Figure 3), the leading states were in the Northeast, Pacific Northwest (Washington state), and also Colorado among Rocky Mountain states. Several of the prairie and midwestern states has moderate levels of use for business purposes, while states in the south and west had low to very low levels of mobile internet use for business needs. Overall, for both types of use – personal and business, spatial arrangements of mobile internet use show several similarities, point to agglomerations, clusters and some outliers (such as WV for personal use). It is pertinent to note that overall, business use (ranging between 12.6-17.4%) of mobile internet significantly lags personal use in US states in 2021.

While descriptive mapping was completed for all 12 dependent variables, the broad categories (personal and business use) dependent variables maps are shown as illustrative examples. Maps of the other 10 dependent variables are available upon request.

Figure 3 Spatial patterns of mobile internet use for business purposes in US states, 2021



Clusters of Mobile Internet Use for Personal Purposes

K-means clusters (k=6) of mobile internet use for personal purposes shows that Washington D.C. as the sole member of cluster 1 (Table 2), representing highest use, followed by 9 states in cluster 2, which represents high use. These states are in in the Northeast in the Boston-Washington megalopolitan area (Connecticut, Maryland, Massachusetts, Rhode Island, New

Jersey, Virginia, and others), in the Pacific Northwest (Washington), Rocky Mountains (Colorado), and upper Midwest (Minnesota). A total of 20 states, 5 in cluster 3 and 15 in cluster 4 comprise moderate use of mobile internet for personal purposes. These states are agglomerated all over the country including the Northeast, West, prairies, Midwestern rust belt, and the South. Cluster 5 is comprised of 17 low use states located in the Midwest, Appalachia region, and South. Finally, Louisiana and Mississippi are in cluster 6, representing the lowest levels of mobile internet use for personal purposes. The clusters are mapped in Figure 4. Table 2 shows cluster centers corresponding to each dependent indicator of personal use. The ratio of highest to lowest use varies between 1.105 to 1.402 indicating that that the extent of disparity between leaders and laggards is not too high.

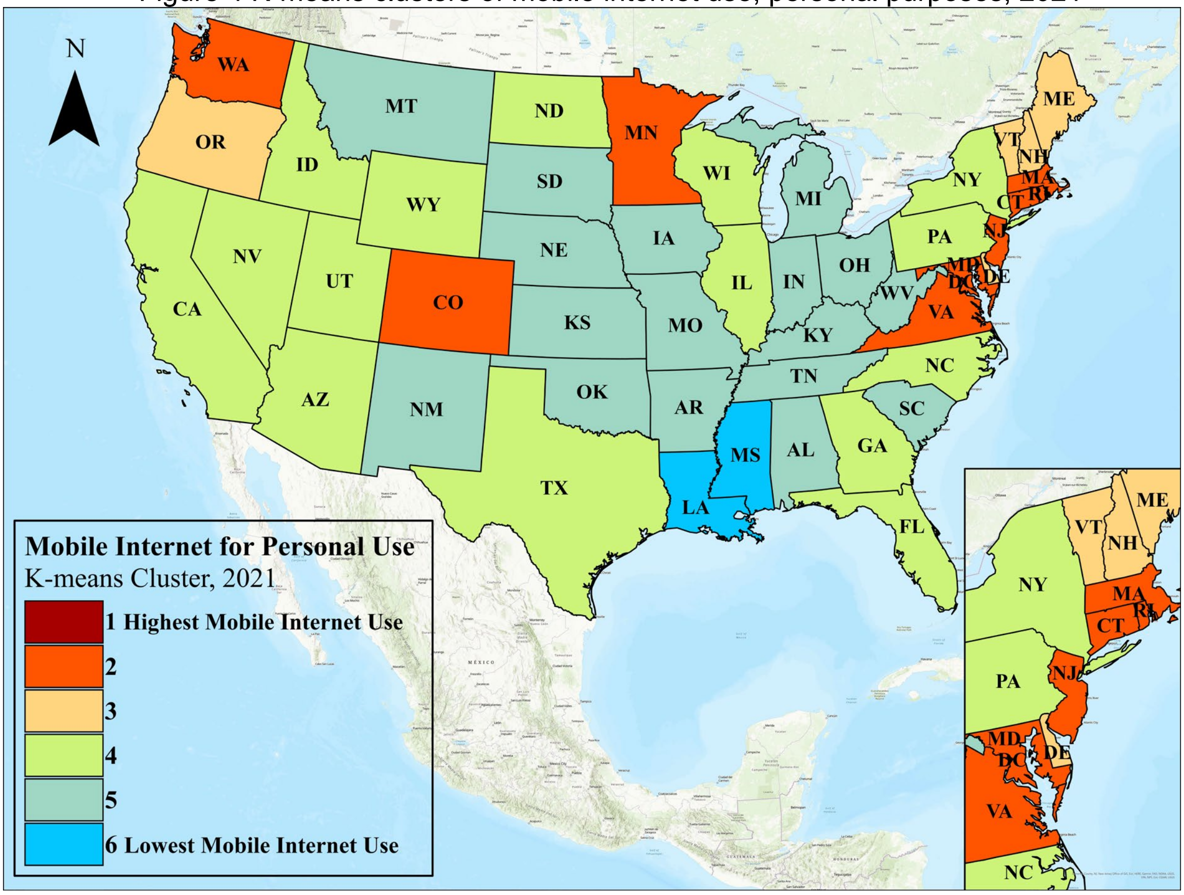
Table 2: K-means clusters of Mobile Internet Use, Personal Purposes, 2021

	1 Highest Mobile Internet Use	2	3	4	5	6 Lowest Mobile Internet Use	MAX	MIN	Ratio = MAX/MIN
Cell Phone for personal use	0.595	0.570	0.565	0.563	0.558	0.538	0.595	0.538	1.105
News on cell phone	0.475	0.439	0.425	0.403	0.382	0.363	0.475	0.363	1.310
Social Media on cell phone	0.441	0.407	0.402	0.391	0.381	0.365	0.441	0.365	1.210
Access search engine on cell	0.560	0.518	0.512	0.489	0.471	0.439	0.560	0.439	1.274
Text friends & family	0.644	0.628	0.644	0.611	0.604	0.577	0.644	0.577	1.116
Make video call	0.349	0.290	0.276	0.276	0.261	0.249	0.349	0.249	1.402
Number of States	1	9	5	15	17	2			
	District of Columbia	Colorado Connecticut Maryland Massachusetts Minnesota New Jersey Rhode Island Virginia Washington	Delaware Maine New Hampshire Oregon Vermont	Arizona California Florida Georgia Idaho Illinois Nevada New York North Carolina North Dakota Pennsylvania Texas Utah Wisconsin Wyoming	Alabama Arkansas Indiana Iowa Kansas Kentucky Michigan Missouri Montana Nebraska New Mexico Ohio Oklahoma South Carolina South Dakota Tennessee West Virginia	Louisiana Mississippi			

Table 3: Cluster Characteristics – Mobile Internet Use for Personal Purposes

Cluster	Med Age	African Am Pop.	Asian Pop.	Hisp. Pop.	Age Dep Ratio	Urban Pop.	Mgmt Bus Science Arts Occp.	Serv. Occp.	Patents Issued	Social Capital	Cell Ph. Bill>$75	Freedom
1	34.10	0.45	0.04	0.11	0.50	100.00	0.36	0.07	0.0008	1.45	0.56	1.09
2	38.97	0.11	0.06	0.14	0.67	85.74	0.22	0.08	0.0013	2.73	0.59	0.82
3	42.22	0.06	0.03	0.06	0.70	60.44	0.21	0.09	0.0009	2.98	0.58	0.85
4	37.62	0.10	0.05	0.18	0.71	80.49	0.18	0.09	0.0008	1.97	0.58	0.95
5	38.67	0.10	0.02	0.09	0.74	65.75	0.17	0.08	0.0005	2.00	0.55	0.99
6	37.45	0.35	0.01	0.04	0.72	61.30	0.15	0.08	0.0002	0.50	0.54	0.80

Figure 4 K-means clusters of mobile internet use, personal purposes, 2021



There are a few noticeable differences between the personal use clusters. As shown in Table 3, states in the highest and high use clusters (clusters 1 and 2) tend to be more urban compared to those in moderate, low, and lowest use clusters, with the exception of cluster 4, in which the average urban population is almost 81%. Age dependency ratio also tends to increase from the highest and high use to the moderate and low use clusters indicating the presence of higher per capita children and seniors. On the occupational front, the proportion of population engaged in management, business, science, and arts occupations is highest is clusters 1 and 2 at 36% and

22% respectively, but progressively decreases to 15% in the lowest cluster 6. These differences in demographic and economic attributes point to underlying factors that differentiate US states in terms of their mobile internet use for personal purposes.

Mobile Internet Use for Business Purposes

K-means clusters (k=6) of mobile internet use for business purposes show strong similarity with the corresponding clusters for personal purposes. Washington D.C. with an urban population of 100% is in Cluster 1, followed by six states (in the Northeast, plus Colorado, and Washington state) in Cluster 2 (Table 4). Moderate use of mobile internet for online banking, bill payment, mobile-based purchase, and other business-related activities is found in 12 states in cluster 3, followed by moderate-low use in 20 states in cluster 4.

Table 4: K-means clusters of Mobile Internet Use, Business Purposes, 2021

	1 Highest Mobile Internet Use	2	3	4	5	6 Lowest Mobile Internet Use	MAX	MIN	Ratio = MAX/MIN
Cell Use for business	0.174	0.166	0.158	0.147	0.141	0.126	0.174	0.126	1.386
Mobile Banking	0.300	0.284	0.272	0.253	0.237	0.217	0.300	0.217	1.384
Purchase with text message	0.344	0.321	0.309	0.293	0.281	0.260	0.344	0.260	1.322
Redeem mobile coupon	0.192	0.172	0.164	0.155	0.146	0.141	0.192	0.141	1.355
Mobile Bill Payment	0.210	0.201	0.197	0.188	0.183	0.174	0.210	0.174	1.207
Research product online	0.412	0.392	0.377	0.360	0.343	0.320	0.412	0.320	1.288
Number of States	1	6	12	20	9	1			
	District of Columbia	Colorado Maryland Massachusetts New Hampshire Virginia Washington	Connecticut Delaware Idaho Minnesota Nevada New Jersey North Dakota Oregon Rhode Island Utah Vermont Wyoming	Arizona California Florida Georgia Illinois Indiana Iowa Kansas Maine Missouri Montana Nebraska New York North Carolina Ohio Pennsylvania South Carolina Tennessee Texas Wisconsin	Alabama Arkansas Kentucky Louisiana Michigan New Mexico Oklahoma South Dakota West Virginia	Mississippi			

Cluster 3 states are predominantly in the North and Northwest, Upper Midwest, and the Northeast. Cluster 4 states are found all over the country in the Midwest, South and Southeast, and also in the West. Low to very low use states (10 total) in clusters 5 and 6 are in the rural Appalachia, deep South, and West (New Mexico). Much like personal use clusters, the ratio of highest to lowest use for the six dependent indicators of business use of mobile internet varies between 1.207 to 1.386 indicating that the extent of disparity between the leading and lagging states is not too high.

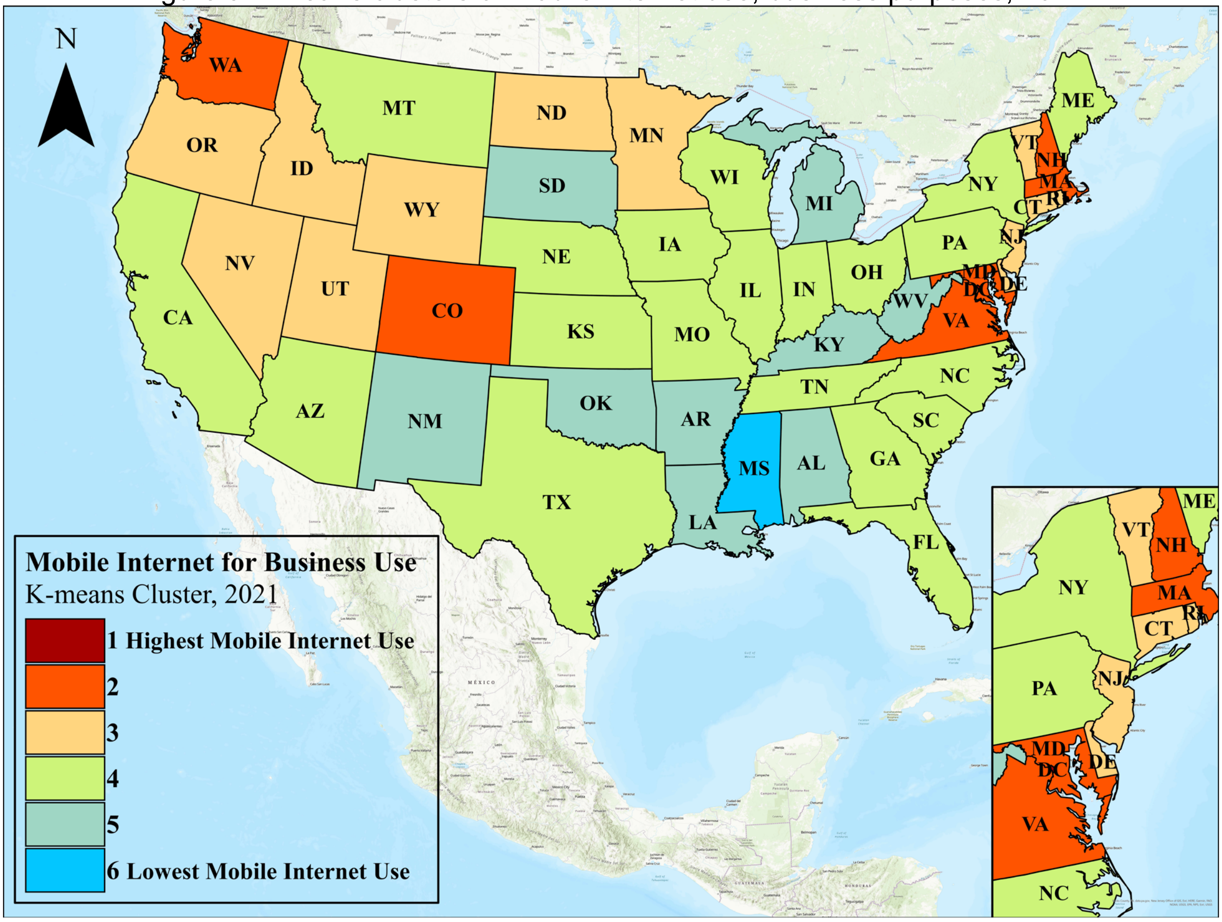
For business use clusters, it is noticeable (from Table 5), that states in the moderate and low use clusters are comparatively less urban than highest and high use clusters with an almost 17% difference in urban population per capita. Another noticeable difference is in the proportion of population engaged in management, business, science, and arts occupations. States in clusters 1 and 2 average 36% and 23% of their populations in MSBA occupations, while states in clusters 5 and 6 average 16% and 14% respectively. Some other differences such as patents issued per capita are also observed between the high and low use clusters. Overall, cluster analysis findings point to some demographic, occupational, and innovation-related underlying factors in mobile internet use differences for both personal and business purposes.

Table 5: Cluster Characteristics – Mobile Internet Use for Business Purposes

Cluster	Med Age	African Am Pop.	Asian Pop.	Hisp. Pop.	Age Dep Ratio	Urban Pop.	Mgmt Bus Science Arts Occp.	Serv. Occp.	Patents Issued	Social Capital	Cell Ph. Bill>$75	Freedom
1	34.10	0.45	0.04	0.11	0.50	100.00	0.36	0.07	0.0008	1.45	0.56	1.09
2	39.08	0.11	0.06	0.12	0.66	80.88	0.23	0.08	0.0013	2.86	0.60	0.99
3	38.47	0.06	0.04	0.13	0.71	77.50	0.20	0.09	0.0009	2.72	0.58	0.86
4	38.82	0.12	0.04	0.13	0.72	74.33	0.18	0.08	0.0007	2.03	0.56	0.93
5	38.69	0.12	0.02	0.10	0.74	63.38	0.16	0.08	0.0004	1.40	0.55	0.96
6	37.70	0.38	0.01	0.03	0.74	49.40	0.14	0.07	0.0001	1.00	0.52	0.75

Finally, it is important to note that the clusters of both personal and business use of mobile internet show states that are spatially contiguous, as seen in Figures 4 and 5. This spatial contiguity of clusters is in alignment with Tobler's first law of geography, which states ""Everything is related to everything else, but near things are more related than distant things (Tobler, 1970)." This spatial arrangement has implications; the agglomeration of states that are similar to each other in terms of their mobile internet use for both personal and business purposes points to the possible presence of spatial bias, which manifests itself in the form of spatial autocorrelation (Longley et al., 2015). Spatial autocorrelation analysis of the 12 dependent indicators of mobile internet use for the diagnosis of spatial bias is outlined as a future research direction.

Figure 5 K-means clusters of mobile internet use, business purposes, 2021



DETERMINANTS OF MOBILE INTERNET USE

Ordinary Least Squares (OLS) stepwise regressions were conducted to analyze the associations of 12 independent variables – demographic, occupational, innovation, social capital, affordability, and extent of freedom with the 12 dependent indicators of mobile internet use. For each OLS regression, the sample size is n = 49 states (lower 48 states plus Washington D.C.), therefore care was taken to ensure that no more than 5 explanatory variables were used for any regression.

OLS regression results (in Table 6) reveal that the most dominant correlates of mobile internet use are median age and age dependency ratio among the demographic variables, management, business, science, and arts occupations (MBSA) among the occupational variables, and affordability (measured by the proportion of population whose monthly cell phone bill exceeds $75). Median age is positively associated with 10 out of the 12 dependent variables, indicating that age increases, mobile internet use for both personal and business needs tends to increase. This finding is somewhat surprising since higher age has often been perceived to lower technology adoption and usage, particularly internet use. However, it may be the case that the ubiquity of cell phones, in particular smartphones is gradually allowing individuals across age groups to access and use the internet and participate in cell-phone based digital activities more evenly. Affordability is also positively associated with 11 out of the 12 dependent variables indicating that as the proportion of population in US states with monthly cell phone bill exceeding $75 increases, mobile internet use tends to increase. Since higher cell phone bills are often associated with high volume data plans, it is likely that those with such plans are more likely to engage in a wide variety of activities using cell phones, particularly those that consume higher volumes of data such as watching and accessing the news, making video calls, and researching products and services online. Age dependency ratio is inversely associated with 7 out of the 12 dependent variables indicating that as the proportion of those younger than 19 years old and older than 65 years old increases, mobile internet use tends to decrease. This combined with the positive association of median age with the dependent variables points to the dominance of cohorts in age groups 20-64 years with mobile internet use. Viewed in another way, this cohort, also referred to as the working age population appears to drive mobile internet use for both personal and business purposes.

Management, Business, Science, and Arts (MBSA) occupations is found to be positively associated at the .01 level or lower with 7 out of the 12 dependent variables. MBSA include a broad set of occupations including management, business, and finance, computer and mathematical, engineering, architecture, healthcare, and life, physical, and social sciences. Those engaged in such occupations are often highly educated and high earners (Pearson correlation coefficients of MSBA with Bachelors education of .958, and with median household income of .846, both significant at the .001 levels). It is likely that such individuals are likely to be more skilled internet users and their professional and personal needs spur mobile internet use for both personal and business purposes.

The three dominant correlates – median age, MBSA occupation, and age dependency ratio are followed by the extent of freedom, measured in the study by the freedom index. Extent of freedom in US states is found to be positively associated with 6 out of the 12 mobile internet use dependent variables. The index of freedom, comprised of personal, fiscal, and regulatory components points to the overall importance of societal openness in relation to mobile internet based activities. This is a novel finding for the US digital divide, particularly in light of personal freedom oriented societal discourse in the United States during the COVID-19 pandemic.

Apart from these variables, race and ethnicity is found to have inverse association with a small set of dependent variables, particularly the indicators of business use. Such inverse associations of African American and Hispanic segments of the population are consistent with lower levels of technology (internet) access, adoption, and usage among these race and ethnic groups. That said, increases in internet connectivity in minority race and ethnic groups have been reported between 2019-2021 (Goldberg, 2022). Among other variables, urban population is found to be positively associated with only 2 of the 12 dependent variables – cell phone use for business purposes, and for viewing the news on a cell phone. While the urban-rural digital divide in the United States has been documented in several contexts, urbanization is a not a dominant correlate for mobile internet use. OLS regressions also reveal limited association of social capital with 2 of the 6 dependent indicators of personal use, including text messaging family and friends. This finding points to the limited role of social bonding and transfer of skills between cell phones users using mobile internet. Lastly, service occupation and patents issued per capita are found to have no association with any of the dependent variables.

The Variance Inflation Factor (VIF) for each of the regressions is lower than a cutoff of 5.0 (bottom of Table 6) indicating that multicollinearity is not of concern. Finally, our conceptual model of mobile internet use explains 62.2-92.6% of the variation in the dependent variables, showing the robustness of the predictive power of the proposed model.

Table 6: OLS Regression Results

		Personal Use						Business Use					
	Independent Variables	Individual used Cell Phone for personal use	Individual has viewed the News on cell phone	Individual used cell phone to access Social Media	Individual used cell phone to access a search engine	Individual used cell phone to text message friends/family	Individual Used Cell Phone For Video Call	Individual used Cell Phone for business use	Individual used mobile device to do banking	Individual used cell phone to make purchase w/ text	Individual used cell phone to redeem a mobile coupon	Individual paid bills with mobile phone	Used Cell Phone to Research Product
Demographic	Median Age	0.750***	0.299***	0.193*	0.242***	0.639***	0.104*		0.183**	0.175**	0.175**		0.164**
	African-American Pop%							-0.215***				-0.292**	
	Asian Pop. %						0.167*					-0.530***	
	Hispanic Pop. %							-0.460***		-0.128*			
	Age Dep. Ratio		-0.223***	-0.243**	-0.152*		-0.334***				-0.414***	-0.572***	-0.223***
	Urban Pop. %		0.131*					0.170*					
Occupational	Management, Business, Science, & Arts Occupations %		0.317***	0.330**	0.398***	0.129		0.425***	0.397***	0.268**		0.097	0.404***
	Service Occupations %								0.124*	0.158**			
Innovation	Patents												
Social Capital	Social Capital Index	0.415***				0.223*							
Affordability	Monthly Cell Bill is at least $75		0.475***	0.503***	0.540***	0.435***	0.642***	0.484***	0.581***	0.723***	0.668***	0.497***	0.498***
Freedom	Freedom Index	0.161*		0.237**	0.150**	0.228*			0.134*				0.143**
	Var. Inf. Fact.	1.010	2.733	2.474	2.474	3.605	2.042	3.081	2.36	3.051	1.326	2.43	2.474
	Adjusted R^2	0.729***	0.926***	0.801***	0.885***	0.729***	0.898***	0.911***	0.857***	0.894***	0.841***	0.622***	0.891***
	Sample Size	49	49	49	49	49	49	49	49	49	49	49	49
	* p < 0.05, ** p < 0.01, *** p < 0.001												

Overall, OLS regressions findings shed light on the importance of demographic (age-related), economic (MSBA occupation), and affordability factors for mobile internet purposeful use in US states. Regressions findings also reveal that freedom and societal openness in US states also influences mobile internet's purposeful use. The limited influence of traditional factors such as race and ethnicity as well as urbanization is also revealed. The findings are also largely similar for both types of purposeful use of mobile internet – personal and business. The implications of these findings are discussed next.

DISCUSSION AND IMPLICATIONS OF FINDINGS

The findings in Figures 2 and 3 provide overall contrast between personal use and business use of the mobile internet. Although there are similarities in the generally much higher relative use of the internet in the north of the US compared to the South, there are some fine spatial differences that are revealing.

Consider first that the range of personal use is slightly higher than for business use. This can be observed by looking at the legends for the personal compared to the business use. The high category for personal use, compared to the low category, is about 8 percent higher, whereas for business use the high category is only 5 percent higher. This implies that personal use of cell phones is slightly more uneven in proportion of use throughout the nation, which might relate to the near saturation of cell phones in the US population, as seen in the 85% presence in households of internet subscriptions in 2018 (Martin, 2021), a figure that is expected to be higher in 2021 due to greater need to use the internet during the pandemic (McClain et al., 2021. On the other hand, the slightly lower percentage variation in business use might be the result of a broad range of pandemic impacts on businesses, many of which scaled back on workforce and capital expenditures.

Comparing the spatial distributions of personal and business mobile use more closely (Figures 2 and 3), it is also evident in the most populous states with the largest metropolitan regions in the country, namely New York, Illinois, and California, were in the lowest category of personal mobile use, but in moderate or high categories for business mobile use. This might reflect that New York was among the hardest hit metropolitan areas in the nation in the first year and a half of the pandemic, which might have marginally lowered mobile personal uses. Chicago and to a lesser extent, Los Angeles metropolitan areas were also hard hit.

Discussion and implications of cluster findings

K-means cluster analysis for personal use and business use resemble each other more closely than the contrast just discussed for the individual personal and business variables. The cluster approach may realize these greater similarities through the algorithms of calculating cluster groupings. In both cluster analyses, the very highest singleton cluster is Washington D.C., which reflects the very high dependency on the mobile internet there. From the standpoint of explanation, Washington DC has high education, is 100% urban and has high concentrations of MBSA occupations. It is interesting also that DC has a high proportion of African American population, which reflects improvements in racial/ethnic mobile internet usage. At the low end of clusters is Louisiana and Mississippi for personal mobile internet use and Mississippi for business mobile internet. These states are known to have very low technology and internet utilization from other studies. There is mostly strong geographic agglomerations following Tobler's Law. This includes at the high end (cluster 2) the agglomerated areas in the Boston to Washington megalopolis, although for business use, cluster 2 splits into two pieces. For both cluster maps there are several isolated cluster 2 states, in particular, for personal use, Washington state, Colorado, and Minnesota, and for business use, Washington and Colorado.

Discussion and implications of regression findings

The regression findings reveal as determinants many aspects that are heretofore unreported. This includes the positive effect of median age, which is opposite to many other studies, but may reflect pandemic influences on evening out age differences. The strong effect of MBSA occupations may relate to its close correlation with education and it also confirms the Florida (2012) results on creative occupations tied to technology-based cities. The strong association with monthly cell bill of at least $75 has rarely been reported in US studies and points to the need to have future research to determine why it has appeared so prominently in 2021. The lack of association for urban population for both personal and business dependent variables reflects an evening out of the geographic spread of the mobile internet, while also possibly reflecting pandemic-related movement of people and household out of urban areas. Again, the explanation points to need for further research emphasizing fine points of urban geographies.

CONCLUSION, LIMITATIONS, AND FUTURE RESEARCH

This study has analyzed mobile internet use for the states of the United States. The study utilizes a variety of survey and government data. The dependent variables are for year 2021, which reflects the influence of the covid-19 pandemic. The conceptual frame is SATUM, which includes spatial and multivariate analytics. The dependent variables reflect purposeful use of mobile devices and groups the usage into five variables each for personal and business usage. The independent variables are ones either induced from the digital divide literature or reasoned by the investigators, an approach appropriate for exploratory research.

The findings indicate distinctive and in some ways new geographical patterns of dependent variables and k-means clusters. There are new patterns that emerge such as the states with big metro areas being classified in the lowest cluster category for personal use and the distinctive cluster leadership of Washington DC in mobile internet purposeful use. Some of the mapping subtleties are not immediately interpretable and need further research.

The OLS regression analysis is surprising in the positive effect of median age, and the strong effects of MBSA occupation, monthly cell phone bill of at least $75, inverse effect of dependency ratio, and impact of the Freedom Index, especially for personal use, while the usual effect of urban has little presence.

The study has the limitation of using the state geographic unit, which might obscure more detailed within-state tendencies. It also does not do a direct comparison of 2021 dependent variables with the same set of pre-pandemic ones.

It is hoped that this exploratory study will stimulate further research to explain some outcomes and associations that are unclear in interpretation based on the digital divide literature. It is also hoped that future research will expand the range of purposeful uses and begin to sort out patterns and groupings of the many purposeful uses available.

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DECISION SCIENCES INSTITUTE
Qualified Charitable Distributions Four Plus Years After Tax Reform

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ABSTRACT

The Internal Revenue Code allows certain seniors to make direct charitable distributions from their individual retirement accounts (IRAs) without including the transferred amount in gross income. This provision for qualified charitable distributions (QCDs) can benefit many more seniors than before because of changes made by the Tax Cuts and Jobs Act of 2017 (TCJA), which greatly increased the standard deduction, and many individuals will no longer itemize their deductions. This paper explores this provision and the possible benefits, especially in light of tax reform.

KEYWORDS: Qualified Charitable Distributions (QCDs), Tax Reform, Charitable Contributions, Individual Retirement Accounts, Required Minimum Distributions

INTRODUCTION

Internal Revenue Code (IRC) § 408(d)(8) allows direct charitable contributions to be made from individual retirement accounts (IRAs) without the donor being required to include the amount in gross income. Of course, amounts excluded from income under this provision are ineligible to be claimed as charitable contributions for taxpayers who itemize their deductions.

The qualified charitable distribution (QCD) was added by the Pension Protection Act of 2006 (Pension Protection Act, 2006). The QCD originally passed as a temporary law but was extended multiple times and made permanent by the Consolidated Appropriations Act, 2015 (Consolidated Appropriations Act, 2015). While no law is necessarily permanent, the QCD has no expiration date at this time.

The effects on tax planning are substantial and not to be ignored. Some of the benefits to be enjoyed are simply reducing adjusted gross income with its various effects; claiming the enhanced standard deduction and still receiving a tax benefit from charitable giving; and for many, paying less tax on Social Security benefits and possibly reducing their Medicare insurance premiums.

While this section of the tax code will not benefit everyone, it can be important to a specific set of taxpayers who meet the requirements and who desire to make contributions to charities. Of course, charities will want to approach potential donors who may benefit from this tax law, as it might increase the amount of contributions received. Because this tax provision is no longer temporary, donors and charities can better plan how to use this tax law without having to worry about its expiration.

QUALIFIED CHARITABLE DISTRIBUTIONS

Current law (IRC, § 408(d)(8)) allows distributions to be made directly from a traditional individual retirement account (IRA), but not other traditional retirement accounts, to a charity without having to be included in the taxpayer's income and then claimed as a charitable contribution deduction. QCDs have several limitations or qualifications.

- The contribution must be made directly from the IRA to the charitable entity. It cannot be withdrawn from the IRA by the account holder and then contributed to the charity. Thus, a QCD would require cooperation between the IRA manager and the charity so an appropriate transfer could be made.
- Most entities that qualify for charitable contribution status can receive these contributions, but private foundations and donor advised funds are excluded.
- The account holder must be at least 70½ at the time of the transfer.
- The annual amount for a QCD is capped at $100,000, so the ability to take advantage of this tax provision is not unlimited (IRC, § 408).
- With other charitable donations, if the donor receives something of value from the charity, the value received must be subtracted from the amount contributed. However, for QCDs, the entire amount of the donation must otherwise have been deductible (i.e., nothing of value can be transferred to the donor).

While taxpayers who itemize can take a deduction for charitable contributions, this is not true for QCDs. Because the taxpayer already gets a tax advantage by not claiming the IRA distribution as income, no further tax advantage is available.

TAX REFORM

The Tax Cuts and Jobs Act of 2017 (TCJA) (Tax Cuts and Jobs Act, 2017) is known for a large number of changes including temporary (generally 2018 – 2025) reductions in tax rates, repeal of the personal and dependency exemptions, increase in the child tax credit, and a substantial increase in the standard deduction. The other changes included in the bill, though massive, do not generally impact QCDs. Perhaps the most significant aspect is the impact on whether taxpayers itemize their deductions or not. Because fewer taxpayers are itemizing their deductions under this tax reform, many of them who make significant charitable contributions may not be getting a specific tax advantage by doing so. However, if they qualify for a QCD, they can get a tax benefit from their contributions without itemizing.

The increase in the number of taxpayers claiming the standard deduction, rather than itemizing, is revealed in the Internal Revenue Service's Statistics of Income Report.

Table 1. Individual Tax Return Statistics (selected).
(SOI, 2019, Individual Income Tax Returns Complete Report, Table A)

	2017	2018	2019
Number of individual tax returns filed	152,903,231	153,774,296	157,796,807
Number of individual tax returns claiming the standard deduction	104,013,115	134,271,137	138,307,804
Percentage of tax returns claiming the standard deduction	68.03%	87.32%	87.65%

ADVANTAGES OF QUALIFIED CHARITABLE DISTRIBUTIONS

Several possible advantages can result from the ability to make charitable contributions directly from an IRA. The charitable contribution deduction for cash contributions is limited, generally to 60 percent of adjusted gross income (AGI) from 2018 to 2025 (50 percent for years leading up to 2018, and remarkably, 100% for 2021 only) (IRC, § 170(b)(1)(G)). If a taxpayer gives more than is allowed, the excess can be carried forward for up to five years and provide a potential future tax benefit. However, if a QCD is made, the amount, although not deductible, is excluded from income and never affects the contribution base. Therefore, a taxpayer can give up to an additional $100,000 directly from an IRA without worrying about this amount being limited. Note however, if the distribution had been taken, followed by a contribution to charity, AGI would increase with multiple ramifications.

Taxpayers, especially seniors who may no longer be paying interest on a mortgage, might not have enough total deductions to itemize, especially with the enhanced standard deduction and the limited deduction for state and local taxes from 2018 to 2025.

> Example. The standard deduction on a joint return for 2022 is $25,900, but there is an extra $1,400 each for those over 65 years of age, meaning that the standard deduction is $28,700 if both are 65 or over. If such a couple had only $10,000 of other itemized deductions and wished to make a charitable contribution of $20,000, they would only gain a tax benefit from $1,300 of the contribution [$10,000 + $20,000 - $28,700]. However, if this couple was able to make the $20,000 charitable contribution through a QCD, their income would not change, they would claim the standard deduction, for a net reduction in their taxable income of $20,000 ($18,300 more than they would have received from the itemized deduction).

One aspect of tax reform limits the deduction for state and local taxes to $10,000. As a result, many fewer taxpayers will itemize, especially couples since the $10,000 limit is the same for them as it is for singles and heads of household.

> Example. Owen, age 67, itemized his deductions in 2021, but did not anticipate itemizing in 2022 – 2027. Late in 2021, Owen accelerated some charitable contributions. Owen does not anticipate making significant charitable donations until he reaches age 70½ in 2025 when he can make QCDs from his IRAs.

For 2021, couples could deduct up to $600 ($300 for other taxpayers) of cash charitable contributions from AGI without itemizing deductions (IRC, §170(p)). That reduced some tension because until reaching age 70½ they can make small deductible contributions. If they had reached age 70½, they could combine making smaller contributions in cash within the

$300/$600 limitation and make larger contributions as QCDs. Time will tell whether Congress extends this provision.

Many items involved in the income tax calculation are affected by the amount of AGI. For example, a reduction in AGI might result in:

- Less of the senior's Social Security benefit being included in AGI;
- Reduction of the senior's Medicare insurance premium;
- More medical expenses being deductible by some taxpayers because they are deductible to the extent they exceed 7.5 percent of AGI;
- Higher casualty loss deductions, even though the number of allowable casualties was reduced by TCJA, because they are reduced by 10% of AGI;
- Reduction or elimination of the 3.8 percent § 1402 net investment income tax;
- Reduction or elimination of the 0.9 percent additional Medicare tax.

A traditional IRA can include amounts that were contributed both on a pre-tax or an after-tax basis, either directly into the account over a period of years or rolled over to an IRA from an employer-sponsored retirement plan. The contributions that went into the IRA on a pre-tax basis will be taxed as they are distributed. The contributions that went into the IRA on an after-tax basis will not be taxable when they are distributed. However, the earnings from both pre-tax and after-tax contributions in an IRA are deferred from taxation until distributions are made. For regular distributions from an IRA with both pre-tax and after-tax amounts, the amount of the annual distribution is split between taxable and nontaxable portions, at least until all the after-tax contributions have been withdrawn (IRS Publication 590-B). If an individual has multiple IRA accounts, they are all treated as one account and all distributions for the year are treated as one distribution in calculating the taxable and nontaxable portions of the distribution (IRC, § 408).

However, a special rule exists for QCDs. Since only the taxable portion of an IRA distribution can become a QCD, the law allows the entire distribution to come from the taxable portion of the IRA (up to the taxable amount in the IRA) first, thus increasing the benefit of the QCD to the taxpayer (IRC, § 408). If a taxpayer has multiple IRAs, they are again combined in determining the taxable portion that can meet the definition of a QCD. Of course, once a QCD is made from the IRA, a recalculation would need to take place as to the taxable and nontaxable amounts for future IRA distributions.

For a traditional IRA, once the account holder reaches the age of 72, annual distributions from the IRA are required. These are called required minimum distributions (RMDs). The RMD each year is recalculated based on the value in the account and the expected lifespan for the account holder under government prescribed mortality tables (IRS-Retirement Topics). The taxpayer can choose to withdraw more than the RMD from the IRA in a given year, but taxes will be due on all portions taken in cash (both contributions and earnings) that were not previously taxed.

Although the government allows tax deferrals for certain IRA contributions and for the increase in value during a normal working period for the taxpayer, the account cannot grow tax free in perpetuity. The government wants to get taxes on the money at some point in time, so the RMD is set so a portion of the pre-tax account balance becomes taxable each year. However, if a QCD is made from the IRA, the amount of that distribution helps to meet the RMD for the year, but the qualifying distribution would not be taxable. Besides the amount of the distribution itself not being taxable, the exclusion might keep the taxpayer in a lower tax bracket than if the RMD all had to be claimed as income for the year. If more than the RMD is distributed from an IRA in a given year, either as a withdrawal or for a QCD, the excess withdrawn or transferred would not count toward future years' RMDs.

The $100,000 limit on QCDs is an individual, annual limit. Therefore, up to $100,000 can be transferred in this manner each year. In addition, if a spouse also has an IRA, joint filers could actually exclude up to $200,000 per year from QCDs but community property laws are ignored, so both spouses cannot make a QCD from one spouse's IRA (Treas. Reg. § 1.408-1(e)). IRAs left in an estate could be subject to both income and estate taxes. Any amounts distributed before death through QCDs would reduce potential estate taxes.

IMPLICATIONS AND DISCUSSION

While QCDs may have great advantages for taxpayers who qualify to use them, specific requirements must be met, so not all taxpayers can benefit. A taxpayer must be at least 70½ years old and must have saved money in an IRA, either through direct contributions or through a rollover from some other retirement plan.

Direct rollovers are generally tax and penalty free, as are withdrawals that are deposited in a different retirement account within 60 days (IRC, §408(d)(3)(B)). Once a taxpayer reaches age 59½, there are generally no penalties, so these rollovers can defer any tax and if the rollover is to an IRA, the funds are available for possible QCDs. Any penalties assessed by the plan sponsor would complicate planning. There may also be plan specific limitations.

> Example. Richard, denying his advanced age, placed rollover funds into an IRA and the money was placed in a 5-year investment with early withdrawal penalties. Upon reaching age 72, Richard wanted to roll the IRA money into an employer sponsored § 401(k) that does not require RMDs because Richard is still working. The penalties in Richard's case are significant enough to cause Richard to delay the rollover.

For a QCD to work, the taxpayer would also need a desire to contribute to a qualified charity and get cooperation from the charity to process the direct contribution and provide appropriate acknowledgement. As mentioned above, those who qualify to use this exclusion of income from an IRA for charitable purposes can possibly have significant tax advantages.

Permanence in this tax law aids the ability of individual taxpayers to plan longer-term donation/tax strategies. Taxpayers can work with their tax advisors to better maximize the benefit of whatever charitable contributions they want to make. Permanence in this tax law also allows charities to develop better planning tools to encourage and educate donors and potential donors of the advantages to this tax law.

> Example. Philip has worked many years and made significant contributions to his company's § 401(k) plan, but he has no IRAs. Philip could roll over some of his § 401(k) balances to an IRA and then make the QCDs from that account.

> Example. Keith and Marie have accumulated significant wealth as real estate investors. Most of their assets are commercial rental properties held in limited liability companies (LLCs) that report as partnerships. They have no retirement accounts and are a bit stressed because their only significant itemized deductions have been personal state and local taxes plus charitable contributions. With the $10,000 limit on the deductions for state and local taxes and the $25,900 (or more) standard deduction, they will receive no tax

benefit from the first $15,900 of charitable contributions. Keith or Marie could arrange to take a partner's salary from an LLC. The salary, called a "guaranteed payment," would be deductible to the LLC and ordinary income to the owner. Keith and Marie could then make modest deductible contributions to IRAs and then QCDs from the IRAs. This is not cost free, as the guaranteed payments would be subject to self-employment taxes.

MUST BE PART OF A COMPREHENSIVE FINANCIAL PLAN

While QCDs may now be more favorable for a larger group of taxpayers because of tax reform, cash and QCDs are not the only choices available for making charitable contributions. Gifting of highly appreciated property, for example, provides a very attractive result. Except for ordinary income property and certain tangible personalty not used in the exempt function of the charity, the donor is entitled to a deduction equal to fair market value and never incurs income tax on the appreciation. Charitable individuals could also include the charity as a beneficiary on life insurance.

Under current law, the heir or estate gets a step-up in the basis of the appreciated property, but not in a traditional IRA since the distributions are income in respect of a decedent. Donating IRA balances, that are not subject to the step-up, stack up rather nicely against gifts of appreciated property. However, those considering major gifts may consider making both.

These are just some examples of why, although QCDs may produce favorable benefits for a larger group of charitable taxpayers under tax reform, other alternatives for funding charitable intentions must be considered if the contributor has varied means to contribute. The financial plan should consider all the options available to achieve the optimal amount and timing of benefits to the donor and the charity.

CONCLUSION

QCDs can be made from an IRA without having to be included in income. Because of tax reform at the end of 2017 (Tax Cuts and Jobs Act, 2017), more taxpayers may be benefitted by making charitable contributions through a QCD, as fewer taxpayers are itemizing deductions because of the increase in the standard deduction. For those who meet the requirements, a QCD can be a way of contributing to a charity while gaining some possible tax advantages which might be better for the taxpayer than a specific distribution from the IRA which would be included in income, even if that amount is then donated to charity and subtracted as a charitable contribution deduction on the tax return. The implications for both taxpayers and charities can be significant. However, even if the QCD law does not change, other tax laws that change can affect the benefits taxpayers can achieve through a QCD, so multi-year tax planning needs to consider these changes over time.

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DECISION SCIENCES INSTITUTE
Recalls, Reputation, TMT, and Reverse Logistics:
The Effects on Operational Performance

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ABSTRACT

Firms' reverse logistics operations are generally designed to retrieve, recover, or recapture for value a used product from a customer. However, how firms' reverse logistics operations respond to either a voluntary or involuntary product recall is an under-research phenomenon. Product recalls are costly, and firms need to better understand how to anticipate and respond these events. Employing an integrated contingency theory and punctuated equilibrium theoretical perspective, this exploratory study investigates product recalls and its impact on firms' reverse logistics operations. Both Contingency Theory and Punctuated Equilibrium Theory are useful for understanding how firms interact with their internal and external environments. We are also interested in understanding whether the impact of a product recall is mediated by the firm's top management team (TMT) composition, and [brand] reputation. This study builds on exiting empirical work by Wowak & Boone (2015). We provide a Reverse Logistics Process Model and a Reverse Logistics Disruption Probability Matrix to offer greater insight and understanding of firms' reverse logistics operations. We contribute to the literature by providing a novel theoretical perspective through which to view the product recall and reverse logistics phenomenon.
KEYWORDS: Product recalls, Reverse logistics, TMT, Supply chain management

"An ounce of prevention is worth a pound of cure."
--Benjamin Franklin

INRODUCTION

Supply chains are generally designed to optimize the one-way, i.e., forward flow of goods and services (Wowack & Boone, 2015). However, there is the occasion, not so rare these days, for the return flow of goods back to the focal company. These reverse flows can wreak havoc on a company's reverse logistics operations and ultimately operational performance. One form of reverse flow is a product recall. In 2015, the National Highway Transportation and Safety Administration (NHSTA), the Consumer Product Safety Administration (CPSA), the Food and Drug Administration (FDA) and Food and Safety Inspection Service (FSIS) issued a total of 4,217 product recalls (Statistica.com, 2017). Although there was some fluctuation in the numbers – it was over 5,008 in 2012, before falling to 4,181 in 2014 and has been increasing steadily to 4,217 in 2015 - companies still seem ill-prepared for product recalls. While companies may prepare for a disruption in the forward logistical operations (Shefi & Rice, 2005), there appears to be minimal to almost no planning in their reverse logistical operations for a product recall.

Products re-enter a firm's reverse logistics operations for a variety of reasons (Sowinski, 2011; Witt, 2007). In their study, Lyles, Flynn & Frohlich (2008) noted that there were two primary reasons for a product recall: 1. manufacture defects in which the product does not conform to specifications; and 2. design defects in which the product does not meet safety standards (p.169). However, there are some instances when the product recall has a positive outcome. Companies may seek to recover a product at the end of its useful life (Georgiadis &Vlachos, 2004). This study focuses on the negative reasons why a product re-enters a firm's reverse supply chain and its impact on a firm's reverse logistics operations and ultimately, firm operational performance. In the literature, reverse logistics is defined as "The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purposes of recapturing value or disposal" (Chan et al., 2012:1319 c.f. Rogers & Tibben-Lembke, 2001:130). We regard reverse logistics as the process of efficiently and cost-effectively recapturing products from consumers that are either for reuse in the secondary market, at the end of their useful lives, for disposal, or that may be a danger to the public health. We posit that product recalls significantly punctuate a firm's forward and reverse logistical operations. These firms then seek to find convergence to return to standard operations.

Product recalls can be particularly challenging for firms focused on the forward flow of goods to customers (Mollenkopf et al., 2011). Firms engaging in a product recall do not always possess the logistical means to retrieve the product from consumers or to divert it to some third-party logistics provider. Whether the product is biological (e.g., food) or non-biological (e.g., an electrical device), or defective or dangerous, determines the recall process and logistical strategy (Simonsen & Lippincott, 2008). In some instances, a defective product may be destroyed rather than returned to the manufacturer. Although the literature treats a product recall as distinct from a supply chain disruption (see Wowak & Bone, 2015), a product recall may be regarded as the proximal cause of a focal firm's supply chain disruption. There is discussion in the literature that these types of disruptions are totally within the firm locus of control (Lyles et al. 2008). This view may be derived from the fact that product recalls are the result of a company's action or inaction, i.e., a failure of the firm's internal processes (Wowak & Boone, 2015). However, because the disruption occurs in the firm's reverse logistics operations, the focus should be on decision-making on the firm's top management team (TMT). In their study, Chan et al (2012) focused on several barriers that inhibit implementing RLO in the automobile industry. We highlight one of those barriers in the study – the management barrier. In this study, we seek to address the following research questions: 1. What is the relationship between an unannounced product recall and a firm's reverse logistics operations? 2. To what degree does TMT composition, and brand reputation mediate the effects of a product recall on a firm's reverse logistics operations? 3. Does a product recall negatively effects a firm's operational performance?

Product recalls have been discussed extensively in the literature and practitioner press (DiBenedetto, 2007; Field, 2006; Simonsen & Lipppincott, 2008; Sowinski, 2011; Witt, 2007). However, with the limited exception of Smith et al. (1996) and studies by Kocabasoglu et al. (2007); Magno (2012); Mollenkopf et al. 2011, and Wowak & Boone (2015), not much attention has been devoted by scholars to understanding the importance of reverse logistics and its impact on firm performance. In their study, Georgiadis & Vlachos (2004) noted that the long-term effects of product recalls on firms' reverse logistics systems are an understudied phenomenon. In this study, apply a contingency and punctuated equilibrium theoretical perspective to increase our understanding of this phenomenon. Punctuated equilibrium (Gersick, 1991; Tushman & Romanelli, 1985) has been utilized in the literature to explain how companies may respond to supply chain disruptions. Contingency theory helps us to understand how firms operate in their task environment (Lawrence & Lorsch, 1967; Thompson, 1967). Integrating these theoretical perspectives increases our understanding of the effects of product recalls on firms' reverse logistics operations. We are not aware of any studies where such an integrated theoretical framework has been utilized to predict or explain how firms may respond to a product recall or how they manage their reverse logistics operations.

In examining the punctuated equilibrium effects of product recalls on firms' reverse logistics operations and firm performance, we make several contributions to the literature. First, we provide a novel theoretical perspective to understand the phenomenon. Second, we examine the role of the TMT in RLO strategic decision-making process. Finally, we examine some contextual factors that may determine the effectiveness of firms' reverse logistics operations.

PROPOSED RESEARCH MODEL AND THEORETICAL FRAMEWORK

This study integrates two theoretical perspectives: punctuated equilibrium and contingency theory. Firms experiencing a supply chain disruption seek to regain stasis as quickly as possible. Punctuated equilibrium offers a perspective to help us understand the impact of disruptions on supply chain management. Punctuated equilibrium posits that organizations process through rather stable periods, i.e. convergent periods which are punctuated, i.e. disrupted by reorientations which demark and set the bearings for the next stable, i.e. convergent period (Tushman & Romanelli, 1985). This describes what happens when there is a disruption in a firm's supply chain. For example, before the earthquake and tsunami that disrupted Toyota's operations in 2011 occurred, the company enjoyed relatively stable operations, i.e. a period of converegence. The earthquake and tsunami *punctuated* Toyota's operations. Toyota's recovery demarks its reorientation back to stasis, i.e. normal operations.

In developing their model of organization evolution, (Tushman & Romanelli, 1985) identified three constructs: *convergence*, which they defined as the incremental change mechanisms which supports the firm's overall strategic orientation in a socio-poitical and technical-economic environment; *reorientation,* which they define as the reordering of patterns of consistence toward a new alignment; and *executive leadership*, which serves as the key mechanism of intervention. This last point highlights the fact that leadership from TMTs is an especially crusial factor for firm's return to normalcy after a disruption. Although punctuated equilibrium focuses primarily on internal organizational functions, (Gersick, 1991), we posit that is may be helpful iin our understandng of how firms can respond to exegenous shocks.

The source of uncertainty/risk inside the supply chain and can lead to changing relationships between focal firm and its partners in the supply chains. While punctuated equilibrium aids in our understanding of firms' internal processes, we integrate it with contingency theory to examine firms' responses to endogenous and exogenous shocks. Van de Ven et al. (2013) noted that contingency was useful for studying supply chains. Contingency theory posits that the structure of an organization is contingent on its operating environment; i.e. the interaction of its subsystems; and the belationship between the nature of the task and the organizational structure Donaldson, 2001). Firms' organizational performance depends on the fit between its structure and processes (Drazin & van de Ven, 1985). Changing environmental conditions and changing relationships with external actors require structural changes within the organization (Child, 1972). If a firm experiences a disruption, it must make structural adjustments to is strategies regain fit with the environment (Donaldson, 1987). The (SARFIT) model is useful also useful in explaining how firms respond to a disruption. The proposed research model below depicts the relationship among the variables.

Insert Figure 1 approximately here

PROPOSITION DEVELOPMENT

Product Recalls and Firm Performance

A product recall is a complex and costly process in which a company seeks to retrieve a product that was sold to and is currently being used by customers (Hora, Bapuji & Roth, 2011; Witt, 2007). The various regulatory agencies, Consumer Protection Safety Administration (CPSA), the Food and Drug Administration (FDA) and the National Highway Transportation and Safety Administration (NHTSA) all provide guidance to manufactures on how to proceed with a recall. Recalls can harm a company's brand name which is often the company's most valuable asset (Simonsen & Lippincott, 2008). However, some companies with a good reputation can mitigate the effects of a product recall (Rhee & Haunschild, 2006). A review of the literature indicates that some industries seem to be plagued by recalls: toy industry (DiBenedetto, 2007; Hora et al., 2011); auto industry (Rhee & Haunschild, 2006; Smith et al., 1996); consumer electronics (Field, 2006; Smith et al., 1996); and medical device industry (Thirumalai & Sinha, 2011). The consumer electronics industry and the auto industry are often featured in news stories regarding the quality of their products (Smith et al. 1996).

Supply chain disruptions can have significant impact of a firm's operational and financial performance and can sometimes result permanent damage to the brand, loss of reputation and goodwill with customers (Kumar & Schimitz 2011; Speier et al., 2011). The disruption may be even more detrimental when the company is facing a reverse logistics problem. Product recalls create significant challenges for firms reverse supply chains. Supply chains are more resilient at responding to forward flow disruptions (Ambulkar et al. 2015; Sheffi & Rice, 2005). However, the infrastructure is generally not in place for many companies to handle the large-scale unscheduled reverse flow of goods. These reverse flows are extremely expensive. "Reverse logistics is not mainstream shipping" (Witt, 2007). In the general course of business companies will ship a full truck load (FTL) of goods. When there is a recall, the reverse flow may be less than a full truck load (LTFTL). Given the foregoing discussion we posit that firms that issue a recall are more likely to experience negative operating performance.

P1. *Product recalls are negatively related to firm operational performance.*

Product Recalls and Reverse Logistics

Firms generally are not prepared to handle more than staple returns, e.g., a consumer returning a piece of electronic equipment a week after the purchase. Although most firms do not have expanded reverse logistics operations, they can still engage in strategic endeavors to mitigate the costs of returns or recalls on their bottom lines. Firms can improve their financial and operational performance by implementing quality management (QM) practices (Kaynak, 2003; Zhang & Xia, 2012). Implementing QM lowers the risk that the firm will produce defective products. Reducing the probability of recalls benefits firms' operational and financial performance. However, it has not been borne out that the benefits of QM are sustainable (Beer, 2003). In their study, Zhang & Xia (2012) noted a lack of focus on quality can have damaging effects on a firm's bottom line as evidenced by the massive recall of beef products by Hudson Foods.

Announcing the recall of a product initiates the reverse logistics process (Ni, Flynn & Jacobs, 2014). The product may be returned to the original equipment manufacturer (OEM) of some third-party logistics provider (3PLs) (Witt, 2007). How quickly or slowly a company responds to a problem with its product determines whether a recall becomes a crisis. There may be a narrow window of opportunity through which companies may successfully initiate a recall. In their study, Hora et al. (2011) noted that companies faced two problems: 1. the time difference between the product's sale and the announcement of its recall; and 2. the time between the announcement and the actual recovery of the product through the reverse supply chain. Johnson and Johnson's handling of the tampering with Tylenol in 1982 is now considered a casebook example of how companies operate when issuing a recall. Berman (1999) provides a framework for how companies should engage in the recall process. We provide a modified classification system (see Table 1 below) which delineates the difficulty of recovering a recall product (Berman, 1999). Samsung Electronics, which recently experienced some issues with its Galaxy Note 7 bursting into flames, had begun a voluntary recall process before the regulatory agency became involved in responding to consumer complaints. The company eventually removed the product from the market and released the Galaxy Note 8. The proposed research model is presented below.

Insert Table 1
approximately here

In accordance with US federal regulations, manufactures can voluntarily initiate a recall. "Manufacturers and/or distributors may initiate a recall at any time to fulfill their responsibility to protect the public health from products that present a risk of injury or gross deception or are otherwise defective" (21 CFR Part 7, Subpart C- Recalls). Announcing a recall can have significant financial implications for a company. Recalls are viewed as "unanticipated economic events" (Zhao, Li & Flynn, 2013). These types of events reduce shareholder value and can pose a significant risk to a firm's viability. In their study, Shah, Ball & Netessine (2017) noted that one of the largest hamburger producers in the U.S. sought bankruptcy protection after a recall of 21.7 million hamburgers in September 2007. Given the foregoing discussion, I argue that a product recall will have a negative impact on a firm's performance.

P2. *Product recalls are negatively related to firm reverse logistics operations.*

Top Management Team Composition

Recalls can be voluntary or involuntary. Whether to recall a product is a strategic decision for a company that can be costly and depends on several factors internal to the company's decision-making process. Sometimes, the decision whether to issue a recall rest with the oversight federal agency, e.g., FDA, CSPC, NHTSA, FSIS, or a court order. Further complicating the decision-making process regarding announcing a recall is the quality of a firm's senior management team. In their study, Wowak & Boone (2015) note that a firm's top management team (TMT) and organizational culture might be precursors to determining whether a firm experiences a product recall. This study considers TMT composition a mediating factor in the relationship between a recall and a firm's reverse logistics operations.

One of the major functions of top management executives is to influence the management culture to encourage collaboration and achieve sustained strategic performance (Feng & Zhao, 2014). However, despite this massive call for top management support, existing supply chain management (SCM) literature avoids going into detail on the subject (Sandberg & Abrahamson, 2009). It has been argued in previous studies (e.g., Kaynak, 2003; Kaynak & Hartley, 2008) that top management support is essential for implementing various operational objectives. TMT's characteristics field of [strategic] vision is shaped by his (mostly) or her demographic characteristics (Hambrick & Mason, 1984). Senior executives are creatures of their education and functional expertise and tend to view the world through their demographic prisms. Top managers who pay close attention to their task environment will adopt strategies to mitigate, if not completely, eliminate, man-made supply chain disruptions. In like manner, TMTs with Chief Marketing Officers (CMOs) or Chief Supply Chain Officers (CSCOs) are more likely to mitigate the effects of a product recall. In their study, Kashmiri & Brower (2016) investigated whether top management teams (TMTs) decreased the likelihood of a product harm crisis. Following Nath & Mahajan (2008), we argue that a TMT's composition is a factor in determining the strategic decision-making of its reverse logistics operations. Therefore, we argue that the composition of a firm's TMT will have an effect of reverse logistics operations.

P3. *When there is a product recall, the composition of a firm's top management team will mitigate the effect of the product recall on the firm's logistics operations such that when there are members with Supply Chain Management experience or a Chief Supply Chain Officer (CSCO) the effects of the product recall will be less negative.*

Brand Reputation

Corporate reputation is one of the most important competences for determining economic benefits (Rhee, 2009). Conversely, a firm with a damaged reputation can suffer financial loss in the market (Rhee & Valdez, 2009). The same fate may befall a firm that does not have an established brand, i.e., brand reputation. Brand reputation may be defined as the consumers' perceptions of quality associated with the product or service (Sengupta, Balaji, & Krishnan, 2015). Companies seek to position themselves in the market so that consumers associate their products with some level of quality. Companies with a good brand reputation are more likely to attract more customers (Veloutsou & Moutinho, 2009). Companies with a good reputation and a good brand image may retain their position in the market after a recall. Toyota enjoyed significant brand reputation prior to its recall in 2009. Eighty-three percent of adult Americans had a positive image of the brand (Kelly, 2012). Despite the recall, the company suffered a mere five percent drop in its positive brand disposition (Kelly, 2012). Other companies without such an established brand as Toyota may have suffered a worst fate in the market. It was reported in the business press that British Petroleum (BP) was still suffering from its tarnished image four years after the gulf oil spill in 2010 (Olenski, 2014).

Consumers generally do not invest significant amounts of time research a product (Akdeniz, Calantone & Voorhees, 2013). They pay attention to various cues and often rely on brand names (Akdeniz, Calantone & Voorhees, 2013; Amblee & Bui, 2008). The reliance on brand names is associated with the quality of the product. Consumers associate quality with certain brands of products, e.g., Mercedes Benz, iPhone, Tiffany's. This association reduces consumers expectations about a particular purchase. Therefore, consumers are more likely to forgive a company with a strong or good brand recognition.

P4. *When there is a product recall, a firm's brand reputation will mitigate the effects of a product recall on the firm's reverse logistics operations such that the effect is less negative when there is greater brand awareness.*

Reverse Logistics

Companies seem more prepared to handle a disruption in the outward flow of goods, which is the normal course of business than a reverse flow of goods. Firms reverse logistics operations are designed to process returns. However, existing supply chain infrastructures are not necessarily designed to handle recalls. A review of the literature indicates that reverse logistics (RL) has been generating more scholarly inquiry (Abdulrahman, Gunasekaran, & Subramanian, 2014; de Brito & Dekker, 2003; Dowlatshahi, 2000; Georgiadis & Vlachos, 2004; Jayant, Gupta, & Garg, 2012a, 2012b; Kleber et al., 2002; Kocabasoglu, Prahinsk, & Klassen, 2007; Pokharel & Murtha, 2009; Rogers & Tibben-Lembke, 2001). While there has been some discussion about managing "returns" not much attention has been devoted to the infrastructure necessary to process recalls. "A recall is easier if the infrastructure is in place" (DiBenedetto, 2007:93). Other scholars, regard reverse logistics as "the management or return flow due to product recovery, goods return, or overstock, from a closed-loop supply chain" (Jayant et al., 2012a, 2012b).

Much of the literature on reverse logistics (RL) has been in response to environmental concerns (Abdulrahman et al., 2014), or capturing value in the secondary market from used products (Pokharel & Murtha, 2009; Rogers & Tibben-Lembke, 2001). In his study, Dowlatshahi (2000) noted that BMW plans to have a "totally reclaimable" automobile this century. Companies can also utilize reverse logistics to reduce the costs of inputs (Dowlatshahi, 2000). Caterpillar recently created a separate remanufacturing division to handle the return of old engines that the company is refurbishing for resale. These efforts are proving fruitful for the company (Hufford 2022). Despite these efforts at utilizing their reverse logistics operations to focus on the environment and on sustainability efforts, firms are still not prepared for the disruption caused by a product recall. In their study, Shefi and Rice (2005) developed a disruption profile where they outlined the various stages in the disruptions process. Reverse logistics should follow a similar strategy. Recalls do not happen without some warning. There is usually some indication there is an issue with a product. Simonsen & Lippencott (2008) note that companies learn of problems with their products through a variety of sources, including but not limited to: customer complaints, claims, news coverage, and regulatory agencies such as the FDA, CPSA and the NHTSA. Further, some recalls come at the end of the useful life of the product. The product may be retrieved from the consumer to be destroyed, or so the manufacturer can recover whatever value is left in the product (Kocabasoglu et al. 2007). We posit here that a firm's logistics operations can significantly impact its operational performance. such that firms with comprehensive RLO can mitigate the negative effects of a product recall. The following reverse logistics probability matrix is presented here (see Figure 6 below).

P5. *When there is a product recall,* a *firm with a comprehensive reverse logistics operations RLO) can mitigate the negative effects of a product recall such that there is less drag on operational performance.*

DISCUSSION AND CONCLUSION

We are undertaking this study to investigate the effects of a product recall on a firm's reverse logistics operations. In the model presented in this paper, we argue that the effects of a product recall on firm performance is mediated by the firms' TMT composition, brand reputation and reverse logistics operations. Previous studies of product recalls have not addressed firms' reverse logistics operations or examined the mediating effects of the aforementioned variables. This study makes that contribution to the literature.

Product recalls, whether voluntary or involuntary, are a costly endeavor for companies. The oversight federal agencies: National Highway Transportation and Safety Administration (NHSTA), the Consumer Product Safety Administration (CPSA), the Food and Drug Administration (FDA) and Food and Safety Inspection Service (FSIS) all issue guidelines on initiating recalls. The degree to which companies follow these guidelines is an open question and can be the subject of future empirical investigation. In addition to the internal costs of the recall, firms also face external, i.e., societal costs. Hora, Bapuji, & Roth (2011) note that firms face direct and indirect costs because of a product recall. Some of these costs include managing the reverse flow of products, disposal costs, legal and liability costs due to any litigation, loss of brand image and erosion of market value (Hora et al., 2011:766). For example, the mounting litigation costs facing the airbag maker, Takata, may have been a factor in determining why the company sought bankruptcy protection (Tajitsu, 2017). Although previous studies have focused on costs, they have not addressed the importance of the firm's reverse logistics operations in managing a recall. Further, there is little evidence that firms have a reverse logistics strategy. One of the goals of this paper is to offer some prescriptions for how firms can improve their reverse logistics operations.

Theoretical Implications

Product recalls are disruptive events. Companies experiencing this form of disruption seek to regain their operating equilibrium. In this study, we utilize two theoretical perspectives: punctuated equilibrium (Gersick, 1991; Romanelli & Tushman, 1994; Tushman & Romanelli, 1985) and contingency theory (Donaldson, 1987, 2001; Lawrence & Lorsch, 1967; Thompson, 1967). Punctuated equilibrium posits that organizations progess through rather stable periods, i.e. convergent periods which are punctuated, i.e. disrupted by reorientations which demark and set the bearings for the next stable, i.e. convergent period (Tushman & Romanelli, 1985). When companies are forced to initiate a product recall, it disrupts the normal flow of business. Companies then seek to "get things back to normal." Since punctuated equilibrium focuses primarily on internal organizational functions, we complement that theory with contingency theory to explain how companies relate to their task, i.e. external environment during a recall. Contingency theory posits that organizations seek to maintain fit with their operating task environment. The task environment consists of four major sectors: 1.customers (distributors and end-users); 2.suppliers (labor, capital, materials, equipment, and work space); 3.competitors (for markets and resources); and 4.regulatory groups (government agencies, unions, and inter-firm associations) (Thompson, 1967). A company facing a recall may interact with some of all of these various sectors.

This study considers three mediating factors that influence a firm's reverse logistics operations. The theoretical model is based on prior studies (see Reyes & Meade, 2006); Saruchera& Asante-Darko, 2021) which examined these variables and the direct or indirect effect of firm performance. To the extent that a firm has the senior managers with the requisite experience, an established brand and engages in quality management determines the effect on its reverse logistics operations. Firms that practice quality management are also less likely to experience the negative effects of a product recall. For example, when Apple issue a recall of the iPhone 5, the company did not appear to suffer any negative reaction from the public. Given the frequency of recalls, this researcher hopes this study will prompt other researchers to investigate this phenomenon.

Managerial Implications

Firms may utilize other strategies to reduce the likelihood or mitigate the effects of a product recall. In their study, Wowak & Boone (2015) wondered whether having a Chief Supply Chain Officer (CSCO) on a firm's top management team (TMT) could mitigate the probability of a recall. Other scholars have wondered about a firm's TMT composition and its effects on product recalls and firm performance. Nath & Mahajan (2008) investigated whether the presence of a Chief Marketing Officer (CMO) on a firm's TMT influenced firm performance. I believe that having a CSCO on the firm's TMT will positively influence the firm's strategic direction and better position the company to have reverse logistics strategy.

Companies generally do not operate a reverse supply chain. This activity is usually a response to issue with the firm's product. It seems obvious that the risk that something can go wrong with a product is not zero. Therefore, companies should, at a minimum, have a strategy for managing the reverse flow of goods. One area of future investigation would be to conduct a case study of firms that have experienced repeated product recalls and to investigate whether these firms have a reverse logistics strategy or have designed a reverse logistics supply chain. While companies must incur the costs of a recall, some companies are spreading the cost of a return. Best Buy, Dick's Sporting Goods, and Home Depot among others have begun the process of tracking customers returns (Safdar, 2018). The idea penalizing consumers who return products, for whatever reason, may have undue consequences. What this situation suggests is that these companies may not be prepared for a return and are unlikely to be prepared for a recall. It is inevitable in the life of a company that it will experience a product recall. Even the venerable Apple has issued recalls. Other companies, such as Ford and General Motors (GM) have issued multiple recalls. We are confident that having a CSCO on the firm's TMT to devise its reverse logistics strategy can reduce the damage to its brand image.

Contributions

This paper makes several contributions. First, unlike most of the previous research investigating reverse logistics as a strategy for sustainability strategy (see Mokhtar et l., 2019; Turrisi et al., 2013), this study focuses on product recalls and their effects on RLO. Product recalls are a major concern for companies. Second, this study directs researchers' attention to this well-known but understudied phenomenon and apply punctuated equilibrium and contingency theoretical perspectives to advance the discussion. Finally, we offer some prescriptions to practitioners seeking to address product recalls. Some companies, and indeed some industries tend to suffer recalls more than others. The automotive industry which has been the subject of several studies continues to have recalls. We propose a recall probability matrix and a recall process model to aid companies in their decision-making processes. The approach suggested here is not novel. Organizations tend to be more "crisis prone" than "crisis prepared" (Pearson & Mitroff, 1993). If firms view a product recall as a crisis, the following strategies can be implemented prepare for and to manage a product recall. Firms should craft a communications strategy. It is important to communication with consumers and the regulatory agencies and manage the recall rather than allow circumstances to dictate the firm's response. Firms should also have a contingency plan in place in the event of a product recall. Waiting for the event to plan for it is often too little too late. Firms should develop a continuity plan. Firms should have a strategy for continuing operations during the recall process. Finally, firms should treat a product recall as a crisis and employ crisis management practices. Pearson & Clair (1989) and Pearson & Mitroff (1993) have provided excellent guidance in this area.

Limitations and Future Research

Product recall is a nascent area of research (Wowak & Boone, 2015). This study seeks to increase our understanding of the impact of product recalls on firms' reverse logistics operations. Since it is exploratory, one limitation may be the choice of mediating variables. Future research can explore examining the impact of this variable on firms' reverse logistics operations. Future research can also investigate the differences between a voluntary and an involuntary recall. Do firm that initiate a voluntary recall perform better than firms that are forced by some legal or regulatory entity to initiate a recall? Future research may also investigate the distinction between product recall and product returns and the impact of each type of event on a firm's reverse logistics operations. This study also does not address the difference between a voluntary recall and an involuntary recall. Do companies pursue different strategies for each type of recall? Or will the same strategic approach work for both types of product recalls? Future research can address these questions.

Conclusion

This study examined the reverse flow of goods in a firm's supply chains. It is almost inevitable that a firm might experience a recall. These reverse flows can wreak havoc on a company's supply chain which is generally designed to meet customers' demand. Given the likelihood of a recall, firms should be prepared for product returns. This study advances our understanding of the recall and reverse logistics processes and offers some prescriptions to practitioners to anticipate and mitigate the effects of a product recall.

Reverse logistics has been and remains a growing concern for practitioners seeking to address returns and recalls. While returns have received some treatment in the academic community, recalls have not received comparable treatment. Although there is a significant body of literature on supply chain disruptions, there is not enough attention given to the disruptions caused by the backwards flow of goods to a company. This is an important issue companies need to address and an area where researchers can add valuable insight. This study begins the discussion which can be joined by other researchers seeking to advance theory in this area and to address practitioner concerns.

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Revealing Underlying Factors of Absenteeism: A Machine Learning Approach

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ABSTRACT

Absenteeism is a prolific problem amplified in environments of adversity. In a partnership between the Fight for Life Foundation, Butler University, and Indiana University, we are leveraging techniques in machine learning to develop an understanding of absenteeism, with the mission to provide support to youth in underserved portions of our community. The Building Dreams platform, developed by Fight for Life, collects data reported by educators in terms of core values that are associated with either in-class participation or individual behavior. In this work, we propose a multi-phased classifier, leveraging several machine learning techniques, to develop an understanding of absenteeism within the underserved schools. From over 20,000 recorded behaviors, we were able to train a classifier with 90.2% accuracy and uncovered a major underlying factor directly affecting absenteeism. Such knowledge can drive impactful policy and programming changes necessary for supporting the youth in communities overwhelmed with adversities.

KEYWORDS: Socio-Emotional Learning, Machine Learning, Classification, Absenteeism

INTRODUCTION

The Fight for Life Foundation, founded in 2007, provides schools and counselors additional support for youth to develop the social and emotional qualities to be successful. Aimed specifically at underserved communities, the foundation's mission has made an impact on hundreds of students across 15 different schools in central Indiana. Leveraging technology and a unique gamification system, Fight for Life has the capability to be integrated into a school's curriculum while simultaneously collecting behavioral data and providing online tools to allow educators and administrators quick intervention plans and policies. In the current phase of the foundation's growth, research is being conducted into the viability of different machine learning and artificial intelligence models for assessing the linkage between social-emotional core values and a student's success. The online platform brings to light patterns that have the potential to go unnoticed. This data-driven awareness is a basis for resources provided to a school, from the foundation, to support social-emotional core values, equipping students with the skillsets needed to effectively managing their emotions and relationships.

The Foundation's mission is rooted in its belief of Social and Emotional Learning (SEL). The fundamental thesis of SEL is that students thrive when their socio-emotional needs are being met. Large scale studies involving over 90,000 youth, between kindergarten through the twelve grade, have shown the positive impacts of SEL programs on the improvement of academic performance, reduction of drop-out rates, as well as lower reported cases of drug use and problematic conduct (Durlak et al., 2011, Taylor et al., 2017). The Fight for Life Foundation offers SEL-specific resources to schools in underserved communities to reinforce the criticality of social and emotional aspects within the classroom. In such communities, the adversities surrounding a student's daily life require additional support beyond the traditional curriculum. Good social-emotional learning programs do not operate in isolation, but help students learn that their decisions determine their consequences while helping them foster skills in coping, self-awareness, and self-control thereby increasing their likelihood of school attendance and successful outcomes.

LITERATURE REVIEW

Rastrollo-Guerrero J et al. (2020) and Albreiki B et al. (2021), both conducted comprehensive surveys of recent literature within the space of machine learning applied to data from academic environments. The papers reviewed were chosen from journals with high impact factors and conference proceedings from the most reputable professional conferences, including IEEE and ACM. The authors reported significantly high accuracies from predictive models used in forecasting academic performance, however, 70% of the papers conducted studies at the collegiate level. Furthermore, the authors discussed the high precision of artificial neural networks on behavioral data, as it relates to academic performance, but cited that these approaches constitute a small minority of the researched models, whereas the most common models demonstrating promise were support vector machines (SVM) and naïve bayes classifiers. E. S. Bhutto et al (2020) present further evidence of the effectiveness of the SVM model when used to predict academic performance, however the approach is only demonstrated for a target consisting of two classes. These studies demonstrate the effectiveness of machine learning models; however, the evidence is predominately exhibited for university students in the narrow field-of-view of academic performance and drop-out rates. Our proposed work broadens this focus to understand the connection between absenteeism, and other at-risk factors, for elementary school students, while considering the correlation of these factors with social and emotional behaviors. Moreover, we have not found any literature solely focused on the application of machine learning methodologies to the field of Socio-Emotional Learning for understanding absenteeism.

THEORETICAL DEVELOPMENT/MODEL

In our proposed methodology, we employed both unsupervised and supervised machine learning models to analyze SEL data collected from kindergarten to twelve grade students during the Fall term of the 2021/2022 school year. The following section summarizes the data collected within the Building Dreams platform, created by the Fight for Life Foundation, and the models trained to identify at-risk students. More specifically, the aim of the models is to classify each student into a one of three classes: red, yellow, and green, representing at-risk, medium risk, and low risk students, respectively. With a clear separation between classifications, one can study the factors defining each group to recognize key drivers in behavior and subsequently offer targeted support. For this work, we chose to focus on gaining insight into underlying factors of absenteeism.

Data Collection

The data used in this study was acquired during the Fall 2021 term at a school in central Indiana. This school was selected because of the broad adoption of the Fight for Life Building Dreams platform across all grade levels. 26,741 datapoints were collected on 332, K-6, students, where each datapoint characterizes a reported behavior relative to the 10 core values summarized in Tables 1. Core values, and the underlying reasons, are reported in either a positive or negative perspective by educators or administrators and are regarded as either in-class participation or being related to individual behavior. Engagement with the FFLF program is accomplished through a unique gamification process where students earn or lose yards relative to the game of football. For instance, positive observation of core values is reported as a first down, while negatively recognized behavior is reported as a sack. In serious situations, a sack can result in a student being removed from class and is reported as a red zone. Furthermore, extra points and flags are reported when they demonstrate positive character traits, or concerning behavior, respectively. SEL emphasizes the criticality of healthy peer relationships, therefore core values associated with in-class participation are more heavily weighted since they reflect interactions with others. Extra points and flags are weighted the least but still make an impact in a student's overall assessment.

Table 1. Reported core values

Core Values	
Description	**Code**
Enthusiastic in class	CV1
Focused within class	CV2
Meet or exceed expectations on assignments	CV3
Demonstrates initiative	CV4
Follow directions	CV5
Respect other's space	CV6
Respect for physical settings	CV7
Demonstrate accountability	CV8

Respectful communication	CV9
Positive relationships	CV10

The dataset was used to create machine learning models for identifying at-risk, medium risk, and low risk students, labeled as red, yellow, and green, groups, respectively. The following section summarizes the methodology used for developing a classifier capable of classifying students based on the proportions of reports relative to first downs, sacks, extra points, flags, and red zones. The dataset, $S \in \mathbb{R}^{26,741x25}$ is mapped to a new domain, $S' \in \mathbb{R}^{332x5}$, where each datapoint is defined by a feature vector for each student, s_i.

$$
\begin{gathered}
s_i = \left[x_i^{fd}, x_i^{s}, x_i^{ep}, x_i^{f}, x_i^{rz}\right], \qquad (1) \\
x_i^{fp} = \frac{r_i^{fp}}{r_i}, x_i^{s} = \frac{r_i^{s}}{r_i}, x_i^{ep} = \frac{r_i^{ep}}{r_i}, x_i^{f} = \frac{r_i^{f}}{r_i}, x_i^{rz} = \frac{r_i^{rz}}{r_i} \\
r_i = r_i^{fp} + r_i^{s} + r_i^{ep} + r_i^{f} + r_i^{rz}
\end{gathered}
$$

Where $r_i^{fp}, r_i^{s}, r_i^{ep}, r_i^{f}, r_i^{rz}$, denote the total reports of first downs, sacks, extra points, and red zones, respectively, for student s_i.

Methodology

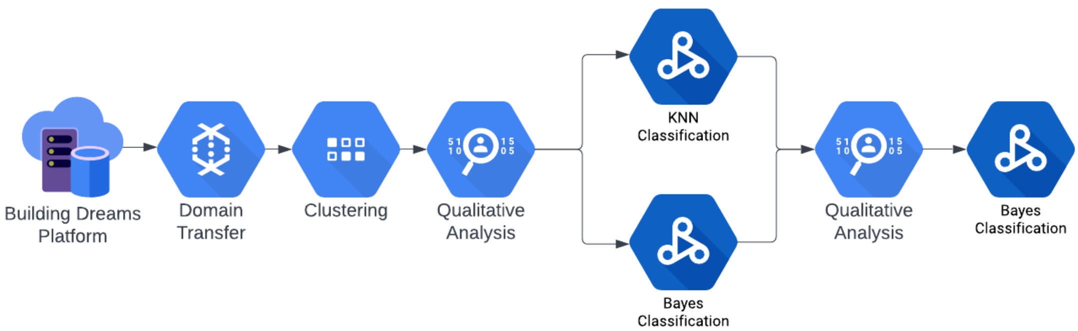


Figure 1. Overview of proposed methodology

The proposed methodology is a coupling of unsupervised and supervised models, ultimately leading to a model for classifying students as at-risk, medium risk, and low risk. Data reported by educators per student is unlabeled, therefore an unsupervised technique is employed to explore strong boundaries separating students. Figure 1 illustrates the entire proposed methodology for developing an effective machine learning model for the classification of behavior data from the Building Dreams platform.

Clustering and Initial Label Qualitative Analysis

In this work, K-means clustering, and qualitative analysis, were leveraged at a classroom level for identifying three classes of students, $C = \{C_{LR}, C_{MR}, C_{HR}\}$, characterizing low-risk, medium-risk, and high-risk students, respectively.

Datapoints from each classroom are independently clustered into three clusters where K-means clustering aims to create K clusters by minimizing within cluster distance. In this work, the Euclidean distance was used as the cost function to minimize. For a set of students in a classroom, $\Gamma_i = \{s_1, s_2, \dots s_n\} \subseteq S'$, and set of three clusters, $G = \{G_1, G_2, G_3\}$, the iterative clustering algorithm is defined by the optimization problem,

$$\min_G \sum_{G_i} \sum_{\Gamma_i \in G} \left\| \Gamma_i - c_{G_i} \right\|^2 \tag{2}$$

$$c_{G_i} = \left[\overline{x_i^{fd}}, \overline{x_i^{s}}, \overline{x_i^{ep}}, \overline{x_i^{f}}, \overline{x_i^{rz}} \right], \forall s_j \in G_i,$$

The cluster centers, c_{G_i}, are evaluated qualitatively to map $G_i \rightarrow C_j$, and all classroom-level clusters are assigned labels, $C_{LR}, C_{MR}, or\ C_{HR}$. The process is repeated for all 15 classrooms, resulting in 45 feature vectors associated with the desired class labels. Of the 15 classrooms, 9 clusters made sense from the qualitative analysis, with clear separation between the clusters. The resulting 27 cluster centers from those 9 classrooms were used as training data for two classifier models used to predict the class label for the remaining 6 classrooms.

Classification

After initial labels are determined, two classifiers are trained on the cluster centers c_{G_i}that were successfully labeled in the previous phase. Naïve Bayes classifiers rely on the conditional probability that a given feature vector, s_i, belongs to C_j.

$$p(C_j \mid x_i^{fd}, x_i^{s}, x_i^{ep}, x_i^{f}, x_i^{rz}) \tag{3}$$

Since $\{s_i \in \mathbb{R} | 0 \leq s_i \leq 1\}$, the Gaussian Naïve Bayes classifier is used to estimate the likelihood component of Bayes theorem, highlighted in (4), using a Gaussian distribution defined from the mean and standard deviations of each feature in the training sets.

$$p(C_j \mid x_i^{fd}, x_i^{s}, x_i^{ep}, x_i^{f}, x_i^{rz}) = \frac{p(C_j)\ \boldsymbol{p(x_i^{fd}, x_i^{s}, x_i^{ep}, x_i^{f}, x_i^{rz} \mid C_j)}}{p(x_i^{fd}, x_i^{s}, x_i^{ep}, x_i^{f}, x_i^{rz})} \tag{4}$$

Bayes classifiers operate on conditional probabilities defined by an entire training set, whereas K-nearest neighbor (KNN) classifiers assign class labels based on feature similarity within an evaluation set. A class label is defined by the most common label residing within the evaluation set of the K most similar datapoints. In this work, the Euclidean distance (5) was used as the similarity measure driving the decision process of the KNN classifier.

$$d(s_i, s_j) = \sqrt{\left(x_i^{fd} - x_j^{fd}\right)^2 + \left(x_i^{s} - x_j^{s}\right)^2 + \left(x_i^{ep} - x_j^{ep}\right)^2 + \left(x_i^{f} - x_j^{f}\right)^2 + \left(x_i^{rz} - x_j^{rz}\right)^2} \tag{5}$$

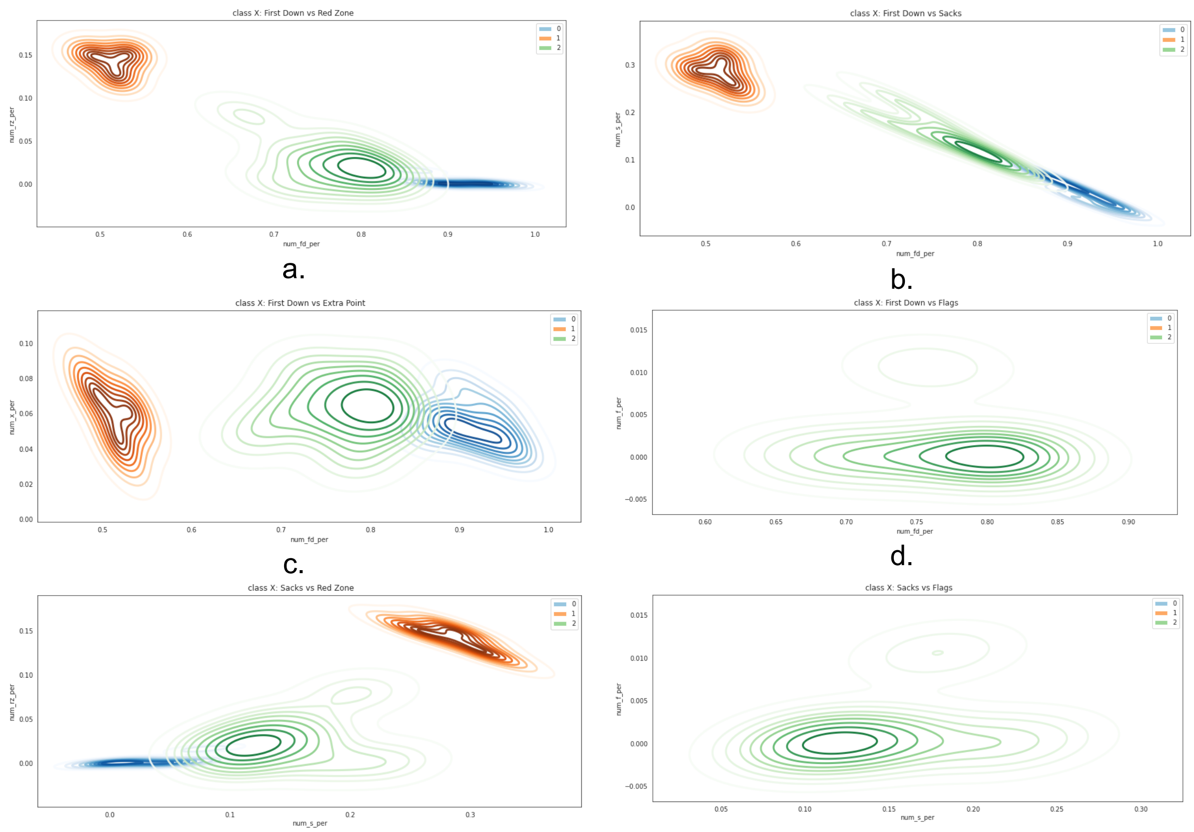
The ideal neighborhood size, K, was found empirically by training and evaluating models over the entire viable range. For this work, a neighborhood size of 5 was found to produce the most accurate classifier for the available data.

Label Refinement Qualitative Analysis and Final Classifier Model

Both classifiers are trained on the high confidence data from the previous phase then used to predict the class labels on the data with less confidence after the initial clustering and qualitative analysis. The resulting prediction from each classifier are compared where a label is assumed to be accurate when both classifiers agree in the outcome, however when the two classifiers produced different predictions, a qualitative analysis of the data is performed to manually decide the appropriate label or decide if the cluster should be completely disregarded. The final cluster centers from all classrooms then become the training set for a generalized Bayes classifier used to label all current and future students.

RESULTS AND DISCUSSION

Figure 2 provides a visualization of the clustering results for a single classroom, illustrating the most critical features that differentiate the clusters, while Figure 3 summarizes the cluster centers for 9 of the 15 classrooms. For the example shown, first downs, sacks, and red zones, appear to be strong differentiators of the clusters. This pattern is also observed in Figure 3, where C_{LR} is defined by a values first downs and lower percent reports of sacks and red zones. Conversely, C_{HR}, is characterized by the lowest percent reports of first downs and highest occurrences of sacks and red zones. Visualizations for all classrooms were generated and evaluated to associate each classroom-level cluster with the most appropriate label, C_i. Clustering was performed on all classrooms, resulting in 45 datapoints from the three clusters for each of the 15 classrooms, however 9 of the 15 classrooms naturally fit into highly differentiated clusters. The highlighted features in Figure 3 were used to determine that clusters 1, 2, and 3, exemplify low-risk, medium-risk, and high-risk students, respectively.



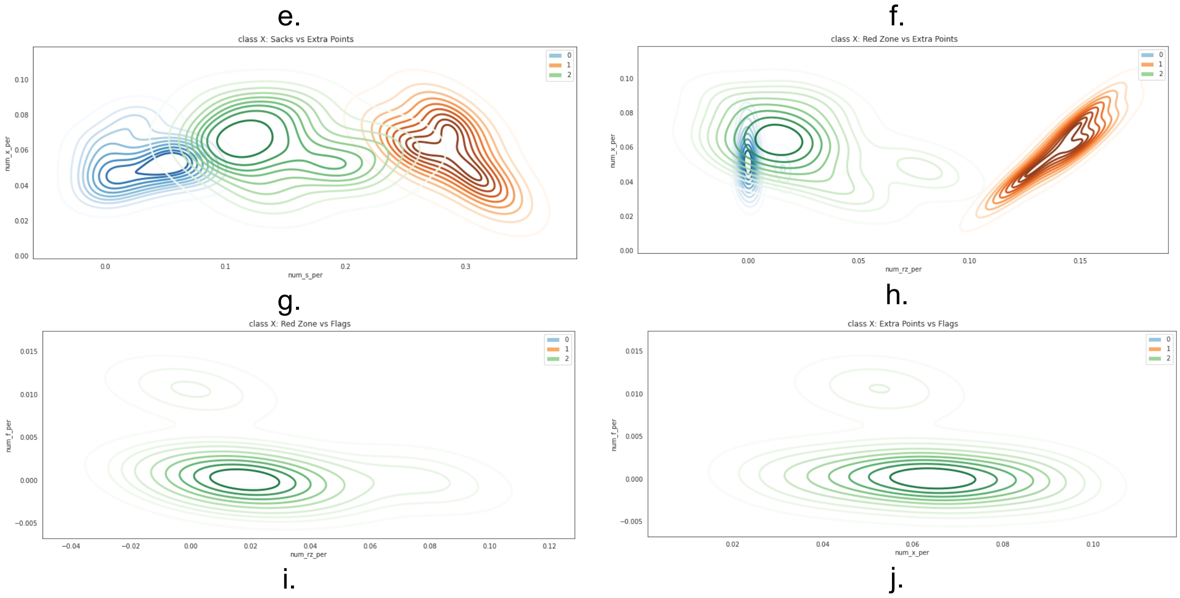
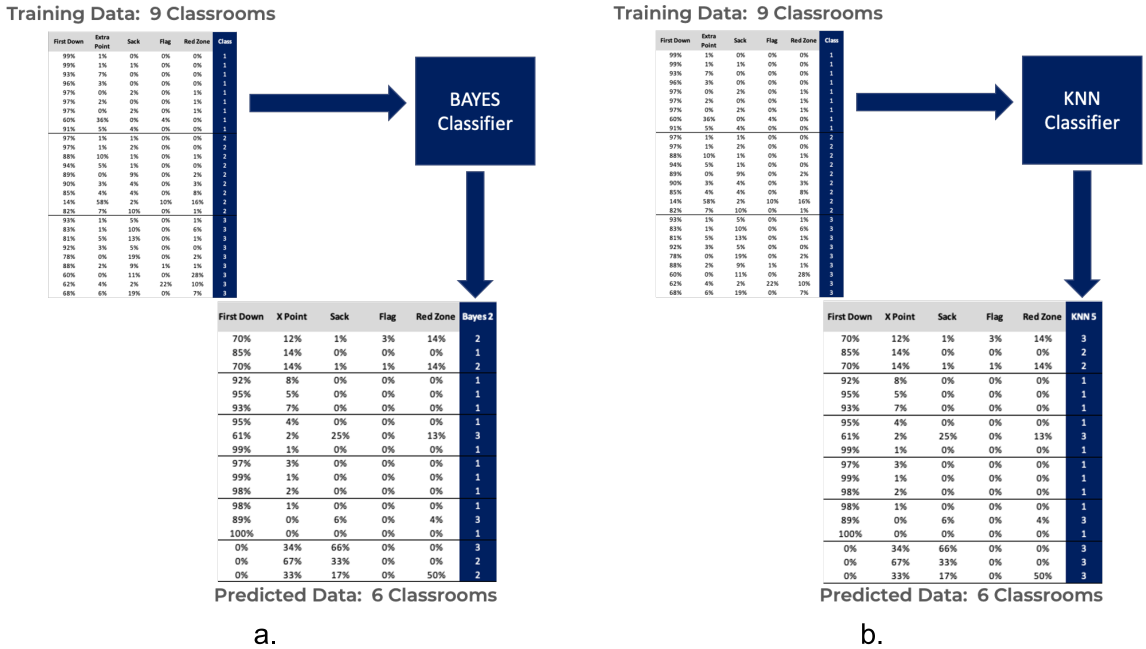


Figure 2. Sample clustering visualizations for a single classroom, showing distributions of percent reports for first downs vs red zones (a), first downs vs sacks (b), first down vs extra points (c), first downs vs flags (d), sacks vs red zones (e), sacks vs flags (f), sacks vs extra points (g), red zones vs extra points (h), red zone vs flags (i), and extra points vs flags (j).

First Down	Extra Point	Sack	Flag	Red Zone	Class
99%	1%	0%	0%	0%	1
99%	1%	1%	0%	0%	1
93%	7%	0%	0%	0%	1
96%	3%	0%	0%	0%	1
97%	0%	2%	0%	1%	1
97%	2%	0%	0%	1%	1
97%	0%	2%	0%	1%	1
60%	36%	0%	4%	0%	1
91%	5%	4%	0%	0%	1
97%	1%	1%	0%	0%	2
97%	1%	2%	0%	0%	2
88%	10%	1%	0%	1%	2
94%	5%	1%	0%	0%	2
89%	0%	9%	0%	2%	2
90%	3%	4%	0%	3%	2
85%	4%	4%	0%	8%	2
14%	58%	2%	10%	16%	2
82%	7%	10%	0%	1%	2
93%	1%	5%	0%	1%	3
83%	1%	10%	0%	6%	3
81%	5%	13%	0%	1%	3
92%	3%	5%	0%	0%	3
78%	0%	19%	0%	2%	3
88%	2%	9%	1%	1%	3
60%	0%	11%	0%	28%	3
62%	4%	2%	22%	10%	3
68%	6%	19%	0%	7%	3

Figure 3. Average cluster centers per classroom



First Down	X Point	Sack	Flag	Red Zone	KNN 5	Bayes 2	COMPARE
70%	12%	1%	3%	14%	3	2	FALSE
85%	14%	0%	0%	0%	2	1	FALSE
70%	14%	1%	1%	14%	2	2	TRUE
92%	8%	0%	0%	0%	1	1	TRUE
95%	5%	0%	0%	0%	1	1	TRUE
93%	7%	0%	0%	0%	1	1	TRUE
95%	4%	0%	0%	0%	1	1	TRUE
61%	2%	25%	0%	13%	3	3	TRUE
99%	1%	0%	0%	0%	1	1	TRUE
97%	3%	0%	0%	0%	1	1	TRUE
99%	1%	0%	0%	0%	1	1	TRUE
98%	2%	0%	0%	0%	1	1	TRUE
98%	1%	0%	0%	0%	1	1	TRUE
89%	0%	6%	0%	4%	3	3	TRUE
100%	0%	0%	0%	0%	1	1	TRUE
0%	34%	66%	0%	0%	3	3	TRUE
0%	67%	33%	0%	0%	3	2	FALSE
0%	33%	17%	0%	50%	3	2	FALSE

c.

Figure 4. Results of using a Bayes (a) and KNN (b) classifiers, trained on labeled data from the clustering phase. Comparing classifier results when applied to the clustered data that was not easily differentiated (c).

Table 2. Confusion matrix for Bayes Classifier

	C_{LR}	C_{MR}	C_{HR}
C_{LR}	8	0	1
C_{MR}	2	5	2
C_{HR}	0	1	8

Table 3. Confusion matrix for KNN Classifier

	C_{LR}	C_{MR}	C_{HR}
C_{LR}	7	1	1
C_{MR}	1	6	4
C_{HR}	1	2	6

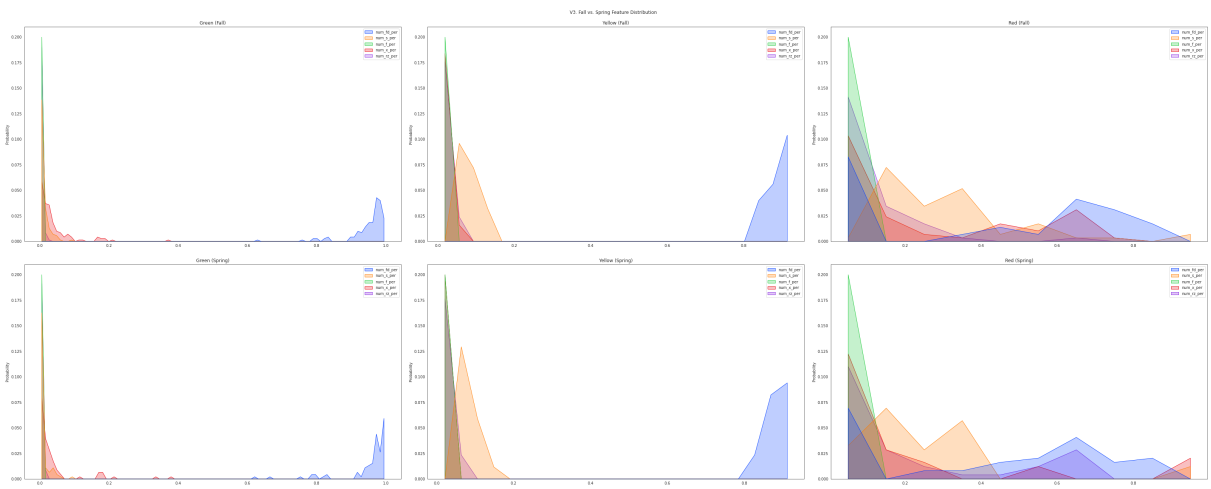
Figure 4, as well as Tables 2 and 3, summarize the results from the classification phase the proposed methodology. The confusion matrices for Bayes and KNN classification steps demonstrate accuracies of 77.8% and 63.0%, respectively. After a second round of qualitative analysis is performed, accepting all labels where the two classifiers agreed, a total of four entries are rejected as outliers and discarded. Further analysis of this classroom data reveals inconsistent reporting behavior from the educators. For instance, as observed in Figure 4c, one classroom did not report any first downs and simply used the Building Dreams platform for recognizing predominately two of the five categories. After completion of the second round of data classification, it is apparent that some classrooms simply do not have three classifications of students, which is the primary disadvantage of the first step where the K-means algorithm attempts to create three distinct groups. We believe we have overcome this drawback by only accepting the clustering results that were observed to be obvious then training classifiers to attempt to label the remaining data.

Table 4. Average features per class after applying final classifier to students in a validation set

Class	Student Count	First Down	Extra Points	Sacks	Flags	Red Zones
C_{LR}	210	96%	4%	1%	0%	0%
C_{MR}	68	89%	3%	7%	0%	1%
C_{HR}	54	63%	9%	21%	1%	6%

The resulting 41 cluster centers and associated labels were used to train a final Bayes classifier that was evaluated to be 90.2% accurate. This classifier, trained at the classroom level, was applied to student data from the end of the Fall 2021 term. Table 4 summarizes the number of students, in addition to the average feature for each class after employing the final model.

To examine repeatability, the model was applied to the Spring 2022 term data and the distributions of each feature were compared to the distributions of the features from Fall 2021. Figure 5 provides these comparisons for the low-risk (a), medium-risk (b), and high-risk (c) groups. We found that the classifier produced consistent results in terms of feature distributions when applied to an additional 20,000 datapoints where the expected label was unknown, for a different term. This demonstrates the model's ability to perform consistently.



a b c

Figure 5. Fall 2021 (top row) feature distribution compared to Spring 2022 (bottom row) feature distribution, for low (a), medium (b), and high (c) groups

In the subsequent section, we investigated how this classifier can be used to better understand underlying factors affecting absenteeism.

Application of the Final Classification Model

The proposed methodology for training an effective classifier was pursued with the purpose of better understand the needs of at-risk students. There are many areas that could benefit from understanding the different between low and high-risk students. We specifically focused on absenteeism, a major issue affecting youth in underserved communities. In this subsection, we will discuss the trends in the data after applying the classification model for identifying low, medium, and high-risk students. The goal was to uncover insights by comparing trends from data labeled as C_{LR} versus C_{HR}.

The first observation is that there is a noticeable discrepancy between data directly tied to attendance and the two groups, so the next step is to compare how the core values varied across the different clusters of students. In Figure 6, we see that the top three differences between high-risk and low-risk student groups are the core values related to peer relationships. Furthermore, we looked at the underlying reasons reported along with the core values. Figure 7 summarizes the most common differences between C_{LR} and C_{HR} data, in terms of supporting reasons. Four of the six reported reasons for the high-risk group are related to peer relationships. Conversely, it is immediately apparent that the low-risk group's most reported supporting reason is a positive recognition of attendance, while the high-risk group is rarely recognized for the same behavior.

These are significant findings because the data supports the key idea that peer relationships are a critical factor affecting absenteeism. The final class labels clearly provide evidence that the implementation of socio-emotional learning components within a curriculum has the potential to improve absenteeism by targeting a possible root cause.

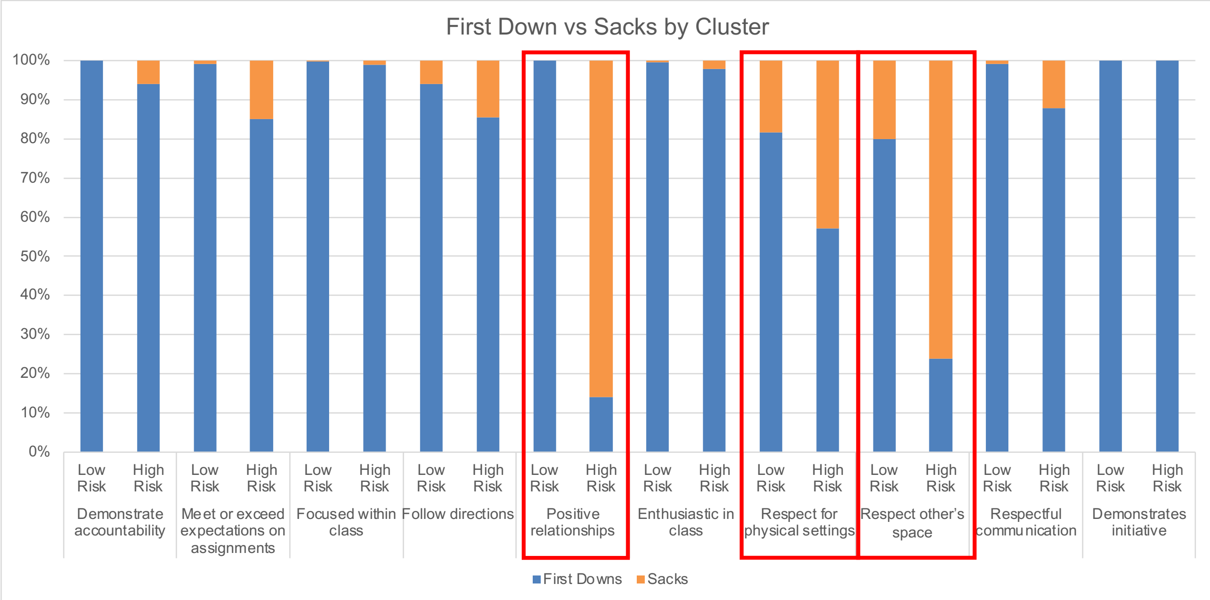
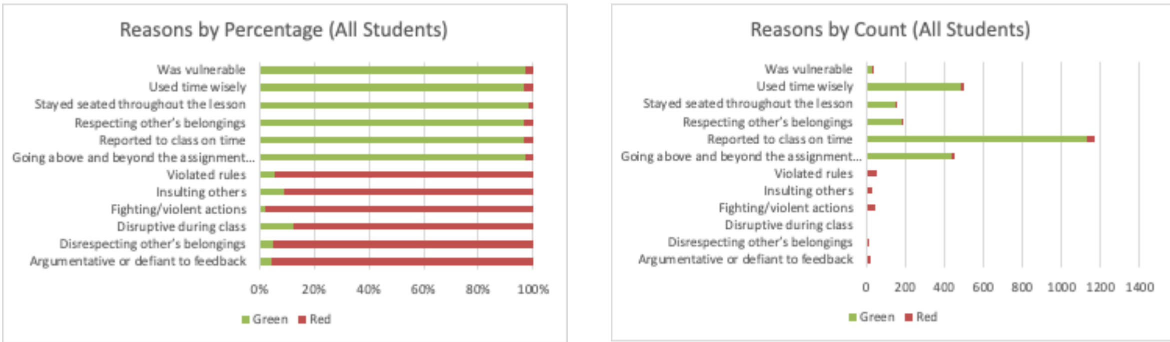


Figure 6. Core value comparison between C_{LR} and C_{HR} labeled data



a. b.

Figure 7. Reported reasons comparison between C_{LR}(green) and C_{HR}(red) labeled data

From the use of final model, we concluded that peer relationships are a significant underlying factor in absenteeism, which is also supported by additional evidence from Table 4. The average percent report of extra points is greatest in the high-risk group. Although extra points are a positive metric, they are solely award for recognized individual behavior. This suggests that students in the high-risk group are engaged at an individual level but require support in developing more positive relationships with their peers.

Lastly, we examined basic demographics relative to each classification group. Figures 8 and 9 illustrate that the highest concentration of high-risk students are between eight and nine years old, and predominately African American or Hispanic. Although the spike of high-risk students in the age range is useful insight, the results by race are not as insightful because 93% of the students in the school are African American or Hispanic. A detailed summary of race demographics is provided in Figure 10. Insights about age help drive decisions on how and when new curriculum will be introduced for addressing peer relationships.

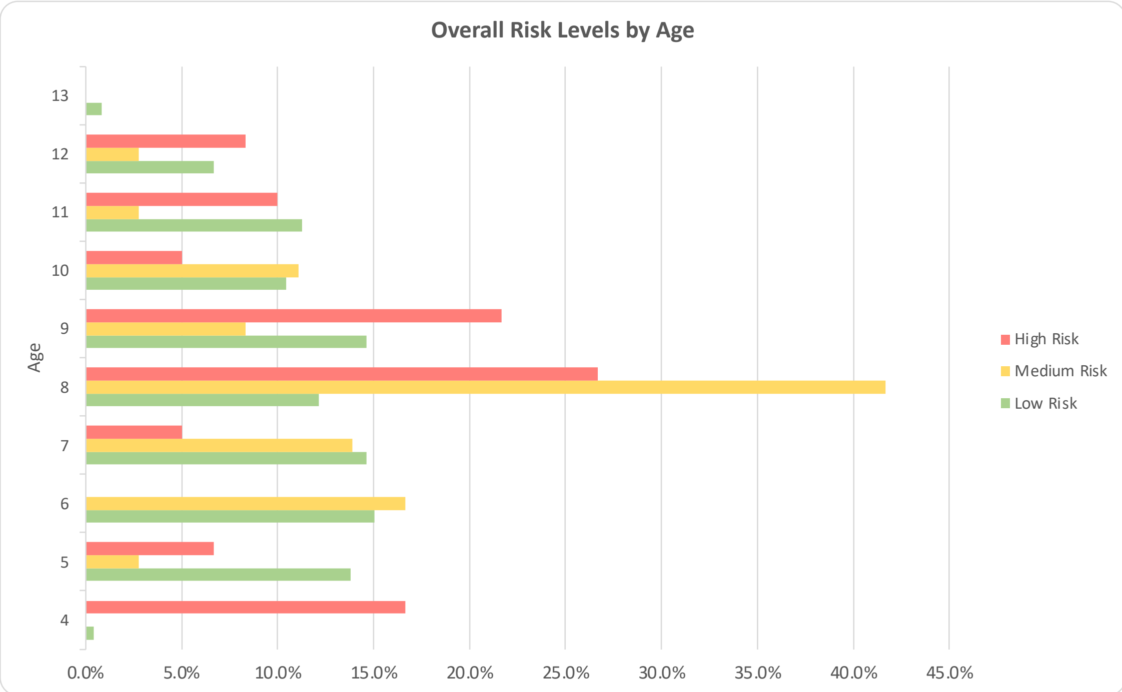


Figure 8. Risk labels by each age group

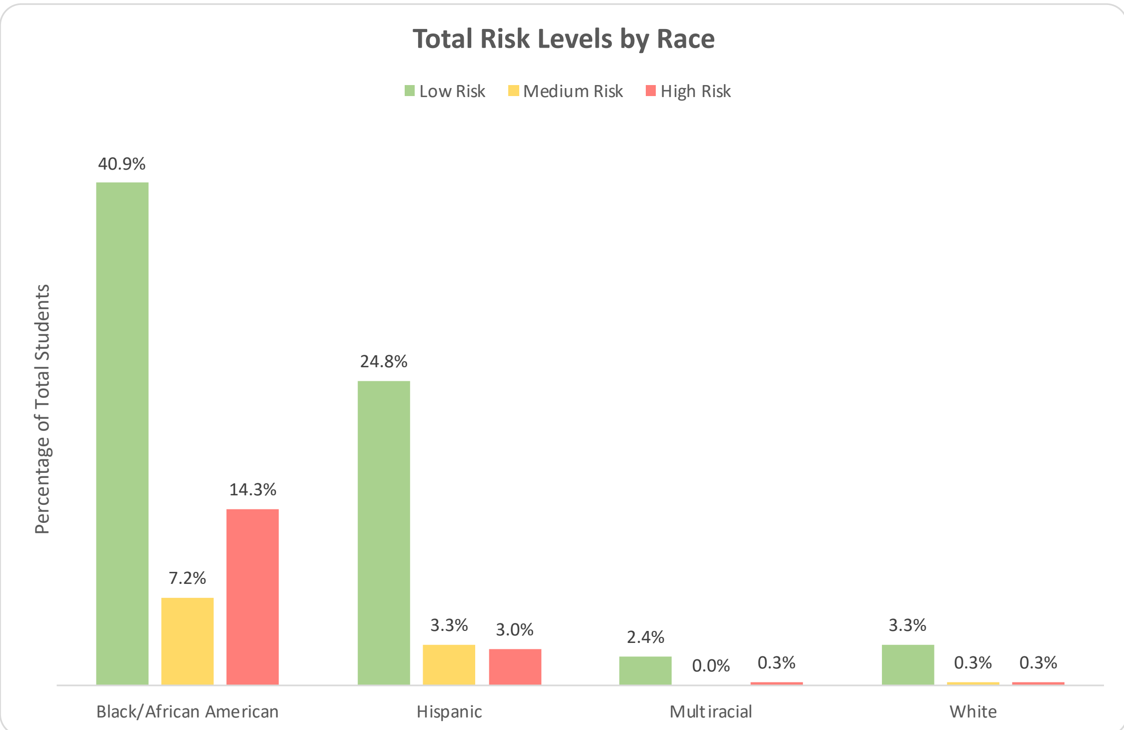


Figure 9. Risk labels by race

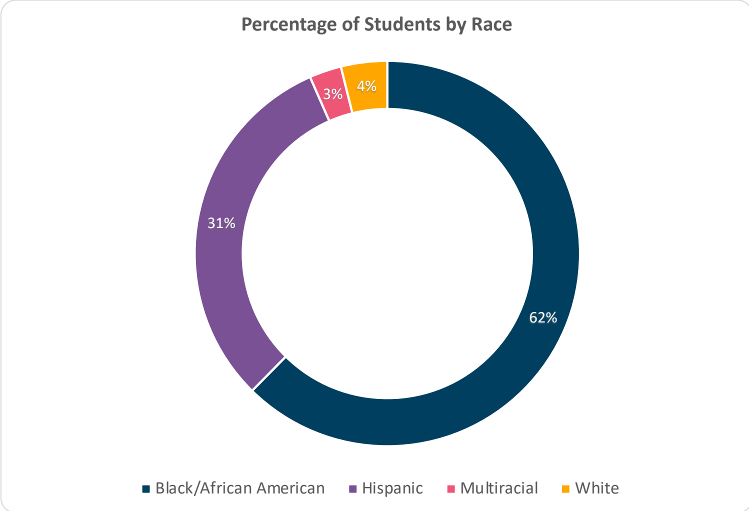


Figure 10. Percentage of students by race

FUTURE WORK

In this work we used two common classification models, KNN and Bayes, along with KMeans clustering and qualitative analysis to identify three distinct groups of students. Although the model is shown to be accurate and consistent, further work will be done to investigate the results from additional classification models, such as Support Vector Machines, Random Forests, and Neural Networks. Furthermore, we recognize that the qualitative analysis can be replaced by a trained decision tree or using a random forest walk to improve the robustness of the proposed methodology. Lastly, this model will be used to investigate other critical research questions regarding academic performance and drop-out rates, as well as testing at additional school sites.

CONCLUSION

The work presented in this paper signifies the initial steps taken to leverage machine learning techniques on SEL data to better understand the areas that could make a significant impact in the lives of children in underserved communities. In collaboration with the Fight for Life Foundation, we have developed a classification model that was used to examine absenteeism. The proposed multi-phased approach was evaluated to be 90.2% accurate in identifying three classes of students: low-risk, medium-risk, and high-risk. Future work will focus on looking at other factors differentiating these groups, such as academic performance and drop-out rates with the ultimate mission of providing expedient support in an effective and targeted manner.

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Roles of ERP systems in global organizations' supply chains in humanitarian and private sectors

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ABSTRACT

This paper investigates 14 different roles ERP systems play in global humanitarian and private sectors' supply chain. The research utilized an online questionnaire and collected data from 103 supply chain professionals. Descriptive statistic – crosstabulation analysis was used to analyze collected data. The hypotheses were tested by using Mann-Whitney Test. Findings highlighted the crucial roles to supply chain performance and identified impacted areas and reflected on their importance to the two examined sector. Such a comparative study was not done before, and results will allow professionals of both sectors to better understand all key roles of ERP systems implementations.

KEYWORDS: ERP, Enterprise Resource Planning, Supply Chains, Humanitarian & Private Sectors, Roles.

INTRODUCTION

Nowadays the private companies became more perplexed in geographical decentralization and structural systems. Thus, to compete in the current environment, private organizations started to invest in supply chain ERPs, which allows communicating effectively internally and externally. Elgohary (2019) argued that the role of ERP in the private sector is to reinforce organizational performance and build a competitive position. The authors investigated the relationship between the capabilities of supply chain ERPs and competitive advantage and performed a survey of 162 companies in Dakahlia Governorate in Egypt. As a result, he determined that the implementation of ERP positively impacts private organizations' competitive position as it increases customer satisfaction. Huang et al. (2019) investigated the challenges of ERP implementation and stated that the lack of top management support hinders the implementation of ERP. However, both studies, done by Elgohary (2019) and Huang et al. (2019), focus on a particular geographical location and a sector. Other authors determined that the expensive cost of ERP retards its implementation in the private sector (Giannakis et al., 2019), the lengthy period for implementation was pointed out by Behera and Dhal (2020), and other implementation risks were identified by Sokolov and Kolosov (2018). However, these studies focus on specific geographical locations and industries.

The humanitarian organizations also actively seek supply chain efficiency and look at the private sector's ideas or introduce tailored solutions. Notwithstanding, the role of supply chain ERP in humanitarian logistics is not to provide the competitive advantage but to assist the humanitarian supply chain professionals in ensuring the on-time delivery of life-saving supplies to the beneficiaries, provide transparent donor reports and establish information sharing between supply chain partners which respond to the emergencies (Siawsh et al., 2019). As stated by Kabra et al. (2017), humanitarian organizations encounter a problem in developing technological culture across the organization. This issue is among the areas where humanitarian organizations can learn from the private sector, as private companies have more experience implementing various ERPs (Nurmala et al., 2017). Many studies were done in the private sector investigating ERP implementation, its roles, successful factors, challenges, and impact on the performance. Some studies analyze d the implementation of ERP in the humanitarian sector. However, there is no research comparing the implementation of ERPs in the humanitarian and private sectors focusing on different locations and industries under a single study and looking at the differences between humanitarian and private sectors globally. There was only one study done by Do Ceu Alves and Matos (2013) that compared the public and private sector's approach to implementing supply chain ERP in Portugal.

Therefore, this research aims to fill the academic literature gap by performing a cross-industries analysis, comparing differences and similarities in roles of ERP systems in the humanitarian and private sector logistics in Africa, Asia, Canada, Australia, Europe, and the Americas.

Research Question: what are the roles of ERP systems in the supply chains of global humanitarian and private sectors' organizations?

The research question was developed by analyzing the roles of supply chain ERPs in humanitarian and private sectors in different organizations based on the literature review and her own experience. From the researchers'' knowledge, the roles of ERPs, as stated by Gavidia (2017), are to have access to the inter-organizational information for the speed reaction and decision-making, increase the logistics' effectiveness and ensure the inter-organizations cooperation during emergencies. As for the private sector, Gupta et al. (no date) argued that the roles of ERPs are the same. Additionally, ERP serves as a tool to increase competitiveness in the market. Therefore, by asking this question, the researchers want to investigate further the roles of ERPs in both sectors.

LITERATURE REVIEW

ERP Overview

Many companies experience challenges while expanding their markets due to the current high customer expectations and corporate environment. Therefore, the ERPs assist them in handling these challenges attracting more attention to the logistics practitioners who try to discover how to deal with today's volatile business environment (Bukamal and Wadi, 2016).
Consequently, ERP is a management tool that administers the company's supply chain information and resources in real-time (Gavidia, 2017; Ridho Tobing et al., 2019). In summary, the ERP can merge different partners externally and internally with a shared database and

facilitate information sharing. ERPs substitute the archaistic incommensurable logistics systems and allow storing all the information in a single database. These systems may physically include two or three separate modules, such as WMS, TMS, and the others located in the central office. If the warehouse is interconnected with transport and distribution systems, the ERP merges them to manage better and understand the whole process. As a result of merging, and as stated by Gavidia (2017), Caon et al. (2020), Gupta et al. (2020), the supply chain ERP facilitates the planning of the private sector production or humanitarian operations, inventory management, orders, and payments follow-up, deliveries, and other supply chain functions and ensure the information sharing between logistics partners.

ERP in Humanitarian and Private Sectors

It is argued by Gavidia (2017) that private organizations actively use supply chain ERP systems for their internal and external partnership as their primary target to generate profit. Thus, the information must be shared in time to eliminate the production's destruction and stay afloat in the market. On the contrary, humanitarian organizations are reluctant and slow in implementing ERPs due to the lack of resources, lack of funding, resistance from senior management, and unstable infrastructure (Gavidia, 2017; Rodríguez-Espíndola et al., 2020). As stated by Caon et al. (2020), humanitarian logistics relies on Excel spreadsheets, which are subject to many mistakes and omissions of information. Therefore, it is challenging to coordinate complex humanitarian operations. When an emergency appears, and many people need food, shelter, and other life-saving items, it is problematic to deliver them due to the absence of a standard ERP. An analysis and review of past studies reveal that little research was done focusing on ERP implementation globally in humanitarian organizations. Past studies on the implementation of ERPs internationally were very general, and most of them were conducted in the private sector. Additionally, these research did not attempt to compare the challenges and success factors, of both sectors. Thus, the research intends to address all these questions in this study and fill the literature gap.

Role of ERP in Humanitarian Sector's Supply Chain

Gavidia (2017) argued that the roles of ERP in the humanitarian sector are to design and optimize the logistics resources via software-based models, establish adequate operations and reporting, and satisfy the needs of different humanitarian supply chain stakeholders. The authors identified the coordination problems within the humanitarian sector between various partners and proposed that ERP can fulfil this industry's requirements. The ERP can facilitate and enable the delivery of life-saving supplies as the humanitarian partners can share the information on the availability of the supplies in stock, procurement in the pipeline, availability of the necessary equipment, and the items required in disaster-effected areas. However, despite the comprehensive information provided in this study, the researchers intend to conduct another survey on potential cross-functional integration of the ERP and include multiple countries.
Recent studies indicated that logistics IT solutions play an essential role during the management of relief operations as it optimizes the supply chain resources, information flow and establishes control over supply chain workflow (Aranda et al., 2019; Caon et al., 2020; Falagara et al., 2020; Budak et al., 2020), improves external and internal communication and facilitate the decision-making (Falagara et al., 2020), reduces thefts at the humanitarian warehouse hubs (Budak et al., 2020), decreases the warehouse costs (Caon et al., 2020) and increases the warehouse personnel productivity (Budak et al., 2020).
The summary of the roles of ERP in humanitarian logistics is in Figure 1.

Previous studies almost exclusively focused on separate contexts, countries, and ERPs. As far as the researchers knows, no previous research compared the roles of supply chain ERP systems in the private sector with those in the humanitarian sector, and this study intends to fill the gap in the literature.

Role of ERP in Private Sector's Supply Chain

Gupta et al. (2020) attempted to understand the roles of ERP with the dynamic capability view theory. The authors stated that the roles of supply chain ERP is to enhance the internal and external cooperation of the supply chain participants and to support the companies in managing their logistics operations and achieving higher productivity. Huang et al. (2019) explored ERP implementation in Taiwan and stated that the role of supply chain ERP is to provide the managers with more decision-making tools, leading to reduced materials and labor costs and an increase in operating income.

Giannakis et al. (2019) provided other essential roles of ERP for the private sector, which include the promotion of supply chain effectiveness, production of different real-time reports, the expedition of the supply chain reaction, improvement of cooperation and coordination among logistics partners, and increase of the shared information quality. Acar et al. (2017), Kelle and Akbulut (no date), and Gupta et al. (no date) supported Giannakis et al. (2019) and stated that the ERPs have information-sharing, cooperative, collaborative, and cost optimization roles. However, despite the clear explanation about the roles of ERP, these studies have some geographical limitations and the absence of other vital roles. Therefore, the authors suggested, and the researchers agreed, that further studies shall concentrate on different contexts, cultural backgrounds, environment settings to determine additional roles of ERP systems and compare them with the humanitarian sector.

RESEARCH METHODOLOGY

Study Hypothesis

Taking into consideration the two research questions, the study tested the following hypothesis:
Research Question: *What are the roles of ERP systems in the supply chains of humanitarian and private sector organizations globally*?

The primary roles of ERP for private organizations are to improve the information flow along the whole manufacturing process, to ensure the logistics' effectiveness, and enhance the competitive advantages in the market (Ranjan et al., 2017). Giannakis et al. (2019) argued that ERP can increase coordination and collaboration between the supply chain partners in private sector logistics. In humanitarian logistics, there are also the same ERP roles, such as information flow improvement (Caon et al., 2020) and better coordination and collaboration among humanitarian participants (Gavidia, 2017). Therefore, the researchers wanted to test the hypothesis H0 and H1 and identify the differences in the roles of ERPs in both sectors.

H0: the roles of ERP systems in the private sector are equal to their roles in the humanitarian sector.
H1: the roles of ERP systems in the private sector are not equal to the roles of ERP in the humanitarian sector.

Data Collection

This was a quantitative cross-industries comparison study collecting the data via a semi-structured questionnaire. The questionnaire was developed to include both closed and open-ended questions to allow variety. Directs contacts with participants in different humanitarian and private organizations were made and also published a link to the questionnaire online on a number of Facebook and LinkedIn groups for logistics professionals targeting those who already participated in the ERP implementation or currently participating. Collis and Hussey (2013) argued that questionnaires allow generating the quantitative description of opinions or trends. Therefore, the questionnaire was developed and divided into main sections to answer the main research questions and test the hypothesis. Table 1 shows the parts of the used questionnaire that have been included in this paper. Collis and Hussey (2013) proposed to generate the preliminary findings by using web-based tools such as SurveyMonkey, Kwiksurveys, Freeonlinesurveys, and Qualtrics, which permit viewing the preliminary findings, export to Excel, and later analyze with the statistical software. This research technique's strength is that it furnishes the scientist with exact results, compares across different categories, and includes the procedures that can increase validity and reliability (Singh, 2007).

Table 1: Survey development and structure

Survey construct	Number of items	Reliability Test (Cronbach's Alpha)	Used scale(s)
General Information	7		
Role of ERP systems in the supply chains of humanitarian and private sector organizations	14	0.854	1) Strongly agree; 2) Agree; 3) Not sure; 4) Disagree and 5) Strongly disagree.

Collis and Hussey (2013) presented the Likert scale example, which can be used to form the questionnaire and then quickly analyze the information. This scale presents the responses in the form of five answers, which are 1) Strongly agree; 2) Agree; 3) Not sure; 4) Disagree and 5) Strongly disagree. The internal logicality of the items was verified by using Cronbach's alpha. As per Table 4, the study instrument's reliability was instituted by estimating the averaging correlation amidst items in the scales of the accordant dimensions introducing the independent and dependent variables. All alpha values for the dimensions were above 0.6 (Cohen et al., 2011). The alpha value for the used construct was 0.854. Thus, all the items could measure the variable.

There were two groups for comparison: humanitarian and private organizations. The data were tested with Statistical Package for the Social Sciences for Windows (SPSS) software by using the Mann-Whitney Test. As Nachar (2008) stated, this test can help the researchers answer the research questions related to the differences among the groups. The authors compared the Mann-Whitney U test with the T-test and stated that it is more powerful and useful in presenting the differences between two groups and test the research's hypothesis. It also gives less wrongful results compared to the t-test (Nachar, 2008). A pilot test of the questionnaire was executed to check the questions' reliability. The questionnaire was verified on a small subset of respondents to define obscurity or shortcomings in the questionnaire and adjust it as per the respondents' comments. During this verification, the emphasis was on filtering the questionnaire to decrease the number of problems that might arise while analyzing the gathered information and enhancing the questionnaire's reliability and validity.

Participants

This study's data was collected from 103 randomly selected participants (53 from commercial organizations and 50 from humanitarian organizations) located all around the globe. The targeted participants were the supply chain executives, consultants, managers, and officers of both industries participating in the implementation of ERP systems. Table 2 provides an overview of profile of participants.

Table 2: Profile of Participants

	Total responses (n=103)	
Question	**Humanitarian (%) (n=50)**	**Private (%) (n=53)**
• Sector	48.54	51.45
Job Profile		
• Supply Chain (Logistics) Executives	44.0	49.0
• Middle Supply Chain (Logistics) Professionals	46.0	30.2
• Junior Supply Chain (Logistics) Professionals	0	13.2
• Supply Chain (Logistics) Consultant	10.0	7.5
Location of Organizations' Headquarters		
• North America	40.0	35.84
• Europe	56.0	28.29
• Asia	2.0	30.19
• Australia	2.0	1.89
• Africa	0.0	3.78
Experience in ERP implementation (years)		
• Less than 1	2.0	3.8
• 1 - 3	24.0	13.2
• 3 - 5	50.0	37.0
• 5 - 10	20.0	26.4
• 10+	4.0	18.9
Years of usage of ERP systems in organizations		
• Plan to implement	4.0	5.7
• Less than 1	12.0	3.8
• 1 - 5	74.0	39.6
• 6 - 10	6.0	30.2
• 11 - 15	2.0	13.2
• 15+	2.0	7.5

Data analysis

There are two groups for comparison in the study: private and humanitarian organizations. The Statistical Package for the Social Sciences for Windows (SPSS) was used to analyze the data.

The gathered data were checked for completeness and only after that was entered into SPSS. The data presentation was done by visualizing the information on different figures, charts, and tables.

RESULTS AND DISCUSSIONS

Results For Research Question: What are the Roles of ERP Systems in the Supply Chains of Humanitarian and Private Sector Organizations Globally?

This study's objective was to examine and compare the roles of ERP systems in humanitarian and private organizations by using SPSS crosstabulation analysis. To respond to question 5, the researchers asked the participants to provide their opinions about the roles of ERP systems and answer the questions rated on a five-point Likert-type scale: 5-Strongly Agree, 4-Agree, 3-Not sure, 2-Disagree, 1-Strongly Disagree. Consequently, the researchers conducted Mann-Whitney tests for each role to test the hypothesis H0 and H1 and determine whether the roles are similar or different in humanitarian and private sectors.

This part of the questionnaire gathered the opinions of supply chain professionals about the different roles ERP systems play in humanitarian and private organizations.

<u>Roles of ERP systems in humanitarian global organizations</u>

Table 3 shows the reported opinions about the examined roles of ERP systems in humanitarian organizations.

The results from the first examined role were consistent with academic literature, which studied humanitarian (Gavidia, 2017) and argued that the role of ERP is to design and optimize the supply chain resources. The results from the second examined role were consistent with academic literature, which studied humanitarian (Gavidia, 2017) and stated that the role of ERP is to establish adequate operations. The results of the examined third role agree with academic literature, which studied humanitarian (Gavidia, 2017) and argued that the role of ERP is to establish adequate reporting. The results of the fourth examined role align with academic literature, which studied humanitarian (Gavidia, 2017; Caon et al., 2020) and argued that the role of ERP is to facilitate the supply chain reaction. The results from the fifth examined role were in sync with academic literature, which studied humanitarian (Gavidia, 2017; Caon et al., 2020; Aranda et al., 2019; Falagara et al., 2020; Budak et al., 2020) and argued that the role of ERP is to share the information on the availability of the supplies in stock. The results from the sisxth examined roles following academic literature, which studied humanitarian (Gavidia, 2017; Aranda et al., 2019) and argued that the role of ERP is to share the information on the procurement in the pipeline. The examined seventh role yielded results that were in accord with academic literature, which studied humanitarian (Gavidia, 2017 and Falagara et al., 2020) and argued that the role of ERP is to improve external communication and cooperation.

Furthermore, the results from the eightieth examined role were in accord with academic literature, which studied humanitarian (Gavidia, 2017 and Falagara et al., 2020) and argued that the role of ERP is to improve organizational internal communication. The results from the nineth examined role were in line with academic literature, which studied humanitarian (Falagara et al., 2020) and argued that the role of ERP is to facilitate the decision-making. In addition, the results from the examined tenth role were in line with academic literature, which studied humanitarian

(Budak et al., 2020) and argued that the role of ERP is to reduce thefts at the warehouses. The results from the eleventh examined role were in line with academic literature, which studied humanitarian (Caon et al., 2020) and argued that the role of ERP is to reduce warehouse costs. Furthermore, the results from the examined twelfth role were in consort with academic literature, which studied humanitarian (Budak et al., 2020) and argued that the role of ERP is to increase the productivity of the supply chain personnel. The examined thirteenth role was not mentioned in humanitarian literature. Thus, the research proposes to add this role to the list. Finally, the examined fourteenth examined role was not mentioned in humanitarian literature and was not supported by the respondents.

Table 3: Roles of ERP systems in humanitarian global organizations

Role	Mann-Whitney test	Percentage of Responses (%)					Item is supported
		Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree	
1. Design and optimize the supply chain resources	0.526	0.0	0.0	0.0	64.0	36.0	Yes
2. Establish adequate operations	0.073	0.0	0.0	4.0	64.0	32.0	Yes
3. Establish adequate reporting	0.604	0.0	0.0	0.0	24.0	76.0	Yes
4. Facilitate the supply chain reaction	0.973	00	0.0	4.0	38.0	58.0	Yes
5. Share the information on the availability of the supplies in stock	0.171	0.0	0.0	0.0	40.0	60.0	Yes
6. Share the information on the procurement in the pipeline	0.190	0.0	0.0	2.0	42.0	56.0	Yes
7. Improve external communication and cooperation	0.404	0.0	8.0	12.0	58.0	22.0	Yes
8. Improve organizational internal communication	0.139	0.0	4.0	4.0	68.0	24.0	Yes
9. Facilitate the decision-making	0.425	0.0	0.0	4.0	24.0	72.0	Yes
10. Reduce thefts at the warehouses	0.061	0.0	8.0	10.0	64.0	18.0	Yes
11. Reduce warehouse costs	0.249	0.0	6.0	12.0	62.0	20.0	Yes
12. Increase the productivity of the supply chain personnel	0.948	0.0	0.0	2.0	62.0	36.0	Yes
13. Reduce obsolete stock	0.056	0.0	6.0	10.0	66.0	18.0	Yes
14. Increase the operating income	0.000	2.0	6.0	72.0	8.0	6.0	No

Roles of ERP systems in private sector global organizations

The results from the first examined role were consistent with academic literature, which studied private sectors (Gupta et al., 2020; Elgohary, 2019; Ben-Daya et al., 2019) and argued that the role of ERP is to design and optimize the supply chain resources. The results from the second examined role were consistent with academic literature, which studied private sectors (Rong et al., 2015) and stated that the role of ERP is to establish adequate operations. The results of the examined third role agree with academic literature, which studied private sectors (Giannakis et al., 2019; Kelle and Akbulut, no date; Elkhouly et al., 2019) and argued that the role of ERP is to establish adequate reporting. The results of the fourth examined role align with academic literature, which studied private sectors (Giannakis et al., 2019; Gupta et al., 2020) and argued that the role of ERP is to facilitate the supply chain reaction. The results from the fifth examined role were in sync with academic literature, which studied private sectors (Giannakis et al., 2019; Gupta et al., 2020; Acar et al., 2017; Kelle and Akbulut, no date) and argued that the role of ERP is to share the information on the availability of the supplies in stock. The results from the sisxth examined roles following academic literature, which studied private sectors (Giannakis et al., 2019; Acar et al.,2017; Kelle and Akbulut, no date; Gupta et al., no date) and argued that the role of ERP is to share the information on the procurement in the pipeline. The examined seventh role yielded results that were in accord with academic literature, which studied private sectors (Giannakis et al., 2019; Acar et al., 2017; Kelle and Akbulut, no date; Gupta et al., no date) and argued that the role of ERP is to improve external communication and cooperation.

Furthermore, the results from the eightieth examined role were in accord with academic literature, which studied private sectors (Giannakis et al., 2019; Acar et al., 2017; Kelle and Akbulut, no date; Gupta et al., no date) and argued that the role of ERP is to improve organizational internal communication. The results from the nineth examined role were in line with academic literature, which studied humanitarian (Falagara et al., 2020) and argued that the role of ERP is to facilitate the decision-making. In addition, the results from the examined tenth role were in line with academic literature, which studied private sectors (Ben-Daya et al., 2019) and argued that the role of ERP is to reduce thefts at the warehouses. The results from the eleventh examined role were in line with academic literature, which studied humanitarian (Caon et al., 2020) and argued that the role of ERP is to reduce warehouse costs. Furthermore, the results from the examined twelfth role were in consort with academic literature, which studied private sectors (Gupta et al., 2020; Bogner et al., 2016) and argued that the role of ERP is to increase the productivity of the supply chain personnel. Also, the results from the examined thirteenth role were in consort with academic literature, which studied the private sector (Huang et al.,2019). Finally, the results from the examined fourteenth role were in consort with academic literature, which studied the private sector (Huang et al.,2019).

Table 4: Roles of ERP systems in private sector global organizations

Role	Mann-Whitney test	Percentage of Responses (%)					Item is supported
		Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree	
1. Design and optimize the supply chain resources	0.526	0.0	0.0	1.9	54.7	43.4	Yes

Role	Mann-Whitney test	Percentage of Responses (%)					Item is supported
		Strongly Disagree	Disagree	Not Sure	Agree	Strongly Agree	
2. Establish adequate operations	0.073	0.0	0.0	1.9	49.1	49.1	Yes
3. Establish adequate reporting	0.604	0.0	1.9	1.9	15.1	81.1	Yes
4. Facilitate the supply chain reaction	0.973	00	0.0	0.0	43.4	56.4	Yes
5. Share the information on the availability of the supplies in stock	0.171	0.0	0.0	1.9	50.9	47.2	Yes
6. Share the information on the procurement in the pipeline	0.190	0.0	1.9	1.9	52.8	43.4	Yes
7. Improve external communication and cooperation	0.404	1.9	5.7	9.4	52.8	30.2	Yes
8. Improve organizational internal communication	0.139	0.0	4.0	3.8	60.4	36.8	Yes
9. Facilitate the decision-making	0.425	1.9	1.9	5.7	24.5	66.0	Yes
10. Reduce thefts at the warehouses	0.061	1.9	3.8	9.4	45.3	39.6	Yes
11. Reduce warehouse costs	0.249	1.9	5.7	11.3	45.3	35.8	Yes
12. Increase the productivity of the supply chain personnel	0.948	0.0	5.7	5.7	47.2	41.5	Yes
13. Reduce obsolete stock	0.056	0.0	1.9	9.4	52.8	35.8	Yes
14. Increase the operating income	0.000	0.0	5.7	9.4	22.6	62.3	Yes

Null hypothesis H0 testing results

The null hypothesis related to the research question reads "*the roles of ERP systems in the private sector are equal to their roles in the humanitarian sector*". The Mann-Whitney test was conducted on all of the 14 examined ERP systems' roles and, with the exception of 14th role, the other roles were retained. Thus, the null hypothesis is retained.

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This research was done to perform a cross-industries analysis on ERP implementation in the humanitarian and private sectors as it was never done before. The research answered the research question by identifying a list of key roles ERP systems play and comparing the results across humanitarian and provide sectors. This section presents conclusions and recommendations, the study's limitations and recommendations for future research.

Conclusions

14 roles were selected from the recent literature of 2015 to 2020, and there was one role that was not included in the literature which studied the humanitarian sector – the role to reduce obsolete stock. Therefore, the authors proposed adding it to the list of ERP roles in the humanitarian sector. It can be concluded that the statement of Huang et al. (2019), who studied the implementation of ERP in sustainable corporations and mentioned that ERPs address the issues with inventory turns and eliminate the waste in limited resources, is also applicable for the humanitarian sector.
The role to increase the operating income, as per participants' answers, is not applicable in the humanitarian sector as the humanitarian logistics does not generate the income but reduce the death and suffering of the people (Gavidia, 2017), while the private sector logistics generates the income (Huang et al., 2019). The Mann Whitney Test for many questionnaire items and the respondents' answers rejected H1 and accepted H0. Therefore, it can be concluded that the roles are similar in both sectors.

Recommendations

The humanitarian sector shall include the role to reduce the obsolete stock to the presentation of justification to the top management in case if the organization is intended to implement ERP.

Limitation and Suggestions for Future Studies

This study is also subjected to some limitations as participants may have provided biased information due to unwillingness to respond honestly. The research could be biased when interpreting the quantitative data and make incorrect conclusions about the findings. The research did not include the full list of ERP roles from the ancient literature because the questionnaire was already lengthy. The results could be biased because the group samples were unequal. The research also did not provide the readers with the organizations' specific names as the questionnaire was anonymized to get more responses and present the overall picture. The study did not capture the organizations' size and their investments in ERPs, which might influence the organizational performance and impact of ERPs.

Future research

Further research could be undertaken to find more ERP systems usages and their roles in the ancient literature and compare private and humanitarian sectors. Further study could include the size of the organizations and their investments in ERPs.

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Sequential Retail Shopping at Airports

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ABSTRACT

In this study we focus on sequential purchasing which remains an unexplored topic in airport retail. Grounded in shopping momentum, we use real-world purchase data from 279,000 passenger boarding cards to examine relationships between first purchase expenditure, walking distances, time available for sequential shopping, crowding, payment type, product involvement, promotions and product type on sequential purchasing at Dubai International Airport. Findings offer a significant theoretical contribution to the travel retail and sequential purchasing literature and have important practical implications for airport retail practitioners.

KEYWORDS: Sequential Purchasing; Retail Shopping; Airports; Shopping Momentum, Regression

INTRODUCTION

Understanding passenger shopping behavior at airports is crucial to driving commercial revenues as “[a]irport retailing is the largest market in the broader international travel retail market” (PR Newswire, 2017). Research on airport retail however, is still in its infancy with existing research examining the characteristics of airport shoppers, such as describing traveler’s shopping preferences (Bohl, 2014; Hsu & Chao, 2005; Omar & Kent, 2001), and identifying various shopping types and their underlying motivations (Freathy & O'Connell, 2012; Geuens et al., 2004). Of interest in the current study is the phenomenon of sequential purchasing which describes the pattern of behavior of a customer who, having made an initial purchase (purchase A), goes on to shop again (purchase B), and may also continue to shop (purchase C) (Yen & Lee, 2012). Prior research on sequential purchasing has largely focused on revealing the internal psychological processes that explain sequential choices (Dhar et al., 2007). Some studies rely on goal-setting theories to explain how a sequence of events transpires and how the results of earlier decisions impact later ones through their impact on goal targets (Brandstätter et al., 2015; Gollwitzer, 2012) while other studies employ self-regulation perspectives to shed light on the impulsive nature of sequential purchasing (Arkes et al., 2002; Vohs et al., 2008). Although insightful regarding the internal psychological processes of consumers, prior research on sequential purchasing has shed little light on the impact of retail atmospherics and contextual influences (Vieira, 2013).

To address this void, this study aims to extend existing research on sequential purchasing to a new retail environment, airport shopping. Grounded in shopping momentum (SM) theory, the objective of our study is to explore antecedents affecting sequential purchasing behavior of travelers in the context of airport duty-free shopping. Our study contributes to existing literature in three important ways. First, we extend the findings of Dhar et al. (2007) by testing established behavioral hypotheses to investigate the concept of purchase momentum using real-world purchase data. In doing so, we explore other nuances in consumer behavior (Albarracin & Wyer, 2000) exhibited as a part of the shopping momentum effect that become evident in a field setting rather than in a laboratory setting. Second, we explore shopping momentum effect (Dhar et al., 2007) using a new set of situational variables which have been largely ignored in previous research. Our research specifically examines the effects of time availability, crowding, payment type, promotions, product type and involvement on sequential purchase momentum. Our focus on these new situational variables provides a richer behavioral description of the consumer shopping process at an international airport.

Third, our research adds to a growing body of literature advocating the need for airport operators and retailers to better understand passengers' consumption behavior within their airports (Castillo-Manzano, López-Valpuesta & Sánchez-Braza, 2018; Chen et al., 2020). Unlike general retail shopping, duty-free shops at international airports are only available to inbound and outbound tourists (Chung, 2015; Sohn & Lee, 2017), and buying behavior is often created by the situational conditions that are unique to the airport retail environment (Crawford & Melewar, 2003). The environment of duty-free shopping, when combined with passengers' feelings of excitement and positive emotions, induces passengers to make unexpected purchases which are more arousing, unintended, and less deliberate compared to planned buying behaviour (Geuens et al., 2004; Omar & Kent, 2001). Although modelling of airline passengers' spending behaviour in airport terminals have been conducted (Castillo-Manzano, López-Valpuesta & Sánchez-Braza, 2018; Omar & Kent, 2001; Tseng & Wu, 2019), the shopping momentum effect is very new to travel retail research and remains unexplored in an airport retail context. We argue that research on the shopping momentum effect in an airport retail setting should be of considerable value to airport retail managers and airport operators when designing strategies to improve the overall shopping experience for passengers and increase non-aviation revenue streams.

We begin by critically reviewing the literature on airport shopping and sequential behavior. Second, we introduce our research model to guide the study and related literature. In doing so, we present hypotheses that examine the antecedents of sequential behavior. Third, we present an empirical study drawing upon boarding card data from passengers who made two purchases in three terminals at Dubai International Airport (DXB). The retail space at DXB is operated by Dubai Duty Free (DDF), and generates annual sales of US$2.01 billion (Dubai Duty Free, 2019). Finally, we present our results and discuss implications for researchers and practitioners.

LITERATURE REVIEW

The Airport Shopping Environment

Prior research on airport shopping has revealed the distinctiveness of the airport retail environment (Crawford & Melewar, 2003; Urry et al., 2016). For example, unlike consumers in a regular shopping environment, a passenger usually goes through what is known as the 'travel stress curve' (Scholvinck, 2000), where getting to the airport, check-in procedures and immigration cause stress to rise. Once passengers complete the final security process and enter the retail area, their stress drops at a time when their self-regulation has been depleted. This is why airport shopping is seen as ‘happy hour’ shopping for airport retailers and features impulse or unplanned purchasing (Crawford & Melewar, 2003), At this time, passengers enter the retail area and become a ‘captive customer’ audience (Omar & Kent, (2001). This type of experience is very different to that of a non-retail airport experience where the customer is not captive in the retail space.

The international airport environment can also trigger a range of other passenger emotions such as timelessness and placelessness (Rowley & Slack, 1999), particularly when travelling across time zones and changing planes (sometimes more than once) to reach their final destination. Airport dwell time, the amount of time post security but before boarding, has a significant impact on a passenger’s shopping decisions. As the waiting time at an airport increases so does the likelihood of making a purchase (Castillo-Manzano, 2010; Castillo-Manzano, López-Valpuesta and Sánchez-Braza, 2018).

While there is some previous research on airport atmospherics, it has tended to focus on service, multi-lingual communication, the ability to pay with multiple currencies, noise levels, lighting and wayfinding (Bohl, 2014). This literature has also focused on how the airport architecture affects passenger movements, describing the airport atmosphere (Adey, 2008), shopping outcomes in an airport retail environment (Baron & Wass, 1996), and how atmospherics influence impulse buying (Crawford & Melewar, 2003; Omar & Kent, 2001). However, airport atmospherics and their link with sequential shopping remains an under-studied research area.

Sequential Purchasing

Prinzie and Van den Poel (2006, pp. 710-711) define “a *sequence* as a succession of events. An *event* is a transition from one discrete state to another, situated along a time continuum”, noting that “[i]n marketing, sequence analysis is applied in choice modelling and is mainly focused on the succession of purchases”. In understanding the cycle in sequential purchasing, is it important to understand the effect that making a purchase has on the individual at each purchase event. The study of sequential purchasing has employed various theoretical perspectives e.g., goal setting, self-regulation and shopping momentum along with justification (Khan & Dhar, 2006) in the purchase cycle.

Viewing sequential purchasing as a goal pursuit, goal-setting theory has been widely used to investigate sequential choices with later choice decisions on goals being affected by earlier choices made with trade-offs between goals and resources (Novemsky & Dhar, 2005; Gollwitzwer, 2012). In particular, most prior research explains sequential purchasing from a utility perspective as a result of self-regulation (Baumeister et al., 1998) and self-control (Dholakia et al. 2005), that is, cognitive resources available after the first choice/decision affect the likelihood of subsequent choices. To enrich the understanding of the internal processes in sequential purchase, Dhar et al. (2007) propose that shopping momentum occurs because the initial purchase triggers the mindset shifting from deliberation to implementation that enhances the purchase of a second, unrelated product. However, research about why certain mind-sets are triggered or enacted to influence sequence purchasing remains limited.

Studies of sequential purchasing have largely relied on experimental methods, which may limit their capacity in providing desired guidance for retail mangers on how to design interventions to influence sequential purchasing. First, external retail atmospherics are usually controlled rather than considered as key influential factors (Kacen et al., 2012); hence their impact is typically understudied. Second, time lapses between sequential choices have not been considered. In previous studies using experimental design (e.g., (Dholakia et al., 2005), the subsequent choice (C2) took place immediately after the first one (C1). However, in a real-life scenario, C2 can take place at varying periods of time after C1, and research has shown that resources replenish over time and affect sequential choices (Tyler & Burns, 2008). Third, prior studies using experimental design tend to use a yes/no purchase decision over a single unit of product item as opposed to multiple items consisting in a typical purchase, e.g., a gourmet sandwich vs. a sweater (Dholakia et al., 2005), a key chain vs. a CD (Dhar et al., 2007), or two different color pens/tops (Vohs et al., 2008). However, Dhar and Simonson (1999) note that the majority of purchases are not made in isolation but take place alongside other product purchases, not necessarily from the same category. Items put in the basket can be both complementary and non-complementary and are chosen for a variety of reasons, both planned and impulsive. A real-life shopping situation rarely involves an either/or decision over a single item. Thus, to strive for more realism and greater practical relevance, research on sequential purchasing needs to be conducted in a natural setting where influences from shopping atmospherics and the shopping journey should be considered as independent variables.

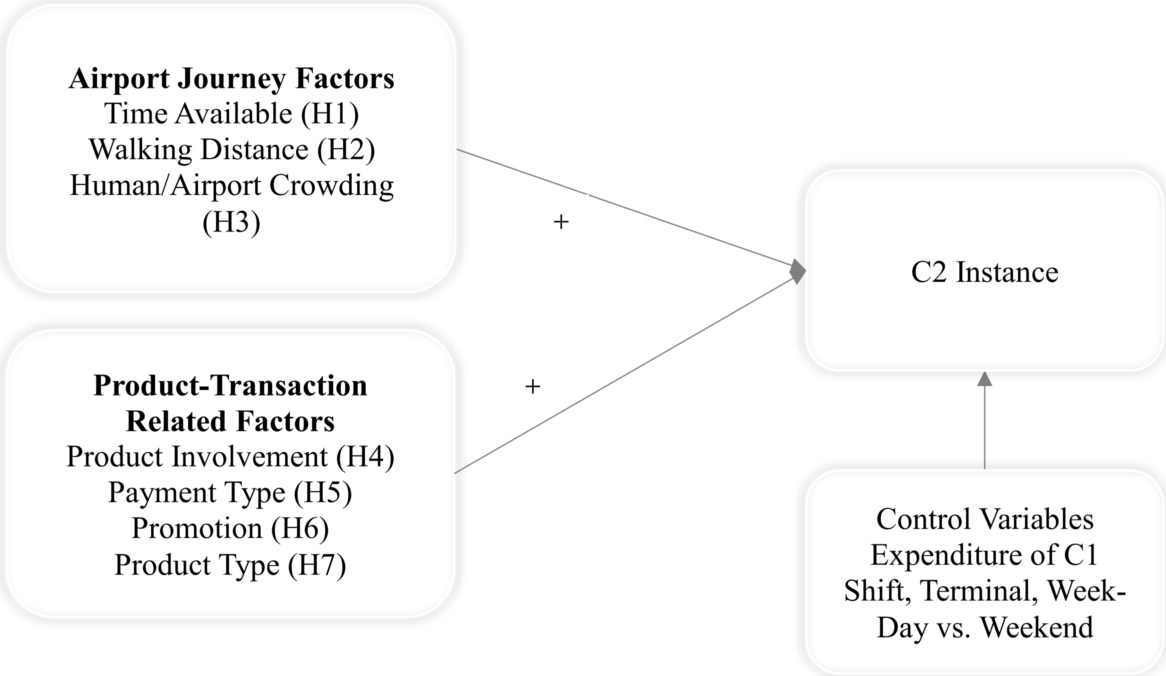
CONCEPTUALIZATION AND HYPOTHESES

The conceptualization underpinning our study is shown in Figure 1. First purchases are referred to as 'Choice 1' (C1), and second purchases as Choice 2 (C2). After payment of the first purchase, should that same customer go on to purchase again, the second basket is referred to as 'Choice 2' (C2) and a sequential purchase has taken place.

Prior research around environmental factors that impact how decisions are made show how data used in a previous decision can impact a subsequent decision (Dhar & Simonson, 1999; Dholakia et al., 2005; Drolet, 2002). While all retail environments share similarities, the context of an airport environment brings with it many differences in the shopping journey and atmospherics, such as time availability, 'last chance' decisions, walking distances and emotions evoked by the airport environment itself. After the stress of check-in, immigration and security, passengers' self-regulation is depleted (Crawford & Melewar, 2003) at which point the 'happy hour' (Omar & Kent, 2001) is experienced by travelers when their mindset moves to a high level of excitement and when they are most open to shop. This shift in mindset is also seen as an underlying assumption in shopping momentum, i.e. from deliberation to implementation (Dhar et al., 2007).

Our conceptual model identifies several groupings of contextual factors within the airport environment that may both promote shopping momentum (implementation) and interrupt shopping momentum (deliberation). These contextual factors are categorized as airport journey-related and product/transaction related.

Figure 1: Conceptual Model of Sequential Purchasing in an Airport Retail Setting



Impact of Airport Journey-Related Factors

Three airport journey related factors are relevant to our study: time available in the retail area, walking distance to the departure gate and crowding. Time available in an airport refers to the time available to a passenger to spend in those areas featuring shops and restaurants (Bohl, 2014) and is outside of passengers' control unlike time spent in a mall (Levy & Weitz, 2009). Bohl (2014) argues that in situations where a limited time is available for shopping, such as an airport, time may influence consumer spending (Volkova & Müller, 2012).

Several studies in an airport environment demonstrate a link between dwell time and sales (Herrington & Louis, 1995; Bohl, 2014), with 50% of all shopping occurring within 30 minutes of passengers entering the retail area (Freathy & O'Connell, 2012). If airport shoppers have limited time availability to shop, they may tend to deliberatate more rather than implement as they consider how much time is needed to get to their departure gate and complete the boarding process. The primary task of taking the flight may curb the need to continue shopping. In this situation, the shopper is still contemplating whether to commit to a potential purchase. This mindset involves the consideration of several alternative possibilities and may be accompanied by uncertainty as to which alternative is best. Any deliberation caused by the amount of remaining dwell time may therefore disrupt the shopping momentum process. Therefore, we hypothesize that the more time passengers have to shop at an airport, the more likely they are to make another purchase. Thus:

H1. The longer the time available between C1 and departure, the more positive the impact on instances of C2.

In a large airport such as DXB, passengers have to walk long distances and the retail offerings are spread over large areas. Once passengers enter the retail areas after security, they experience the 'happy hour' when they are more likely to shop and wander (Crawford & Melewar, 2003; Omar & Kent, 2001), with the majority of shoppers visiting multiple shops (Freathy &

O'Connell, 2012) as they browse to kill time (Baron & Wass, 1996). At DXB, passengers are guided through the retail offerings on their route to their departure gate and, as a result they have very little opportunity to avoid the shopping areas. They are also exposed to more shops the further away their departure gate. Thus, when C1 is far away from the departure gate, passengers have a greater chance of being exposed to external marketing stimuli and may therefore visit multiple store locations during their walking trip. Added to external marketing stimuli are the effects of the travel stress curve (Crawford & Melewar, 2003), in which the stress of the airport journey prior to arriving at the retail area corresponds with a lowering of self-regulation, which makes marketing stimuli even more irresistible, thus increasing the chance of a second purchase by triggering an implementation mindset seen in shopping momentum theory (Dhar et al., 2007). Therefore:

H2. The greater the walking distance between C1 and the departure gate, the more positive the impact on instances of C2.

Human crowding, defined as a state of psychological stress that results when one's demand for space exceeds that of supply (Machleit, Kellaris and Eroglu, 2000), may also affect sequential purchasing. It is typically measured in terms of an objectively measured variable: density (Machleit, Kellaris and Eroglu, 2000). When density restricts or interferes with activities, feelings of crowding are typically experienced (Dion, 1999; Eroglu et al., 2005; Machleit, Kellaris & Eroglu, 1994). Human crowding in the context of airport retail is indicated at two levels: the number of people in the store itself (store crowding), and the number of people in the airport (airport crowding) (Kim & Li, 2009; Machleit et al., 1994). While store crowding can be directly managed by marketers, airport crowding is mainly determined by the flight arrangement, serving as an important contextual factor that marketers need to monitor and respond to closely.

At the store level (store crowding), experiencing spaces in the presence of other shoppers can help to create a sense of social connection and generate positive responses; shoppers also tend to follow the navigation behaviors of other shoppers around them (Harrell et al. 1980), thus the very presence of customers in the store will attract other customers (Argo, Dahl & Manchanda, 2005; Hui, Bradlow & Fader, 2009: Wang & Ram, 2015). Li et al. (2009) found that perceived human crowding had an overall positive impact on shoppers positive emotions (pleasure, arousal, dominance), while Eroglu et al. (2005) and Machleit (2000) showed crowding to impact both store atmosphere and overall shopper satisfaction. More recently, Blut and Iyer (2020) in a meta-analytic study combining the findings from 73 samples and more than 19,000 shoppers, showed human crowding to have a positive impact on shopper satisfaction and behavioural responses. Higher levels of crowding at C1 provides a psychological impulse affecting subsequent consumption decisions at C2 (Dhar et al., 2017; Gómez-Miñambres & Schniter, 2017). We therefore hypothesize that:

H3a. Higher levels of store crowding at C1 will have a positive impact on instances of C2.

In an airport shopping context, airport crowding is experienced right after completing check-in, when the mindset of travelers moves to a high level of excitement and enjoyment for shopping (Bohl, 2014; Crawford & Melewar, 2003; Entwistle, 2007). Overall airport crowding is likely to be perceived as "good crowding" (Kim, Lee, & Sirgy, 2016) and these positive emotions contribute positively to the overall shopping experience. Crowding therefore signals that continued shopping is rewarding and a positive experience, suggesting there is momentum to continue shopping rather than to terminate. We therefore hypothesize that the positive impact of airport crowding will help implementation and have a positive overall impact on shopping momentum and, in turn, the likelihood of C2. Therefore:

H3b. Higher levels of airport crowding at C1 will have a positive impact on instances of C2.

The ‘right’ level of crowding will create an exciting store atmosphere, but too much will cause congestion and make it difficult for passengers to shop. Prior studies have looked at crowding density at just one moment in time and presumed it to be linear and static (Machleit et al., 1994). Dion (1999) however, found that in a real-life situation this linear and static assumption of crowding is not the case and crowding sensations are shaped in many different ways. Eroglu et al. (2005) suggested an inverse U-shape relationship between crowding and satisfaction such that extremely crowded and extremely un-crowded conditions tend to generate the undesirable states of over and under arousal, respectively.

Extremely crowded conditions can result in psychological stress, such as feelings of loss of personal space and a limitation in freedom (Machleit et al., 2000; Michon et al., 2005; van Rompay et al., 2008). In a crowded retail environment, consumers also tend to react with an ‘action’ coping mechanism, i.e., they plan/strategize, and focus on their shopping targets while surveying the shopping environment and managing their time while in the store (Whiting, 2009). Harrell et al. (1980) and Hui, Bradlow and Fader (2009) also suggest that under conditions of extreme crowding, consumers may delay purchases.

In the context of airport retail, over-crowding conditions may increase the perceived risk of missing flights and anxiety. This effect is applicable to both store as well as airport level. At the store level, the over-crowding at C1 implies long queue for payment and more time consumption; while at the airport level, it makes passengers more cautious with the time allocated for shopping. This suggests the existence of an optimal crowding level as the positive effects of crowding decline as physical spaces become overcrowded. Therefore:

H3c. The effects of store crowding at C1 on instances of C2 will form an inverted U-shape.

H3d. The effects of airport crowding at C1 on instances of C2 will form an inverted U-shape.

Impact of Product/Transaction Related Factors

Gollwitzer’s (2012) theory of mindsets finds that the first purchase moves the consumer from a deliberative to an implemental mindset (shopping momentum), which makes sequential purchases possible. How the first purchase is conducted is likely to affect this mindset shift. In this research, we examine the role of four product and transaction related factors: product involvement, payment method, promotions and product type.

Zaichkowsky (1985, p. 342) defined product involvement as “a person’s perceived relevance of the object based on inherent needs, values, and interests”, and tends to be greater for goods that have a higher cost and are bought after considerable research and thought (Clarke & Belk, 1979; Hoonsopon & Puriwat, 2016). Thus, when shoppers consider a high product involvement purchase, they are more likely to look for more information, weigh their decision more carefully and exert more effort and attention on their purchase (Hong, 2015; Quester & Smart, 1998). According to goal systems theory (Kruglanski et al., 2002), activating a goal also activates the cognitive procedures for accomplishing the goal (Büttner, Florack, & Göritz, 2013). We therefore argue that when the first purchase is high in product involvement, an implemental mindset is more likely to happen. Consumers making a high involvement product purchase at C1 should exhibit more cognitive effort on their purchase leading to an implemental mindset, which positively impacts additional consumption. Therefore:

H4a. Products requiring high involvement at C1 will have a positive impact on instances of C2.

However, the impact of product involvement may not be linear, and too little product involvement and too much product involvement may both have negative impacts on purchase outcome. Products that require high involvement tend to more expensive such as gold, jewelry and perfumes (Zaidon, 2016) and take a longer sales transaction time (Lockshin, Spawton & Macintosh, 1997), eating into time available to shop and inducing more anxiety. They also tend to make passengers pay more attention to price cues (Ferreira & Coelho, 2015). Too little

product involvement will have a negative impact on instances of C2 as the customer may have less engagement with the purchase (Pansari & Kumar, 2017), leaving the mindset shift or shopping momentum less likely. Therefore:
H4b. The positive effects of product involvement at C1 on instances of C2 will form an inverted U-shape.

Focusing on budgetary or financial resources leads to a deliberative mindset and interrupts momentum, suggesting that payment type may also impact sequential purchasing. When purchases are made, customers may experience the “immediate *pain of paying*, which can undermine the pleasure derived from consumption” (Prelec & Loewenstein, 1998, p.4). This may cause consumer deliberation which in turn can interrupt the shopping momentum process. Unlike cash payment, a credit card payment means that the customer, mentally at least, receives the product before s/he pays for it (when the statement is received). Money available has been seen to have a positive effect on impulse purchasing (Beatty & Ferrell, 1998) and payment by credit card has been shown to increase the likelihood of an unplanned purchase (Inman & Winer, 2009). Research has also shown that using a credit card increases how much a consumer spends (Saleh, 2012), and this can result in some customers spending beyond their financial means (Pirog & Roberts, 2007). Customers who pay with a credit card are also less price sensitive (Roberts & Jones, 2001) and often purchase higher ticket items (Deshpande & Krishnan, 1980). It is therefore hypothesized that paying for purchases with a credit card will not result in budgetary deliberation that may occur in shopping momentum when paying with cash. Therefore:
H5. Payment with a bank card at C1 will have a positive impact on instances of C2 in that passengers using bank cards for C1 are more likely to buy again.

Retailers typically rely on promotional activities and merchandising tactics to enhance the emotional appeal of products as promotions have been found to encourage shoppers to buy on impulse and therefore more often (Kacen, Hess & Walker, 2012; Mihic & Kursan, 2010). According to regulatory focus theory (RFT), human behavior and motivation is underpinned by two unique systems of self-regulation: promotion focus, which is concerned with aspirations and accomplishments of ideals, and prevention focus, which is concerned with avoiding mistakes and fulfilling obligations (Higgins, 1997; Watling et al., 2012). According to Ramanathan and Dhar (2010, p. 543), “different framing of savings messages in sales promotions may indicate to consumers that they can attain goals associated with either positive outcomes or the avoidance of negative outcomes”. Sales promotion in the form of a price discount activates a promotion focus because they encourage shoppers to consider gains or positive outcomes, such as how they can use the money that they will save from the initial purchase. A price discount sales promotion leads to perceived savings, which in turn motivate shoppers to spend again at other stores. Thus, sales promotion should spread to other, unrelated purchase decisions. International travelers often have a short window of time to shop (Chen et al., 2020), suggesting that the price discount is likely to activate a prevention focus i.e. it creates a desire to avoid negative outcomes such as losing out on a good deal. In summary, we expect a positive relationship between promotions (a price discount at both C1 and C2) and instances of C2. Therefore:
H6. Overall-level promotions (price discounts) at both C1 and C2 will have a positive impact on instances of C2.

Although the consumption of many products involves both hedonic and utilitarian dimensions to varying degrees, consumers typically characterize some products as primarily hedonic or utilitarian. Hedonic products are those whose consumption is primarily characterized by an affective and sensory experience of aesthetic or sensual pleasure, fantasy, and fun, whereas utilitarian goods are those whose consumption is more cognitively driven, instrumental, and goal oriented and accomplishes a functional or practical task (Dhar & Wertenbroch, 2000). While hedonic might initiate a purchase, hedonic products may trigger deliberation in subsequent purchase moments (Fishbach, Freidman & Kruglanski, 2003) and subsequently cause the shopper to pause and potentially resist the purchase as a means of effective self-regulation (Dhar et al., 2007). Kivetz and Simonson (2002) also note that relative to utilitarian purchases, hedonic products are associated with feelings of guilt, and that such negative emotions may carry over to subsequent purchases and therefore interrupt shopping momentum.

In contrast, utilitarian products can help to initiate buying and increase the chances of more buying taking place (Fishbach et al., 2003). People are not only willing to pay more for utilitarian goods (Okada, 2005), but also find it easier to justify spending on them (Prelec & Loewenstein, 1998). Mukhopadhyay and Johar (2009) demonstrated that indulgence is likely to increase only when prior restraint is salient and hence can be used as a justification to make a purchase. According to the licensing effect (Khan and Dhar, 2006), making a virtuous decision licenses individuals to subsequently make a more indulgent choice by boosting their self-concept.

Therefore, adding to shopping momentum theory, the deliberation and interruption in shopping behavior seen when hedonic products are purchased, is less likely to occur when utilitarian products are purchased at C1 and should result in higher instances of C2. This may be further supported through justification (licencing effect) that results from a purchase of utilitarian products at C2, despite self-regulation still being present. Therefore:

H7. Utilitarian purchases at C1 will have a positive impact on instances of C2 in that passengers purchasing utilitarian products in C1 are more likely to buy again.

RESEARCH METHODOLOGY

Data Collection

To explore passengers' shopping patterns, transaction data and boarding card information was obtained at the points of sale of all 81 DDF shops in the Dubai International's (DXB) 3 concourses (25 in Concourse A (CA); 36 in Concourse B (CB) and 20 in Concourse C (CC). Each boarding card had a bar code which was scanned at the POS when a sale was made. It was important that the flight codes used for each transaction matched the flight code scheduled, by airline, for that day. The date, the flight code and the seat number on the boarding pass allowed for a unique identifier for each passenger. Products considered as necessities at both C1 and C2 (e.g., bottles of water, food and coffee) were excluded from data analysis given the research focus on 'real' shopping purchases.

Transaction and boarding pass data for hypothesis validation was collected over a period of six days to ensure that both busy, less busy days and shift patterns were included. While the data was collected in the month of October the passenger mix is reflective of other months throughout the year. On one of these days, there was also a 20% sales promotion across the entire business, except for some low margin categories and products. Integrating transaction date, flight number and seat number as a unique identifier for individual passengers, the transaction data could be linked to individual passengers. The transaction data and boarding pass data included most of our dependent and independent variables, such as total expenditure of transactions, transaction payment method, and detail of products purchased in each transaction. We also incorporated additional data sources for other independent variables, including flight schedule and actual departure data, airport planning data, sales conversion surveys, product involvement surveys, and product category classifications.

In total, 279,383 transactions were captured of which 78,156 (28%) were not usable due to incorrect data on the boarding card, or an incorrect boarding card was given at the point of sale. Upon investigation, the majority of these were boarding cards for transit passengers who had not yet been allocated a seat number. In total, 201,227 transactions were used in the final data analysis. 38% of all sales revenue were to passengers who made just one purchase across all locations; 26% of total sales involved a second purchase, in either the same or a different location; 12% of total sales involved three separate purchases; multiple purchases after that continued to reduce in number. A total of 51,770 passengers used bank credit cards, which accounted for 55.3% of sales in monetary terms (the most popular way to pay) but accounted for only 33% of all transactions.

Measurement
Table 1 provides a summary of the study's variables and measurement.

Table 1: Variable Definition and Operationalization

Variable Type	**Variable Name**	**Variable Description**
Dependent Variable	Instances C2	Instances of C2
Independent variable	Expenditure C1	Expenditure at C1 in value
	Time Availability	Time between C1 and departure time in minutes
	Walking Distance	Walking distance in time between C1 and departure gate in minutes
	Store Crowding	Number of passengers in the store at the time of C1 scaled by the store size
	Airport Crowding	Number of passengers at the airport at the time of C1
	Product Involvement	Product categories that require high involvement in terms of time (minutes) required for sales interaction with staff
	Payment Type	Payment method for C1, i.e. either cash (0) or bank card (1)
	Promotion	Transactions across major categories on 1 day enjoyed 20% off (promotion=1); while the rest days' transactions without this airport-wide promotion (promotion 0)
	Product Type	Products in the basket at C1 being either mostly hedonic or mostly utilitarian
Control Variable	Shift	DDF operates 24/7 and has 3 eight-hour shifts per day (7am-3pm, 3pm-11pm, 11pm-7am)
	Destination GDP	GDP/per capita of each destination city
	Concourse	Data is collected from three different concourses with different layout.

Data Analysis
Since the dependent variable in this study is categorical with only two levels, logit regression was used to obtain the estimation of the coefficients and their significance levels. Log1p() or Log (X+1) was used to statistically transform the continuous variables that were not normally distributed. Following prior literature, we also added the square terms of log-transformed values for store crowding, airport crowding, and product involvement variables to test the inverted-U relationships hypothesized in H3c, H3d, and H4b (Calic & Shevchenko, 2020). Our final regression estimates the logit model below:

$$
\begin{aligned}
&\mathit{Logit}(P(\mathit{Instance\ of\ C2} = 1)) \\
&\quad = \beta_0 + \beta_1\text{exp\_c1} + \beta_2\text{time\_pressure\_c1} + \beta_3\text{walk\_c1} \\
&\quad + \beta_4\text{log1p(nstore\_crowd\_c1)} + \beta_5\text{log1p(ntravelers\_c1)} \\
&\quad + \beta_6(\text{log1p(nstore\_crowd\_c1)})^2 + \beta_7(\text{log1p(ntravelers\_c1)})^2 \\
&\quad + \beta_8\text{log1p(product\_involvement\_c1)} \\
&\quad + \beta_9(\text{log1p(product\_involvement\_c1)})^2 + \beta_{10}\text{payment\_c11} \\
&\quad + \beta_{11}\text{isDisc\_c11} + \beta_{12}\text{h\_u\_c11} + \beta_{13}\text{shift\_no\_c12} + \beta_{14}\text{shift\_no\_c13} \\
&\quad + \beta_{15}\text{CB} + \beta_{16}\text{CC} + \beta_{17}\text{ppp\_gdp} + \varepsilon
\end{aligned}
$$

Two tests were performed to estimate the goodness of fit of the model. The first was the Hosmer-Lemeshow test (Hosmer et al., 1997), as the model included both continuous and categorical independent variables. The second test was the Cox-Snell test (Oxford University Press, 2018) which was used to calculate a pseudo *R* square for logit regression. As multiple independent variables were employed in this study, a multiple co-linearity test was performed, i.e. variance inflation factors (VIF) to determine if the independent variables were highly correlated. Because of the large amount of data, we used R software, an open source technology for statistical computing and graphics, to perform the data analysis and hypothesis validation (Holt, 2016).

RESULTS

Descriptive statistics and correlations are summarized in Tables 2 and 3.

Table 2: Descriptive Statistics

Description	CA	CB	CC	Total
No. of shops	25	35	21	81
No. of categories	34	34	34	34
No. of shoppers	35,881	45,492	45,174	126,547
Total Sales Value (US$)	6,232,730	10,406,406	6,273,788	22,912,924
% Cash sales	40%	44%	49%	44%
% Bank card transactions	40%	39%	27%	36%
% Bank card sales amount	59%	56%	50%	55%
% Other payment (internal sales/credit sales)	1%	0%	1%	1%

Note: CA=Concourse A, CB=Concourse B, CC=Concourse C

Table 3: Correlation of Factors

Var	Name	Mean	SD	V1	V2	V3	V4	V5	V6
V1	Expenditure C1	342.93	1183.45	1					
V2	Time- C1 to Dept Time	39.92	83.15	.02***	1				
V3	Walking distance C1 to Dept Gate	8.64	8.19	.11**	0.23***	1			
V4	Store Crowd C1	14.99	10.78	.13***	-.07***	-.05***	1		
V5	Airport Crowd C1	5503.68	4465.70	.02***	.00**	.00^{ns}	-.16***	1	
V6	Product Involvement C1	3.35	1.52	.44***	-.01***	.01*	.10***	.14***	1

***=.001, **=.01, *=.05, ns=not significant

The Hosmer-Lemeshow Goodness of Fit (GOF) test indicates whether the predicted values are close to or different from the actual values. Where the *p* value is larger than 5%, it can be concluded that the estimation has a good fit. The GoF for the model with instances of C2 as the dependent variable was .187, suggesting that the model was a good fit (Hosmer et al., 2013). A multiple co-linearity test was performed to determine if the independent variables were highly correlated. All of the variance inflation factors (VIF) in the GLM score were below 1.5, indicating low correlation between the variables (Hair et al., 2017). Table 4 summarizes the hypothesis testing results.

Table 4: Hypothesis Testing Results (Dependent Variable: Instance of C2)

Independent Variables	Variable Code	Coefficient Estimate	z-value
Expend of C1	exp_c1	0.22	36.46***
Airport Journey Related			
H1: Time Available	time_pressure_c1	4.24	26.48***
H2: Walking Distance	walk_c1	0.11	9.63***
H3a: Store Crowd	log1p(nstore_crowd_c1)	0.18	4.77***
H3b: Airport Crowd	log1p(ntravelers_c1)	-0.19	-1.17 ns
H3c: Inv U-shape StoreCrowding	$(\text{log1p(nstore\_crowd\_c1)})^2$	-0.01	-1.32 ns
H3d: Inv U-shape AirportCrowding	$(\text{log1p(ntravelers\_c1)})^2$	0.02	1.67 ns
Product/Trans Related			
H4a: Product Involvement	log1p (product_involvement_c1)	1.54	6.83***

H4b: Inv U-shape Product Involvement	(log1p (product_involvement_c1))^2	-0.43	-6.11***
H5: Payment Type	payment_c11	0.19	12.67***
H6: Promotion	isDisc_c11	<0.001	0.22 ns
H7: Product Type	h_u_c11	0.38	19.52***
Control Variables			
Shift	shift_no_c12	0.15	8.61***
	shift_no_c13	0.16	7.81***
Concourse	CB	-0.44	-24.46***
	CC	0.13	6.62***
Destination GDP	ppp_gdp	-0.04	-5.38***

n/a=not hypothesized
***=.001, **=.01, *=.05, ns = insignificant

After excluding outliers, the average time span between C1 and C2 was 37.68 min, and 50% of C2 happened before 15 minutes after the occurrence of C1. Within the 1st quartile of the population studied, C2 took place within an average of 8 minutes, and within the 3rd quartile of the population studied, C2 took place within 29 minutes of C1. Compared to the average dwell time at the airport, which is 4.30 hours, the shopping window for sequential purchasing was relatively short, and the likelihood of a second purchase declined quickly after 10 minutes. In testing the study's hypotheses, we also examined the effect of the expenditure at C1 (β =.24, p< .001). The expenditure at C1 was found to be a significantly and positively related to the likelihood of a second purchase.

Impact of Airport Journey-Related Factors

The time available for sequential shopping had a positive impact on instances of C2 (β= 4.24, p<.001). Time available to browse leads to more purchases, thus providing empirical support for H1. Support was also found for H2, that is, the walking distance from C1 to the departure gate positively impacted instances of C2 (β=.11, p<.001). Prior literature on walking distances at airports has shown that passengers are unwilling to veer or go back from their original path to their departure gate (Freathy & O'Connell, 2012). These findings extend existing knowledge, and show that when passengers' walking distances increase, so does their sequential purchasing behavior. This may be because as passengers walk through the retail area on their way to the departure gate, they encounter an increasing number of stores, which increases the temptation to shop. This increasing exposure to purchase opportunities appears to have a positive impact on any shopping momentum.

Store crowding in the store at C1 positively impacted instances of C2 (β=.18, p<.05), thus supporting H3a. The hypothesized relationship between airport crowding at C1 on instances of C2 (H3b) was not supported (p>.05). Similarly, the hypothesis that the impact of store crowding in the store at C1 on the instance of C2 will form an inverted U-shape (H3c), was not supported. While prior research demonstrates that extremely crowded and extremely uncrowded conditions tend to generate the undesirable states of over and under arousal respectively (Eroglu et al. (2005), such a notion of optimal crowdness seems not applicable in an airport retail context. Possible reasons might be related to the layout of the duty-free shops at airports which typically employ open space, and the short shopping window for passengers.

Impact of Product and Transactional Factors

Hypotheses 4a and 4b were both supported. Products requiring high involvement at C1 had a positive and significant effect on instances of C2 (β = 1.54, p<.001). Consumers considering a purchase that requires high product involvement exert more effort and pay more attention to their shopping journey. Additionally, the results for the positive and significant effect on instances of C2 demonstrated an inverted U-shape (β = -0.43, p<.001), indicating that both too little and too much product involvement negatively impact the possibility of a second purchase. Purchasing with little involvement might be insufficient to trigger shopping momentum; while the opposite would likely exhaust the time permitted for shopping.

A positive and significant relationship between payment with a credit card at C1 and instances of C2 (H5) was also supported (β = 0.19, p<.001), showing a high likelihood of C2 when credit cards are used. Interestingly, we did not find a significant relationship between store-wide promotion and instance of C2, thus H6 was rejected. It may be that budgetary or financial considerations kicked in after C1 and this caused deliberation. Finally, H7 was supported, that is, utilitarian purchases at C1 had a positive and significant effect on instances of C2 (β = 0.38, p<.001). This finding is consistent with the prior research on utilitarian purchases, such that the more virtuous nature of a utilitarian purchase (compared to an hedonic purchase) was more likely to increase the chance of further consumption as a result of the Justification Effect (Fishbach et al., 2003).

IMPLICATIONS, LIMITATIONS AND FUTURE RESEARCH DIRECTIOS

Theoretical Contributions

By focusing on sequential purchasing behavior in an airport retail environment, this study responds to calls for airport operators and retailers to better understand the customer journey within their airports (Chen et al., 2020). Airports have become destinations in themselves, and airport travelers navigate and explore the shopping areas as they do in shopping malls. However, the limited dwell time at airports exerts time pressures, leading to a comparatively short shopping window. The environment of duty-free shopping induces passengers to make purchases which are less deliberate compared to planned buying behavior associated with traditional retailing (Omar & Kent, 2001). This makes shopping momentum, which is new to travel retail research, highly relevant to understanding traveler's sequential shopping in an airport retail environment.

Our research contributes to the literature on sequential purchasing by capturing the dynamics of a real-life setting in an airport retail environment using real-world purchase data. Prior research on sequential purchasing has largely been undertaken in a laboratory type environment providing little understanding of how the context of a live retail environment impacts the customer journey. Grounded in an understanding of internal processes of sequential purchasing, we extend the findings of Dhar et al. (2007) by examining relationships between situational factors that influence the passenger journey and their sequential purchasing. We extend existing streams of research which have examined the effect of time availability, composition of the shopping basket (utilitarian and hedonic) and crowding on sequential purchasing in a laboratory setting. Using real-word purchase data, we demonstrate that time availability, walking distance and store crowding have significant effects on instances of C2. At the same time, we also examine a new set of situational variables including payment type, promotions, product type and product involvement, and how each affects the sequential purchasing behavior of airport travelers.

Our focus on these new variables provides a richer behavioral description of the consumer shopping process at an international airport. For example, previous research on product involvement (Zhang, 2014) examined its impact on C1 alone. Our findings extend this research by demonstrating that the positive influence of product involvement at C1 extends beyond C1 to positively effect instances of C2. Using real-world purchase data, we also respond to Dhar et al.'s (2007) call for research to examine the effect of product type on shopping momentum. We provide evidence for a justification mindset induced by an initial utilitarian purchase that has consequences for subsequent purchases. Prior work examining hedonic-utilitarian choices has primarily focused on isolated decision-making and has not focused on how hedonic-utilitarian choices influence downstream purchases. In addition, existing research has been confined within the boundaries of traditional retail environments and not airport retail.

Our research also extends existing work on the effect of payment type on purchasing behavior in traditional retailing (Saleh, 2012) to the domain of sequential purchasing. The one exception is Dhar et al.'s (2007) study of shopping momentum, which found that payment with differing payment resources interrupted shopping momentum through the deliberation process. However, this study was undertaken in a laboratory setting. The current study extends these findings by demonstrating that payment by bank credit card (as opposed to cash) has a positive effect on instances of C2.

Finally, our research makes a methodological contribution to the airport retail literature by leveraging the primary data captured from transactions and secondary sources, an important exploration of using a big data approach for a systematic examination of airport featured factors.

Practical Implications

As well as significant theoretical implications, our study also provides fruitful insights for operational and marketing practitioners seeking to enhance airport retail performance. First, results showed that when sequential purchasing did occur, it took place in a short space of time (8 minutes for the 1st quartile). However, dwell time at DXB is four and a half hours. Thus, it appears that when passengers start shopping, there is only a short window in which to encourage them to continue. This could be achieved by offering incentives at the point of sale such as a discount on their next purchase to encourage revisiting the store, locating stores within easy reach of each other and designing a store configuration where passengers have to walk past/through all the stores to get to other areas of the airport.

Second, our findings showed a positive relationship between both time available and walking distances on instances of C2. All passengers departing DXB travel internationally are required to arrive at the airport between three and four hours in advance of departure, however over 60% are in transit through DXB and as such, time at the airport is largely pre-defined. The positive relationship between time available (from C1 to the departure time) at the airport and instances of C2 implies that the airport and the retailer need to work together to ensure that procedures that reduce time available are minimized, for example by reducing the time spent at check-in, security and immigration through as much automation as possible. In addition, reducing the time needed to get to departure gates and reducing the time it takes to complete the boarding process will help to increase time available to shop. Our findings also showed that walking distances from C1 to the departure gate had a positive impact on instances of C2. Encouraging passengers to navigate through the retail area is therefore important, and any negative connotations about the effort involved by the passenger should be reduced where possible. Airport design and layout that funnels passengers through the retail space on their way to their departure gates, should increase passenger exposure to the retail offer. Extra promotions or incentives need to be designed to motivate passengers to continue shopping, especially when the store is nearby the boarding gate.

Third, the positive relationship between store crowding and instances of C2 suggests that it is in the retailers' interests to encourage human presence in the store. Good airport design allows constant traffic in the airport to flow through an open store design, mitigating the effects of over-crowding in duty free areas. Understanding how passengers navigate in the busy times and non-busy times of the day are key considerations in airport retail design to maintain the positive impact of store crowding observed in this study. How merchandise is displayed and promoted may need to be expanded, reduced or duplicated in different parts of the retail area to increase the level of store crowding to attract passengers.

Fourth, while high involvement products purchased at C1 had a positive impact on instances of C2, too much or too little product involvement had a negative impact. Retail staff should thus have the best customer service training possible to encourage C2. Retailers should work with product suppliers to train sales assistants about product specific attributes that will help them engage with customers. Having product displays and promotions that are interactive will help customers become more involved in the purchase moment and encourage additional sales. In addition, payment with a bank card at C1 was shown to positively impact instances of C2. Retailers should therefore work with bank card providers to encourage this type of payment and run promotions that encourage and incentivize customers to use their credit cards. Additionally, credit card companies have very detailed analytics of how customers spend at individual retailers and so can design promotions tailored to specific shopping behaviors.

Fifth, utilitarian purchases at C1 had a positive impact on instances of C2. This suggests that airport retailers should emphasize the utilitarian elements of all purchases (whether a product is hedonic or utilitarian), at the first purchase. Training can help sales advisors to communicate the utilitarian value of products to customers. Emphasizing the ‘last chance to buy’ and price savings compared to non-duty-free prices, may trigger the utilitarian characteristics of making purchases from the airport retail offerings.

Finally, we believe the knowledge gained from this study has implications for airport retailer corporate strategy. Airport retail design should incorporate non-shopping activities such as food courts, lounges, and relaxation areas within the overall retail imprint so that when passengers are not shopping, they are immersed in this imprint. Many airports have their retail and food offers on different floors pushing passengers to make time allocations for each when in fact they both can work well together (e.g. a champagne and caviar bar within a luxury retail offer). Airport retailers need to work be a part of the overall airport design conversation by emphasizing how crowding behavior can inform layout planning for the benefit of all. Merchandising layout in airport retail traditionally focuses on the aspirational features of product but now needs to also align with a utilitarian point of view such as “last chance to purchase” and “travel exclusives”. Study findings also have implications for how sales teams should be trained. Training should not just focus on the first purchase but should accommodate how the first purchase can impact subsequent shopping behavior. One training strategy is to focus on the utilitarian aspects of products in addition to offering discounts on next purchases and assist with wayfinding through the overall retail offer.

Limitations and Future Research

Although the data set in this study involved three different concourses, generalization to other airports warrants further examination. Furthermore, shopping behavior may vary across the year. It would be interesting to replicate this research and test the model across other airports of differing sizes and at different times of the year (for example comparisons of summer/winter, time periods around celebrations such as Eid or Christmas (or those local to the airport) versus non-celebratory periods). An examination of potential interactions between context factors and their influence on sequential purchasing would also be insightful. Future research would benefit from looking at the impact on the expenditure of C2 (not just the instances of C2). Future research should also consider the impact of additional variables such as gender, age, culture, the presence of significant others while shopping, budget, income levels and trip purpose.

In addition, given the data availability, our research focused on departure only and did not consider aircraft landing/arrival. Although sales at departure account for the majority of the total revenue, shopping at landing/arrival may be also interesting to examine in future research as it may represent different segments with distinctive motivations from those shopping at departure. In addition, our data analysis relied on the IATA overall loading factor without country or airline specific information which may have prevented the accurate monitoring of crowding. Future research could integrate data from the airport as a more accurate substitute.

Finally, we acknowledge the limitation associated with our focus on the first two purchases only. Given the setup within the retailing area of an airport, it will be interesting to consider the journey as the unit of analysis. Prior research refers to such behavior as trip chaining (Brooks et al., 2008) where consumers visit multiple destinations on a single outing in order to save on travel costs and the fixed cost of making a trip (Wallace et al., 2000). In the context of airports, consumers may also engage in various activities beyond shopping, which could affect the shopping journey as well. In this research, due to the availability of data which only captures the spending with duty free shops and with the majority of passengers engaged in only two instances, future research should expand an understanding of the shopping momentum effect beyond two occurrences of two sequential purchases and trip chaining. Such research would enrich the understanding of the passengers' overall experience with an airport.

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DECISION SCIENCES INSTITUTE
SME Analytics: The Backbone To The Future of Small Business

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ABSTRACT

Our study consists of 50 Small-and-Medium Sized Enterprises (SMEs) from a broad cross-section of industries across the US and examines their leading motivators and obstacles to Big Data Analytics (BDA) adoption. The research reveals there is an overall lack of knowledge of Big Data, financial concerns of adopting technology, challenges gathering timely and sufficient data, and unexpected complexity of analytical tools are critical impediments to BDA implementation among SMEs. Concurrently, the maximization of market competitiveness, productivity, and profitability are some of the most important drivers to the acceptance and incorporation of BDA into small business practices.

KEYWORDS: Big Data Analytics, Small and Medium-sized Enterprises, SMEs, US SMEs

INTRODUCTION

In an increasingly interconnected world, larger corporations are overtaking the global market. There is a growing demand for the adoption of Big Data Analytics (BDA) by small-to-medium enterprises (SMEs) to stay competitive against big powerhouse organizations in the local market. Larger firms can emerge in the global market for analytics technology due to having access to a greater pool of both human and financial capital. SMEs, on the other hand, face many barriers to implementing various business intelligence (BI) tools and techniques into their daily decision-making processes because they do not possess the same resources as bigger firms. BDA by SMEs allows businesses to evaluate consumer data as it is collected and determine how to meet or exceed the current needs of customers (Loh & Teoh, 2021). The market for BDA tools and practices in SMEs has not yet reached its full capacity. SMEs have begun to realize the importance of BDA but implementing data-driven decision-making processes is only the first step. The benefits of upgrading decision-making methods with analytics technology will not be fully identifiable until smaller businesses can start to catch up to the experience larger corporations have already built up in the analytical world.

Our research aims to identify trends of business analytics adoption by SMEs in the United States. Much of the existing literature investigates the presence and the advantages of the use of information systems (IS) by European SMEs (Mulhern, 1995; Cressy & Olofsson, 1997; Pighin & Marzona, 2012; Kiziltan, 2018; Bianchini & Michalkova, 2019). While it is valuable to compare cases in the EU to cases in the US, our contribution to the literature is substantial because SMEs are treated differently in dimensions such as marketing tactics, business landscapes, and overall culture in the US and the rest of the world (Kidalo, 2011). Although SMEs can look to European businesses for inspiration about BDA adoption, results will likely vary.

LITRATURE REVIEW

Previous studies have revealed the many obstructions to SME entry in the BDA world as well as resolutions to the accessibility issues of BDA (Mikalef et al., 2018; Parra et al., 2019; Pighin & Marzona, 2012; Härting & Sprengel, 2019; Bianchini & Michalkova, 2019; Bakhshi et al., 2014; Brock & Kahn, 2017; Safari et al., 2015; Pentina et al., 2012; Esmaeilpour et al., 2016). Mikalef et al. (2018) reviewed 84 journals published since 2010 to reflect on the gap between the technical components of incorporating BDA into SMEs and the strategic planning and organizational changes necessary for successfully applying such BDA to daily practices. Even though BDA has become somewhat of a buzzword over recent years, there has been a lack of empirical studies on the potential business gains in competitive advantage of enterprises that properly assimilate IS into their organizational pedagogies. Therefore, the comprehensive literature review by Mikalef et al. (2018) was able to pinpoint six thematic concepts that are important to investigate: resource orchestration of BDA, decoupling BDA capabilities from Big Data-enabled capabilities, bounded rationality of BDA, turning BDA insights into action, trust of top managers in BDA insights, and business value measurement. Resource orchestration of BDA is a key element that has been missing from much of the existing literature of BDA in SMEs because historically, the literature has been concerned with the analytical tool a business has opted to utilize and not the development of the analytical tool. Similarly, Mikalef et al. (2018) make the important distinction between the tendency for previous researchers to focus on an SMEs adoption of BDA for one specific purpose, or BDA capabilities, rather than an SMEs ability to integrate BDA into all its organizational practices, or Big Data-enabled capabilities. By pointing to the bounded rationality of BDA as a concept that should be further investigated, Mikalef et al. (2018) highlight that the availability of Big Data impacts the observations that can be derived from BDA. Then, taking it a step further, Mikalef et al. (2018) note that it is also meaningful for future works to measure the success of turning BDA insights into actions that add value to a small business. Trust of top managers in BDA insights is an underestimated factor in BI implementation because a business leader may support the idea of data-informed decision-making, yet in practice the business leader will go with their intuition over data. Finally, the final of the six thematic concepts named to be significant influences on the adoption of IS in SMEs is business value measurement, or the mechanism used to measure the success of analytical tool usage. The hype surrounding Big Data has increased the popularity of BI in SMEs, but there is still much exploration to be done to identify effective management techniques (Pentina et al., 2012).

There are many existing conceptual frameworks such as the Technology Acceptance Model (TAM) (Davis, 1985; Venkatech & Davis, 2000; Härting & Sprengel, 2019; Brock & Khan, 2017; Pentina et al., 2012; Esmaeilpour et al., 2016) that can be applied to better understand and explain BDA adoption. Referring to a relevant structure for the addition of analytical tools can aid managers in preparing their business to accept and productively use new technologies. Using conceptual frameworks allows researchers to systemize existing thoughts and develop future procedures that improve upon current speculations of what it means to effectively carry out BDA techniques. Arguably, the most popular framework for technology acceptance is TAM itself. TAM is a widely used model for predicting the adoption of information technology and shows that perceived ease of use and perceived usefulness are the determinants of technology acceptance by individual users. TAM has been used in studying IT adoption in small businesses as well (Riemenschneider et al., 2003; Igbaria et al., 1997). Riemenschneider

(2003) reviews a few studies that discussed TAM and its effectiveness to explain IT adoption by SMEs. For example, a study by Igbaria et al. (1997) investigated 203 SMEs in New Zealand and confirmed that perceived ease of use was a strong determinant of technology adoption by SMEs.

Other studies have investigated factors to show whether a business will welcome or reject new technology by judging the extent decision-makers think the technology will improve job performance and/or will not exert much effort to learn to use (Pentina et al., 2012; Esmaeilpour et al., 2016). The complexity of Big Data is often shadowed by the all-encompassing term of “Big Data” itself. Big Data is not one product, system, etc.; instead, it is a set of complicated and intricate technologies and techniques for gathering, storing, processing, accessing, analyzing, and visualizing data from a plethora of sources and locations. This acts as an impediment for SMEs because Big Data is seen as being so complex, it is often perceived that the instruments used to analyze Big Data must also be complex, difficult to use, and not worth investing time and money into (Brock & Kahn, 2017; Esmaeilpour et al., 2016; Bianchini & Michalkova, 2019; Vajjhala & Ramollari, 2016). The absence of understanding what analytical technologies are capable of is also a major hurdle for SMEs to leap over to experience the full benefits of BDA practices (Pighin & Marzona, 2012; Esmaeilpour et al., 2016; Safari et al., 2015). This problem is worsened by the creators of analytical technologies because they tend to focus on the installation and machine-like components of BDA rather than making sure businesses grasp how to integrate analytical tools into the workplace (Pighin & Marzona, 2012). Then, assuming a business does invest in analytics, there is the burden of obtaining quality data. Relatively speaking, SMEs are much newer to the world of BDA than larger companies, so it is more difficult for SMEs to distinguish inferior from superior data. Therefore, utilizing quality data and accurately analyzing it is one of the overarching hindrances for SMEs (Parra et al., 2019).

There are many impediments making it difficult for SMEs to enter the world of BDA (Pighin & Marzona, 2012; Härting & Sprengel, 2019; Bianchini & Michalkova, 2019; Brock & Kahn, 2017; Safari et al., 2015; Esmaeilpour et al., 2016). Although barriers to entry such as perceived complexity of analytical tools, a general lack of knowledge of BDA, and challenges obtaining quality data to analyze interfere with SMEs’ acceptance of BI, there are also driving forces that promise many advantages to the enterprises that thrive with BDA incorporated into their business models. There also exist plenty of reasons that incentivize effective implementation of analytics instruments and practices. Motivations for the adoption of BDA that demonstrates the usefulness include gaining social influence, competitive advantage, productivity, and profitability.

While the aforementioned impediments to successful BDA implementation in SMEs can seem quite daunting for the owners and managers of smaller businesses, on the other hand, there are usefulness drivers that encourage SMEs to accept analytics processes and put them towards improved decision-making tactics. Perceived ease of use, for example, can stimulate SMEs’ use of BDA because simple to understand technology, staff training, the presence of employees with technical skills, etc. can increase firm confidence in the application of proper analytical instruments. Esmaeilpour et al. (2016) have shown that factors such as low complexity of technology, the presence of staff with prior or taught knowledge of technical skills, and the support of government help employees of SMEs recognize the practicality of BDA. Social influence by a combination of industry professionals, customers, and/or competitors can spur BDA implementation (Pentina et al., 2012). Another big motivator for proper BDA utilization by SMEs is increasing market competitiveness (Bianchini & Michalkova, 2019; Pighin & Marzona, 2012). According to a study of Italian companies by Pighin & Marzona (2012), approximately 60% of small businesses have invested in some form of BDA because they think it will give them more competitive advantage. Finally, there is a lot of quantitative data that shows the positive productivity and profitability growth associated with the adoption of BDA by SMEs (Härting & Sprengel, 2019; Bianchini & Michalkova, 2019; Bakhshi et al., 2014; Bhat & Quadri, 2015). One study of SMEs in the UK states that businesses that would categorize themselves as data-driven were 5% more productive and 6% more profitable than businesses that would not consider themselves data-driven. That being said, the study also showed that only 0.2% of SMEs in the UK were actually using BDA tools (Härting & Sprengel, 2019). Also, of the 500 medium-sized, privately owned companies in the UK surveyed by Bianchini & Michalkova (2019), it was observed that businesses in the top quartile of online data usage are 13% more productive than firms in the bottom quartile. Specifically, businesses that partake in data analysis and reporting were found to be the best performers, as data analysis and reporting is the most significant positive influence of the aspects of data activity. Bakhshi et al. (2014) found that businesses that report they rely on data analysis to make decisions are two times as likely as the average enterprise to have significant benefits from their online customer data and that higher online data leads to over 8% of more productivity.

Overall, the existing literature tends to agree that many SMEs have started to enter the market for BDA, but have trouble attaining true success with analytics tools and practices. SMEs stand to gain efficiency and better decision-making skills by implementing BDA tactics. However, the complexities of the abstract perception of Big Data and the intricacies of producing tangible outcomes from BDA insights hinder SMEs from realizing their full IS and BI potential. Additionally, the large majority of previous literature is concerned with European SME results. Our contribution to the literature will attempt to fill the gaps by highlighting the full scope of the usefulness of BDA as well as the impediments that lower the rate of the adoption of technology in US SMEs.

METHODOLOGY

We conducted interviews to determine BDA understanding and adoption in US small businesses. By collecting qualitative data through interview questions, our research was able to gather primary and descriptive data about the particular incentives and obstacles for analytics technology utilization by smaller US enterprises. There are many internal factors like company culture and external factors like competition in the market that affect the willingness of an organization to adopt BDA (Nguyen et al., 2015).

The sample was chosen from small business databases and directories on the Internet. There was a total of 50 small businesses that were interviewed. Businesses that were asked to participate in our study are small or micro firms with mostly under or around 50 employees. The breakdown of the size of the contributing businesses can be observed in Table 1.

Table 1: Size Breakdown

Number of Employees	Number of Businesses	Percent of Businesses
[0, 10)	32	64%
[10, 40)	13	26%
[40, ∞)	5	10%

The participating enterprises are predominantly from the northeastern US and are across all sectors. The specific breakdown of industries of the contributing businesses can be seen in Table 2. Businesses in manufacturing, construction, utility, and printing sectors were classified as Manufacturing/Construction; businesses in retail and e-commerce sectors were classified as Retail/E-Commerce; businesses in brewery, restaurant, food service, and food delivery sectors were classified as Accommodation and Food Services; businesses in podcasting, music distribution, entertainment & media, film & media, online dating, live entertainment, and event planning sectors were identified as Information Media, Telecommunications, and Entertainment; businesses in venture capitalist and finance sectors were classified as Financial Services; businesses in consulting, marketing, digital marketing, industry representatives, and distribution sectors were classified as Professional, Scientific, and Technical Services; and businesses in beauty, health, and fitness sectors were classified as Health, Beauty, and Fitness.

Table 2: Industry Breakdown

Industry	Number of Businesses	Percent of Businesses
Manufacturing/Construction	6	12%
Retail/E-Commerce	5	10%
Accomodation and Food Services	6	12%
Information Media, Telecommunications, and Entertainment	9	18%
Financial Services	3	6%
Professional, Scientific, and Technical Services	17	34%
Health, Beauty, and Fitness	4	8%

To obtain data from businesses, we provided participants with an open-ended questionnaire and performed a semi-structured hour-long interviews over Zoom. Inquiries were formed with the intention of stimulating conversation with owners and managers about their familiarity with Big Data and tools and instruments used for analytical capabilities. The questionnaire was designed based on extended TAM for firms' adoption of technology and included three main sections (Nguyen, 2015; Ritz et al., 2019). In the first two sections of questionnaire, businesses were asked questions to indicate the usefulness of business analytics for their operations. They were asked about their existing data and IS as well as their knowledge and awareness about current trends and capabilities relevant to their businesses in data analytics. In the third part of the questionnaire, we aimed to explore the ease of use of this technology for small businesses.

All interviews were transcribed and coded. We used structural coding method for the analysis of the transcripts (Saldana, 2021). In the first phase, the coding was based on reading the transcripts line-by-line and categorizing concepts and quotes in responses into an Excel database that was designed based on the questions of the questionnaire. In a second phase, we tried to aggregate the data into general relevant categories. The categories were emerged based on similarities, associations, and overlapping of the coded data from each respondent.

Small businesses need many resources that can facilitate and support the implementation and use of technology. Financial resources, human resources with expertise and available time are among many factors that can bring ease of utilization of business analytics to small businesses. Responses to the questions indicated the extent to which businesses are using available technologies, whether enterprises are cognizant of the availability of data and tools and their usefulness, and what challenges the ease of use and adoption of analytics brings to SMEs. Obtaining first-hand accounts of US SMEs' experiences and issues with BDA will be important for designing and developing better analytical tools that are more relevant to the needs of smaller businesses.

The study of specifically US businesses is relevant because there will be variation in the distinct drivers and hindrances of SMEs by region of the world. Our research intends to procure findings that will provide structured and productive direction for emerging US small businesses.

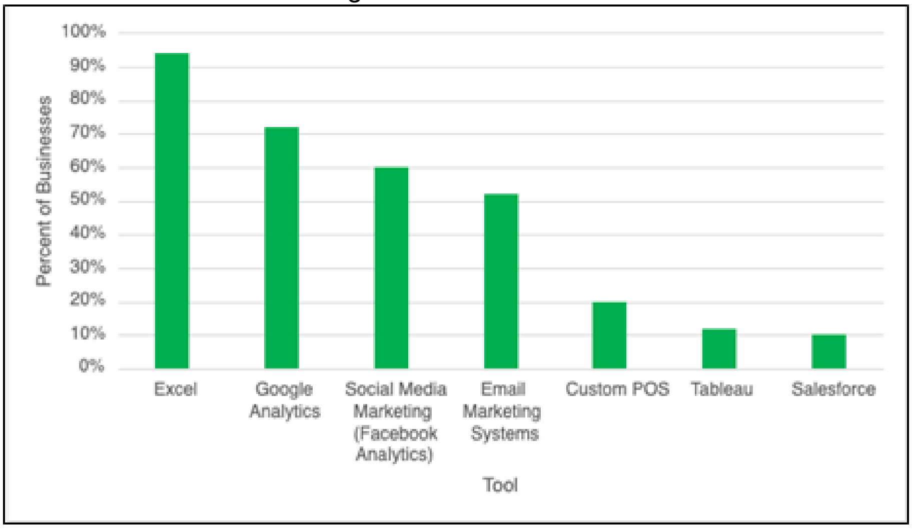
RESULTS

Our interviews with small businesses revealed many similarities in BDA adoption. SME owners were asked about the kinds of analytical tools they use, their awareness of the usefulness of rising trends, and their specific needs for data to access both the reasons for and methods of implementing BDA practices into their business. Other inquiries for the business owners were about the facilitators and barriers to integrating those tools into their daily decision-making.

Tools Utilized

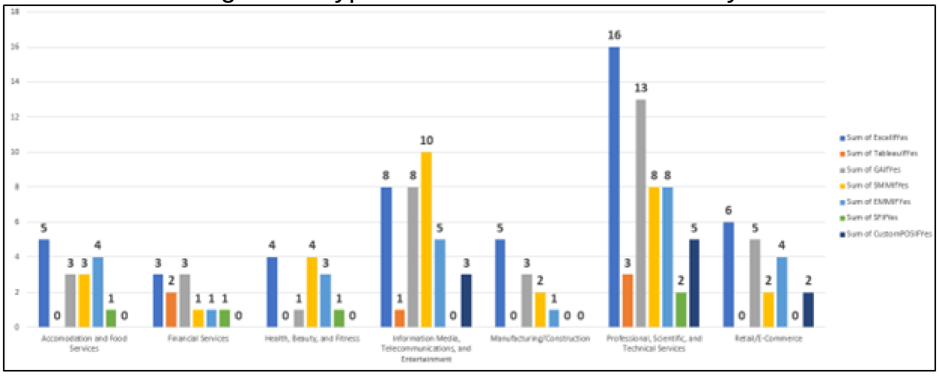
When businesses were asked about their use of tools in the analytics world, the following seven tools were the most utilized: Salesforce, Tableau, Custom POS, Email Marketing Systems, Social Media Marketing, Google Analytics, and Excel, as depicted in Figure 1. Unsurprisingly, almost all the enterprises use Excel to some extent. One business we interviewed stated that "putting data into an Excel sheet is super user friendly." Excel is a program with applicable features to many industries, so it makes sense that 94% of the 50 participating businesses can use this universal tool. The next most popular analytical tools employed by SMEs are Google Analytics, Social Media Marketing, and Email Marketing Systems, respectively. Another enterprise that participated in our survey expressed that "there is a direct need for market analytics and… businesses that do not use it will be deemed obsolete." The results from the portion of the questionnaire about existing data are consistent with the results from the awareness of usefulness of data and analytics portion of the questionnaire; both sets of findings emphasize the demand for new marketing strategies.

Figure 1: Tools Used



Several interesting patterns emerged from the data when the tools used were grouped by individual industries (Figure 2). In all except two cases, Excel was still the most popular tool used per industry. In certain industries such as Information Media, Telecommunications, and Entertainment and Health, Beauty, and Fitness, Google Analytics was used almost as frequently or the same amount as Excel. An SME in the Information Media, Telecommunications, and Entertainment industry stated they "mostly utilize analytics tools to ascertain how different clients and [their] own business is generating traffic, what opportunities exist for growth, and the success of different ad spend campaigns." Additionally, in the Health, Beauty, and Fitness industry, Social Media Marketing tools such as Facebook Analytics are utilized even more than Excel and Google Analytics. Intuitively, this makes sense because both industries rely on an Internet presence to reach a wider consumer audience. For example, an interviewed SME currently uses analytics "to examine hits on pages, interactions with the page, volume of comments left on the page as well as page likes" to see which days gained the most traction and examine which events may have correlated to the upboost in online activity.

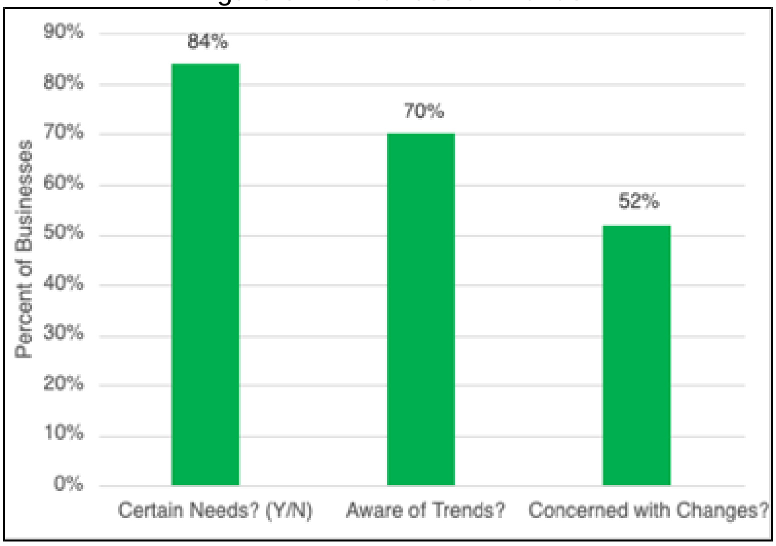
Figure 2: Types of Tools Used Per Industry



Marketing or similar sectors of the economy, such as those in the Professional, Scientific, and Technical Services industry, have a different prioritization strategy in terms of their use of BDA. Their strengths lie in using analytical tools to address the needs of customers, promoting goods and services, and increasing their Internet presence. Another business that was questioned during our study summarized the importance of using analytics for marketing purposes by claiming that "clients want hard numbers to measure the success of a campaign."

The next area of interest of the interview was small business awareness of capabilities and usefulness of analytics in general as well as emerging trends or changes in their industry. Only about half of the businesses contributing data to our research were concerned with their ability to keep up with the fast-paced environment of BDA, but many of those surveyed SMEs that were concerned with staying up to date on analytics admitted that it is probable they "may be missing some opportunities" (Figure 3). Only 68% of businesses said they can recognize trends of data usage in their sector. However, 84% of enterprises acknowledged that there are certain business needs that the adoption of data analytics can fulfill.

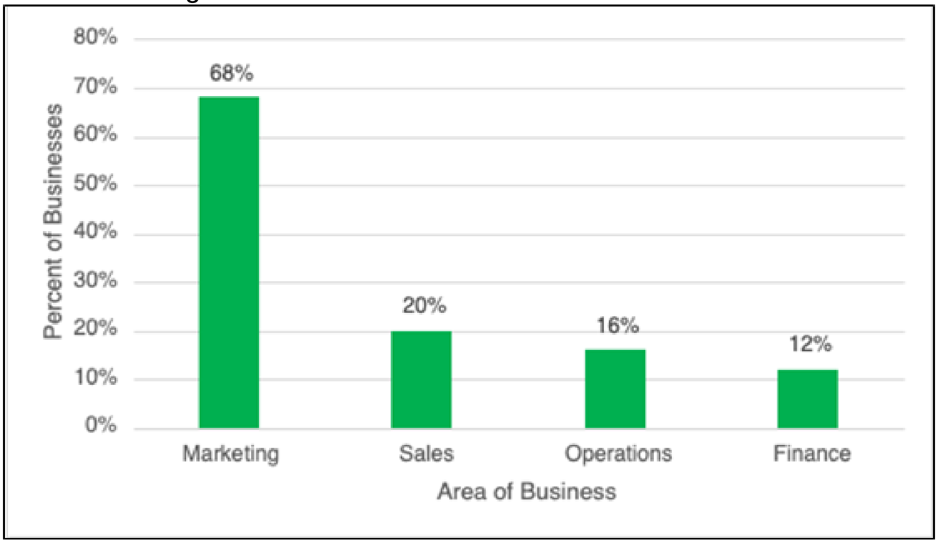
Figure 3: Awareness of Trends



Certain business needs that the adoption of data analytics can fulfill were broken down into four areas of business to help determine the desired outcomes of SMEs when implementing BDA. The four major areas of business are Finance, Operations, Sales, and Marketing. For the purpose of this study, Finance was described as addressing the needs of employees with allocation of company resources: costs, budgets, funding, etc.; Operations was described as involving inputs, supply chains, and other factors of production; Sales was described as capitalizing on leads created by marketing to produce revenue for the company; and Marketing was described as addressing the needs of customers, promoting goods and services, and increasing Internet presence.

It was determined that marketing was by far the most prominent need for data usage in US small enterprises, with over 68% of businesses stating it was the most important aspect of their business (Figure 4). The percent of businesses that have marketing needs (68%) was more than quadruple the percentage of businesses that have the next most popular need for data of sales (20%). Since marketing and sales are very interconnected, it is not unexpected that they were the first and second most sought-after uses of data. Many of the interviewed SMEs stated that better understanding customer demands was their biggest priority, and that the implementation of analytical instruments would help to achieve that goal more efficiently. As an illustration, one business stated that they would like to be able to "track custom events [they] set up, like purchasing specific items" so that they can strategically "run retargeting ads to groups of people who are more likely to buy again."

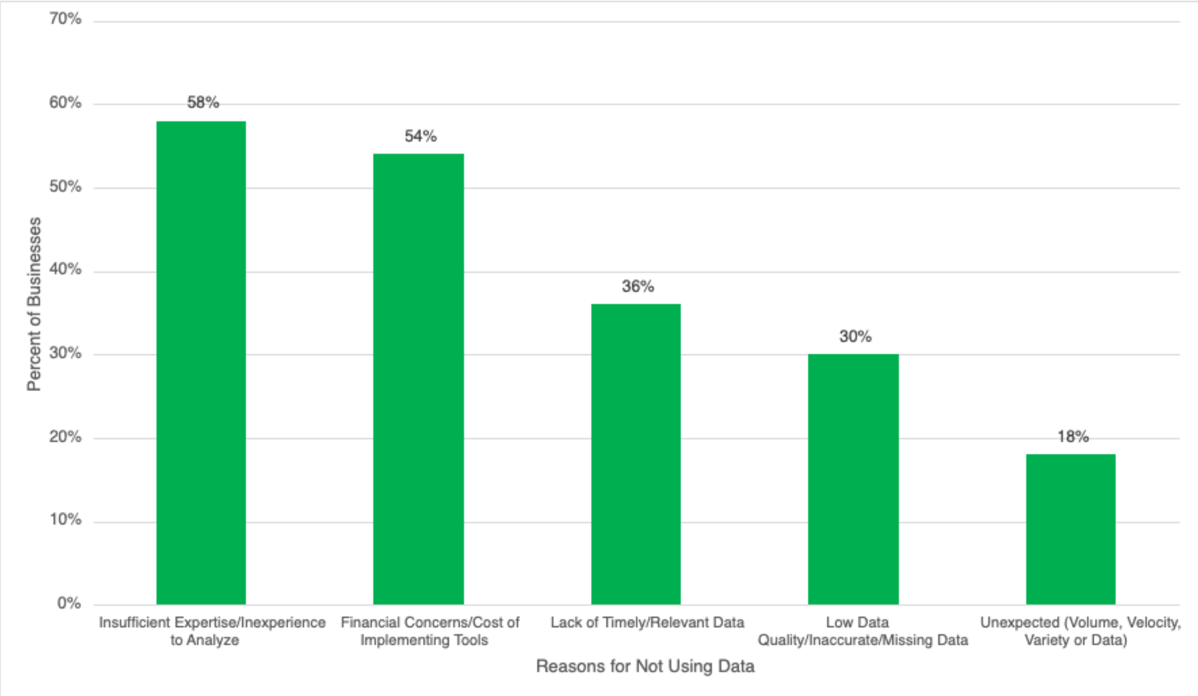
Figure 4: Certain Needs and Usefulness for BDA



Barriers to Ease of Adoption and Use of Analytics

The final component of the questionnaire was the barriers to integrating more business analytics tools. To understand the obstacles preventing small businesses from BDA adoption, participants were asked about the five different reasons for not using data; these were surmised from existing SME literature as the most notable issues smaller businesses tend to have with analytics (Mikalef et al., 2018). The categories were: Unexpected Volume, Velocity, or Variety of Data; Low Data Quality/Inaccurate/Missing Data; Lack of Timely/Relevant Data; Financial Concerns/Cost of Implementing Tools; and Insufficient Expertise/Inexperience with Analysis. It was observed that worries about an absence of staff who are knowledgeable about BDA was the most consistent barrier for US small businesses, with 58% of participating enterprises claiming lack of knowledge and skill set was largest barrier (Figure 5). For example, the sole proprietor of a business was cognizant of the fact that they were “not an analytics expert” and that they “need to spend more time learning new software in order to take the business to the next level.” It is worth noting that many SMEs emphasized the effect of the COVID-19 pandemic on this particular concern. With fewer employees, SMEs can find it difficult to conjure up personnel with expertise with collecting, managing, and effectively utilizing their data. Businesses do not “have the cash available to invest into new systems” due to the pandemic and tighter staffing, so they “do not spend much time nor energy with data right now,” according to multiple SMEs who participated in our study. Additionally, although it was the penultimate barrier to BDA adoption in our study, Low Data Quality/Inaccurate/Missing Data was an issue for almost one-third of the participating businesses. This corresponds with the findings from Parra et al. (2019) that state that SMEs struggle immensely to obtain and then properly analyze sufficient data.

Figure 5: Barriers to BDA Adoption



DISCUSSION

Even though many small businesses can be designated and grouped by their relative size, region, and industry, it is arduous to pinpoint the precise reasons that US SMEs grapple with the implementation of BDA. Every business has a unique number of employees, client base, sector, and so on, so it is important to examine findings from the existing literature in contrast with those of our study to determine overall patterns and similarities.

With respect to existing data and IS used by small businesses, our study found that all 50 participating enterprises use at least one of the seven most popular analytics tools. Contrarily, Härting & Sprengel (2019) found that only 0.2% of all UK SMEs use BDA instruments due to an absence of affordable and manageable infrastructure that supports small businesses in processing Big Data. It is important to note that Härting & Sprengel (2019) looked at the specific Big Data solution of data mining, which has issues of automation and scalability for SMEs. Our results are significantly different from the conclusions drawn from a data mining oriented study because our research broadens the search of analytics instruments utilized by smaller businesses. However, the concept that remains unchanged between our studies and others is that many enterprises cannot handle the timely and/or costly installation and upkeep of analytics technology and it is difficult for SMEs to fully recognize the many potential benefits of BDA. Before the adoption of BDA can even be considered, SMEs must incur substantial expenses to procure necessary software licenses and infrastructure, and hire and train qualified personnel (Assunção et al., 2015). According to our study, the most utilized tool by 94% of participating SMEs is Excel, followed by 72% of businesses using Google Analytics, and 60% using Social Media Marketing such as Facebook Analytics. A similar statistic was also observed in that 83.3% of Malaysian SMEs operating oil stations use Excel for recording, analyzing, and reporting data due to its low cost and perceived usefulness (Jusoh & Ahmad, 2019). Following Excel, marketing-based analytical instruments are the biggest portion of tools used by SMEs. This is supported by a study of the University of Liverpool Online that expressed that their most popular Big Data techniques were overwhelmingly being used for customer intelligence purposes (Brock & Kahn, 2017). A large majority of small businesses are turning to Microsoft Excel and other well-known, low-cost marketing tools because of their flexibility, accessibility, efficiency, and productivity that aligns themselves with the interests of the enterprise and its goals. SMEs often have to turn to simple means of BDA adoption, such as Excel, to improve their decision-making skills because large-scale utilization of analytical tools would require more financial leverage from external forces such as government support for small businesses.

Existing literature also offers some perspective on the topic of SME awareness of usefulness and current BDA trends in the industry and the areas data use is put towards. Of the participating businesses in our study, 70% self-identify as being aware of ongoing applications and trends in analytics. These results are backed by previous European studies. Kiziltan (2018) sampled 171 Turkish SMEs and found that 64.3% of them are aware of Big Data, and Pighin & Marzona (2012) sampled 45 Italian SMEs and found that around 60% of them have invested in Big Data because they feel it will make them more competitive on the market. However, when the EU is considered as a whole, Big Data analysis is only adopted by an average of 10% of SMEs. Of that 10% that have implemented analytics, almost 50% of their data is generated from social media-related sources (Bianchini & Michalkova, 2019). In small-scale studies, there tends to be a higher percentage of businesses that are aware of the potential effectiveness and usefulness of data analytics than in studies with a larger sample size. Regardless of the number of businesses questioned about their familiarity with the presence of data, there are generally certain needs recognized by SMEs, such as marketing, that are taken into account when considering the feasibility and ease of BDA adoption into daily business practices.

Lastly, a comparison of other research projects to ours in terms of barriers to business analytics use reveals complementary findings. Our study established that insufficient expertise or overall inexperience with analytics is the single largest obstacle to successful implementation of BDA with 58% of participating SMEs stating it as a problem (Figure 5). One business that was interviewed epitomized this finding by stating that “since we are so small, it is often difficult to find the bandwidth to focus on sales and business development.” As seen in Figure 5, closely behind Insufficient Expertise/Inexperience with Analysis as a barrier is Financial Concerns/Cost of Implementing Tools with 54% of respondents struggling to keep up with the price of analytical instruments. The study of small businesses in Turkey also shows that a lack of understanding of Big Data was the largest concern out of all the possible challenges of BDA implementation. This was partially due to a shortage of data analysts available in the labor market, which also ties in with the issue of the cost of BDA adoption since SMEs cannot offer competitive salaries for these experts compared to larger organizations (Kiziltan, 2018). Furthermore, Pighin & Marzona (2012) found that businesses that tend to take advantage of data warehousing are relatively larger and older companies because they have the means to obtain personnel with better knowledge and expertise of BDA. Younger NEs that receive support from business incubators or gain wisdom from local chambers of commerce are also educated on existing BDA tools and how to properly use them. While Insufficient Expertise/Inexperience with Analytics is recognized as a separate barrier to the adoption of analytics technology for the purpose of this study, it often goes hand in hand with the issue of Financial Concerns/Cost of Implementing Tools due to the nature of SMEs.

CONCLUSION

The exploratory research of our study has identified trends of analytics utilization in small businesses in the US. Due to the complexity of the term "Big Data" itself, many SMEs face the challenges of perceived complexity of BI and analytics tools used to harness the potential of higher earnings, greater efficiency, and better-informed decisions through effective BDA adoption. Despite the impression that analytical instruments are difficult to use and not worth investing in, many SMEs are deciding that the possibility of advancing their data-driven decision-making skills from more analytics experience is an opportunity too valuable to miss out on. Increased competitiveness on the market and increased productivity are only some of the usefulness and motivators for smaller businesses to implement BDA technology into their daily practices.

Through our study into SMEs, we were able to determine across all industries interviewed, as seen in Figure 4, over 68% of the SME's need BDA technology and support in Marketing. Within that, over 58% stated having insufficient expertise and over 54% having financial concerns (Figure 5). This allows organizations to focus on allocating resources towards those specific needs. Resources can be in the form of monetary sources such as small business grants or tax incentives. Educational resources can be tailored towards combating insufficient experience through running events specifically tailored for small businesses through local chamber of commerce.

To understand the opinions of Big Data and the various uses for it among US SMEs, we used semi-structured interviews to collect qualitative information from small and micro businesses. Our research was able to produce primary, descriptive data about incentives and obstacles for the utilization of analytics technology. The limitations of our small amount of data can be overcome by future studies and surveying more businesses and expanding upon the questions we asked during the interviews. The 50 observances demonstrate substantial qualitative information for observing relationships, but it is a small dataset to work with. Going forward, in order to test causal relationships, there needs to be a larger sample size. It would be beneficial to add more inquires to the interview questionnaire to allow more separation of data, for instance the age of the business and life span would be a big factor in determining how likely some businesses are to integrate analytical tools than others. Furthermore, it would also be advantageous to add inquiries about a few more variables related to existing data and is, awareness about current trends in data analytics, and barriers to business analytics use. Compiling information on factors from smaller enterprises such as what percentage of their budget they spend on BDA, where they collect data from, and how they store data will help with more involved analysis of the patterns held by SMEs towards Big Data.

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Social Commerce Adoption: A Comparative Study between U.S. and Thai Consumers

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ABSTRACT

When compared to Western countries, social commerce is growing much more rapidly in Asian countries. To take advantage of social commerce, it is important for businesses to understand what is influencing online consumers to engage in social commerce. One of the driving influences could lie in a country's culture. This study compares the influential social commerce factors between the United States and Thailand. Five hundred and twenty-five (525) Americans and three hundred seventeen (317) Thai participated in this study. The results of this study reveal the commonalities and differences in social commerce usage between the U.S. and Thai consumers.

KEYWORDS: Social commerce, Technology Acceptance Model, Culture, United States, Thailand

INTRODUCTION

The technological evolution of the Internet has led to the development of Web 2.0 technology giving rise to user-generated content on the web without users having to secure their own domain. This gave rise to social networking websites like Instagram, Facebook, and Twitter where users can create and share common interests among their social network (Zeng et al., 2009). These social networking sites have also provided online vendors a new way to communicate and establish a relationship with consumers (Liang & Turban, 2011). Businesses are engaging in social commerce as a new channel through which to grow their sales revenues (Weisberg, 2011) and as a way to build and maintain the trust of consumers (Kim & Park, 2013).

In addition to business interest, researchers have also taken an interest in studying the concept of social commerce (Cui et al., 2018). A significant area of social commerce research has been focused on the adoption of social commerce (e.g., Akman & Mishra, 2017; Cutshall et al., 2020; Hajli, 2013; Lu et al., 2016; Shen, 2012). Much of the social commerce research has focused on developed economies such as the United States, China, and Korea. However, not a lot of studies have focused on social commerce in developing economies.

This study aims to compare social commerce intention factors perceived as important to online consumers in the United States and Thailand. About one-third of the online consumers in the United States participate in social commerce (Clement, 2019) and around 40 percent of Thai online consumers participate in social commerce (Leesa-Nguansuk. 2019). So, there is still room to grow social commerce among these nationalities. The research question for this study is: What are the social commerce intention factors that are perceived as important to online consumers in the United States and Thailand? The findings from this study will identify the differences and similarities between the online consumers in both countries.

LITERATURE REVIEW

Social commerce has been defined in a plethora of ways. For instance, Liang and Turban (2011) defined social commerce as the use of Web 2.0 technologies to enable social input in the purchasing of products while Lu, Fan, and Zhou (2016) defined social commerce as being the use of social networking sites used to deliver e-commerce. A common thread among these definitions appears in the definition offered by Lin, Li and Wang (2017) who state that social commerce is comprised of commercial actions facilitated by or performed through social networking sites utilizing Web 2.0 tools to enhance the shopping process and allow online businesses to better interact with consumers. This will be the definition of social commerce adopted for this study.

The act of shopping is considered to be a social activity (Dennis et al., 2007). When shopping moved online with traditional e-commerce, the social aspect of shopping was lost. However, the social aspect of shopping has been brought online with social commerce. Previous research (e.g., Hajli, 2015; Liang et al., 2015) has reported that social relationships play a vital role in consumers' intention to buy. It is the social aspect of social commerce that leads businesses to increased revenues.

In social commerce websites, customers are willing to post reviews on a business' website and on their social media accounts for the following reasons: to inform others about their experience; and to help others with their purchase decision (Fullerton, 2017). Additionally, people are reading those reviews. Fullerton (2017) reports that 93 percent of consumers have reported that online reviews have impacted their purchase decision. Consumers are more likely to trust information provided by members of their social network and other online reviews as opposed to product information provided by an online vendor; thus, positive reviews from a consumer's social network lead to increased social commerce intention (Kelly et al., 2010).

Given the rapid growth of social commerce in countries with developing economies, it is important to discover any differences that may exist between consumers in countries with developing economies and in countries with developed economies. For online businesses considering entering the social commerce market in developing economies, it may not be wise to assume a one-size-fits-all approach.

THEORETICAL DEVELOPMENT/MODEL

Cultural Considerations

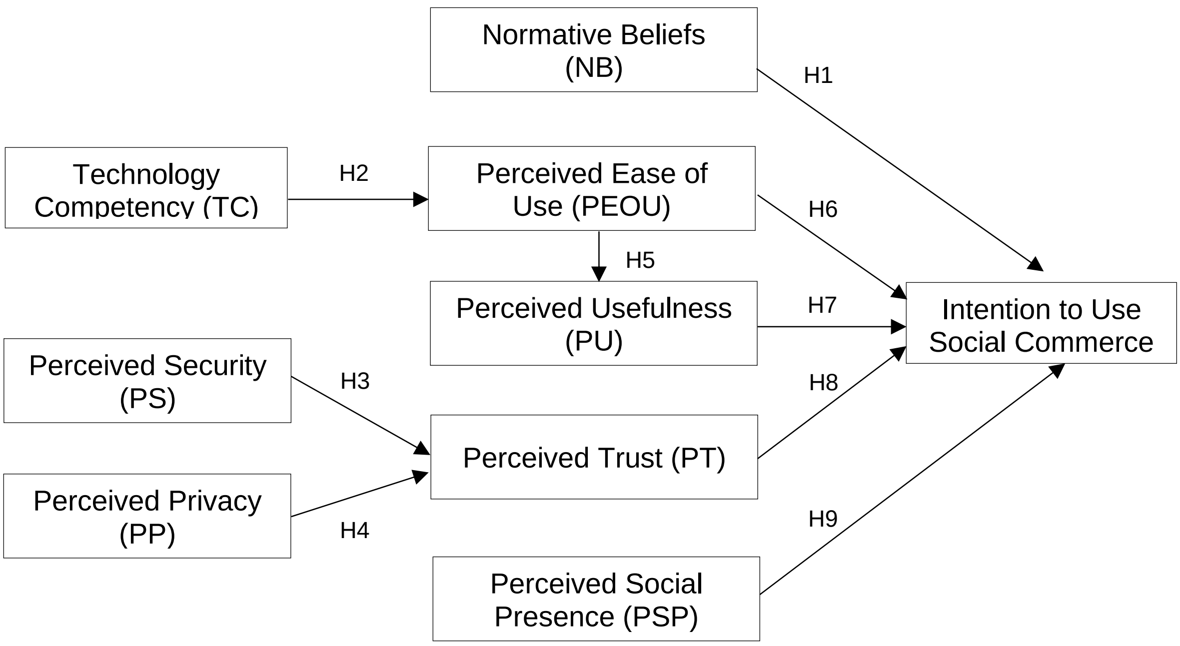
Culture has a long history of guiding consumer behavior in traditional shopping (Gong, 2009). It is not a stretch to think that culture will also influence online shopping behavior. Hofstede (1984, p.21) defines culture as, "the collective programming of the mind which distinguishes the members of one group from another". Hofstede (1984) outlined the following cultural dimensions: Power Distance, Individualism, Masculinity, and Uncertainty Avoidance. This study will briefly look at the individualism dimension of culture.

Individualism is degree to which people are socially bound through close ties to one another (Hofstede, 1984). The culture dimensions including individualism are measured on a scale ranging from 1 to 120. Thailand (individualism score 20) is collectivist society scoring low on the Individualism scale; while the United States scores relatively high (individualism score 91) (Hofstede & Hofstede, 2011). Since social commerce is deeply entwined with the social aspect of shopping, one might believe that Thailand would have a stronger preference for using social commerce than the United States. Thus, we propose the following:

H1a: There is a significant difference between American and Thai consumers in their preference to use social commerce.

To begin examining the factors that are important to American and Thai consumers in their decision to use social commerce, this study starts with the Technology Acceptance Model (TAM) that has been used extensively in the field of information systems research. The popularity of the model is due to its predictive power in explaining the acceptance of information systems (Bagozzi, 2007; Davis et al., 1989; Lee et al., 2003; Legris et al., 2003). This study adds six more factors to the TAM as shown in Figure 1.

Figure 1 Research Model



Normative Beliefs (NB)

NB are the perceptions that an individual has on how they should behave to 'fit in' with their referent group (Evans et al., 1996). This perceived social pressure from one's referent group is a strong motivator in determining the actions of an individual (Changchit et al., 2017). Previous research has demonstrated that NB have a positive influence on behavioral intention (Bock et al., 2005; Featherman & Hajli, 2016). Thus, we hypothesize that:

H1: NB have a positive influence on INT.

Technology Competency (TC)

TC is the perception that one has of their ability to successfully use technology to accomplish a task (Compeau & Higgins, 1995). Accessing the Web is relatively easy with the use of Web browsers. However, online shopping with traditional e-commerce or social commerce may not be as straightforward since the many online stores are not the same (Jarvenpaa & Toad, 1996). Thus, finding a retailer that sells a product, finding the product on the retailer's website, placing an order, and making a payment may be considered an arduous task for some (Vijayasarathy, 2004). Prior studies have found a positive relationship between TC and intention (Davis et al., 1989). We believe that the level of TC that a consumer has will directly impact their perception of how easy social commerce is to use. Thus, we hypothesize that:

H2: TC positively influences PEOU.

Perceive Security (PS)

PS is a crucial part of trust and previous studies have demonstrated the vital role that security plays (Changchit et al., 2018; McKnight & Chervany, 2002). In online shopping, personal information (i.e., credit/debit card information) is often required to be transmitted over the Internet. Security involves the protection of personal information that is transmitted over the Internet and possibly stored as part of a commercial transaction (Pandey et al., 2015). The perception of the security measures that an online vendor has in place is thought to influence the trust placed in that online vendor (Bhatnagar et al., 2000). Thus, we hypothesize that:

H3: PS positively influences consumers' PT.

Perceived Privacy (PP)

Unprecedented levels of data are collected as consumers browse the Web. Once a consumer decides to make a purchase online, even more personal data is captured. Of course, online vendors have the opportunity, and sometimes even incentives, to misuse that data. This is where privacy fits into the trust that is placed in an online vendor. PP is the assumption that an online shopper can control the use of their browsing and transactional data provided while shopping and purchasing online (Jarvenpaa & Toad, 1996). It is the potential exploitation of a consumer's data that leads to hesitation with online shopping (Lin, 2003). PP has been shown in previous studies to have a positive direct impact on trust (Cutshall et al., 2020). Thus, we hypothesize that:

H4: PP positively influences consumers' PT.

Perceived Ease of Use (PEOU)

PEOU is one of the foundational factors of the TAM. For this study, PEOU is focused on the perception that a consumer has about the amount of effort it would require to use social commerce (Davis et al., 1989). The TAM has enjoyed an extensive amount of testing in IS research and it has repeatedly been shown to influence behavioral intention (Agarwal & Karahanna, 2000; Davis et al., 1989; Zhang et al., 2012). The easier social commerce is perceived to use, the more likely PEOU will influence a consumer's intention to use social commerce. Thus, we hypothesize that:

H5: PEOU positively influences consumers' INT.

The TAM also ties PEOU to PU. The easier that a system is perceived to be used, the more likely the user will find the system to be useful (Davis et al., 1989). Gefen and Straub (2000) demonstrated that PEOU is a significant factor in explaining PU. Thus, we hypothesize that:

H6: PEOU positively influences PU.

Perceived Usefulness (PU)

PU is the other foundational factor in the TAM. For this study, PU is the consumer's expectation that social commerce will enhance their ability to find the best product (Davis et al., 1989). Prior studies have repeatedly demonstrated a significant link between PU and INT (e.g., Davis et al., 1989; Wu et al., 2007; Zhang et al., 2012). PU has been linked to e-commerce intention (Pavlou, 2003) and to social commerce intention (Bo & Windsor, 2011). Thus, we hypothesize that:

H7: PU positively influences consumers' INT.

Perceived Trust (PT)

PT is a complex factor with several antecedents. Arguably two of the most crucial factors of PT are PP and PS which are accounted for in this study. Gefen, Rao and Tractinsky (2003) define PT as the consumer's belief that the seller will complete a transaction without behaving in opportunistic ways. Due to user created content in social commerce, it may be easier for a consumer to trust a vendor (Featherman & Hajli, 2016). PT has the potential to be increased with the social interaction of social commerce (Hajli, 2013). Research by Alshibly (2015) has demonstrated the importance of PT in social commerce. Thus, we hypothesize that:

H8: PT positively influences consumers' INT.

Perceived Social Presence (PSP)

The nature of social commerce is its social aspect. With user generated content and reviews and recommendations by other customers and by members in a consumer's referent group, social presence is considered to be higher in social commerce than it is in traditional e-commerce (Kim, 2015). PSP is defined as the belief that others are there in the online environment (Herrando et al., 2017). Shopping is a social activity (Fulk et al., 1987) and online shopping is no different. Kumar and Benbasat (2006) found that customer reviews and recommendations are a basic way to add social presence to online shopping. Therefore, PSP is thought to be positively related to social commerce intention. Thus, we hypothesize that:

H9: PSP positively influences consumers' INT.

RESEARCH METHODOLOGY

Development of Measurement Instrument

The survey instrument for this study was developed by adapting the survey items for PU and PEOU from studies by Venkatesh and Davis (1996) and Venkatesh, Morris, Davis and Davis (2003). Survey items for the other factors added to the TAM were created for this study. The survey items were measured on a five-point Likert scale ranging from 1-strongly disagree and 5-strongly agree. To check the validity of the survey items, three professors and two research assistants were asked to read over the instrument and provide feedback. All necessary changes were made to improve the survey instrument. The instrument was then translated into Thai for the sample group. To assess the translation validity, Thai surveys were translated back into English.

Data Collection

An online survey was employed using Qualtrics to gather respondent data. Social media posts and word-of-mouth were used to recruit participants. Recruitment was conducted in United States for the American respondents and Thailand for the Thai respondents. Respondents were asked their country of residence to verify that only respondents in their respective countries were included in the data analysis. There were 525 respondents from the United States and 317 respondents from Thailand. The participants' demographics are listed in Table 1.

Table 1: Participants' Demographics

Gender						
	Male	Female	No Answer			
U.S.A.	284	239	2			
Thailand	106	211	0			
Age (years)						
	18-25	26-35	36-45	46-55	>55	No Answer
U.S.A.	392	96	27	7	3	0
Thailand	283	19	9	3	3	0
Employment						
	Full Time	Part Time	Not Employed		No Answer	
U.S.A.	115	246	163		1	
Thailand	51	26	240			
Online orders last month						
	0	1-2	3-5	6-9	10-20	>20
U.S.A.	62	165	177	74	27	20
Thailand	45	148	88	17	6	13
Online orders last year						
	0	1-2	3-5	6-9	10-20	>20
U.S.A.	5	32	89	88	133	178
Thailand	19	57	84	62	56	39

Average online transaction amount (United States Dollars - USD)						
	1-20	21-40	41-60	61-100	>100	No Answer
	35	169	128	120	39	34
Average online transaction amount (Thai Baht - THB)						
	<500	501-1,000	1,001-2,000	2,001-3,000	>3,000	
	145	117	26	11	18	

Data Analysis

The statistical software applications of SPSS 25 and AMOS 24 were used to analyze the data. The data analysis is described below.

Reliability Test

To test the internal consistency of the instrument, reliability tests were performed on each factor for each sample group. The Cronbach's alpha values (see Table 2) for the reliability tests were all greater than the recommended value of 0.70 (Nunnally, 1978). Based on the reliability test results, the internal consistency of the measurement instrument is acceptable.

Table 2: Reliability Test Results

	U.S.A.	**Thailand**
Constructs	**Cronbach's α**	**Cronbach's α**
Perceived Usefulness (PU)	0.880	0.854
Perceived Ease of Use (PEOU)	0.883	0.702
Perceived Privacy (PP)	0.908	0.875
Perceive Security (PS)	0.867	0.864
Perceived Trust (PT)	0.838	0.907
Perceived Social Presence (PSP)	0.904	0.858
Intention to Use Social Commerce (INT)	0.876	0.842
Normative Beliefs (NB)	0.804	0.808
Technology Competency (TC)	0.908	0.886
Social Commerce Preference (SCP)	0.808	0.830

KMO and Bartlett's Test

The KMO and Bartlett's test was performed to evaluate the degree of unidimensionality of the scales (see Table 3). The sphericity tests resulted in p-values of 0.000 for all three sample groups. The sampling adequacy was also supported with values of 0.910 (U.S.A. sample), and 0.957 (Thailand sample).

Table 3: KMO and Bartlett's Tests

KMO and Bartlett's Test *(U.S.A.)*			
		U.S.A	Thailand
KMO Sampling Adequacy Measurement.		.910	.957
Sphericity Test	Approx. Chi-Square	10650.835	6674.323
	Degree of Freedom	406	435
	Significance	.000	.000

Common Method Bias

Harman's single factor test was used to ensure that the model is free from common method bias. The SPSS application was used to derive the result by conducting an un-rotated, single-factor constraint factor analysis. The highest variance explained by one factor was 33.293% (U.S.A. sample) and 47.225% (Thailand sample), indicating that there is no concern with common method bias in the samples.

Analysis of Factor Loadings

To evaluate the factors' convergent validity, the factor loadings were verified to determine that each survey item loaded onto the appropriate factor. The results provide evidence that the survey items loaded onto nine factors, explaining 79.657 percent (U.S.A. sample) and 76.709 percent (Thailand sample) of the total variance. The items with factor loadings below the suggested level of 0.5 (Hair et al., 2009), were removed from the data analysis.

Multicollinearity Test

Since multicollinearity can have harmful effects, multicollinearity was assessed in the research model (Cenfetelli & Bassellier, 2009). The Variance Inflation Factor (VIF) ranging from 1.417 to 2.176 (U.S.A. sample) and 1.880 to 3.746 (Thailand sample), all are less than 10, indicating the multicollinearity is not a concern in this data set.

Structural Equation Model

SPSS AMOS 24 was used to examine the research model. The seven (7) SEM fit measurements were assessed to ensure the overall model's goodness of fit. All goodness of fit indices fall within the acceptance levels (see Table 4), indicating that the model demonstrated a good fit with the data (Bentler & Bonett, 1980; Hu & Bentler, 1999; Tucker & Lewis, 1973).

Table 4: Fit Indices for the Models

Indices of Fit	**Value Recommended**	**Model Value (U.S.A.)**	**Model Value (Thailand)**
df/Chi-square	≤3.00	1.654	1.293
Goodness of fit	≥0.90	0.996	0.995
Adjusted goodness of fit	≥0.80	0.969	0.959
Root mean square error of approximation	≤0.06	0.035	0.030
Comparative fit index	≥0.93	0.998	0.999
Tucker Lewis index	≥0.90	0.986	0.994
Normed fit index	≥0.90	0.994	0.996

Hypothesis Testing

To test if there was a difference between the two countries in terms of social commerce shopping preference, ANOVA and Tukey's test were performed. The result of the ANOVA demonstrated that there was a difference in social shopping preference between at least one of the pairs of countries. Post hoc testing was then preformed to determine which pair or pairs of countries exhibited significant differences in their preference for social commerce shopping. The results of Tukey's test are shown in Table 5.

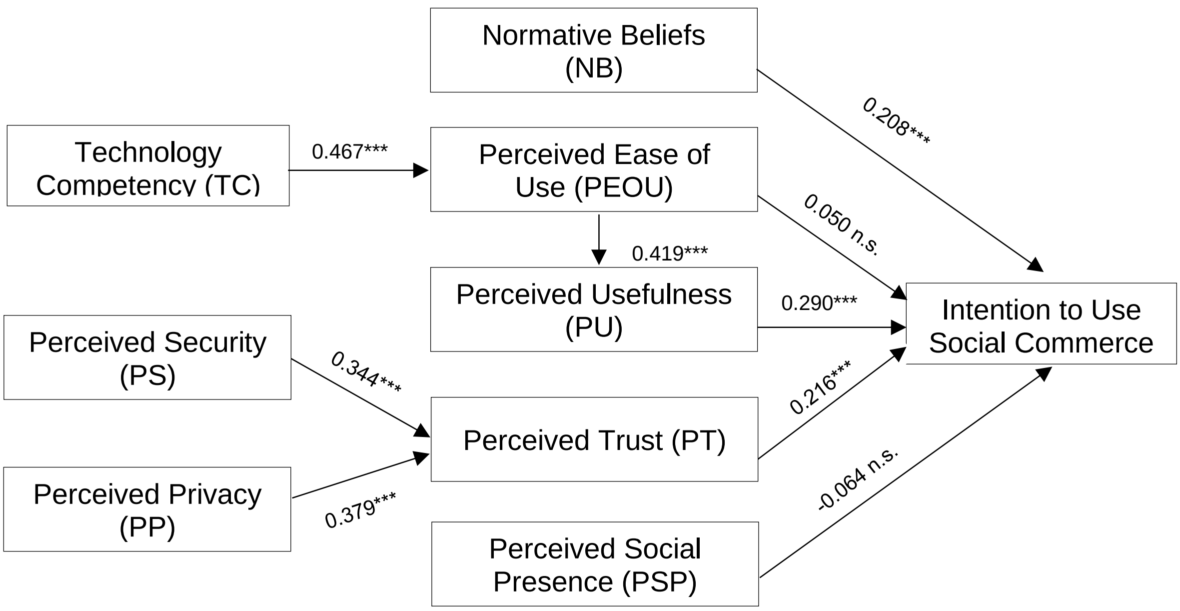
Table 5: Tukey HSD

G1	G2	Mean Difference (G1-G2)	Standard Error	Significance
Thailand	U.S.A.	0.7235*	0.06543	0.000

The mean difference is significant at the 0.001 level.

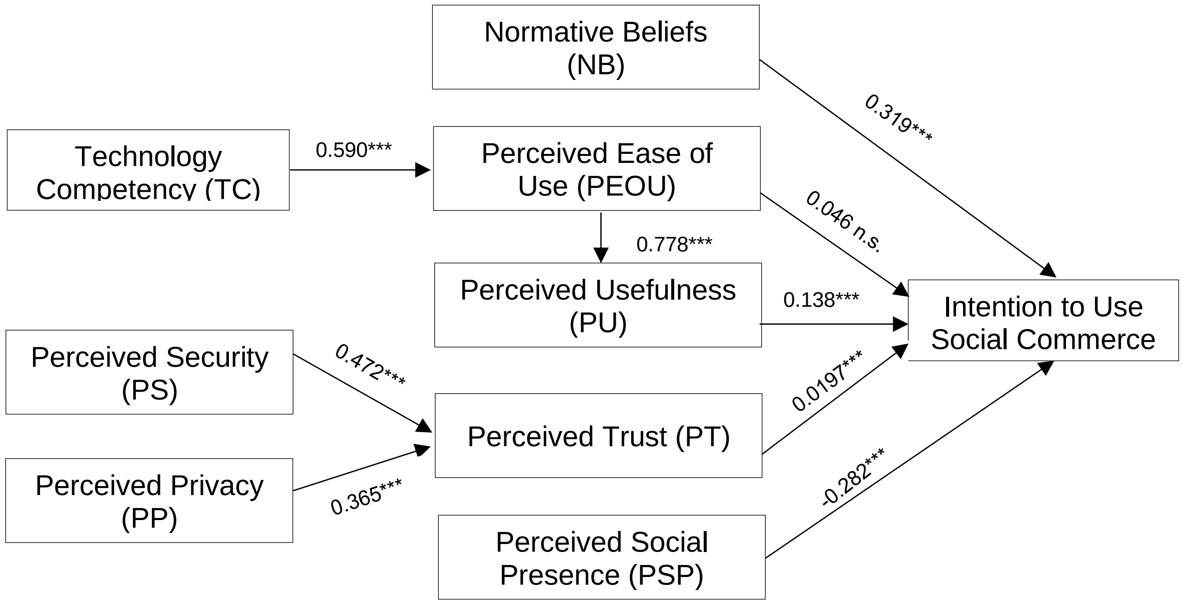
Figures 2 and 3 show the properties of the causal paths including the standardized path coefficients.

Figure 2: U.S.A. Model



* Significant at p < 0.05, ** Significant at p < 0.01, ***Significant at p < 0.001, n.s.- not significant

Figure 3: Thai Model



* Significant at p < 0.05, ** Significant at p < 0.01, ***Significant at p < 0.001, n.s.- not significant

Table 6: Hypothesis Testing and Results

H#	Hypothesis Testing			U.S.A.			Thailand		
				(β)	Critical Ratio	p-value	(β)	Critical Ratio	p-value
1	NB	→	INT	0.208	4.669	***	0.319	5.517	***
2	TC	→	PEOU	0.467	10.171	***	0.590	13.112	***
3	PS	→	PT	0.344	7.782	***	0.472	9.091	***
4	PP	→	PT	0.379	8.552	***	0.365	7.014	***
5	PEOU	→	PU	0.419	10.171	***	0.778	10.862	***
6	PEOU	→	INT	0.050	1.090	0.276	-0.046	-0.767	0.443
7	PU	→	INT	0.290	6.510	***	0.138	2.748	0.006
8	PT	→	INT	0.216	4.661	***	0.197	3.216	0.001
9	PSP	→	INT	-0.064	-1.402	0.161	0.282	4.939	***

RESULTS AND DISCUSSION

Based on the ANOVA and Tukey's post hoc test (see Table 5), there was a significant difference in shopping preference between Thailand and U.S.A. with Thai consumers preferring social commerce to other forms of shopping. A possible explanation for this could be the convenience factor associated with social commerce. With social commerce in Thailand, it is much easier for a consumer to find what they are looking for and still have the social interaction with others on social commerce websites. Thus, H1a was supported.

Analysis of the structured equation models yielded a good fit for both U.S.A. and Thailand models. All seven fit indices fell within the recommended acceptance levels (see Table 4) listed in the literature (e.g., Bagozzi & Yi, 1988; Baumgartner & Homburg, 1996; Bentler & Bonett, 1980; Hu & Bentler, 1999; Tucker & Lewis, 1973).

The hypothesis testing results displayed in Table 6 reveal that hypotheses H1, H2, H3, H4, H5, H7 and H8 were supported while H9 was partially supported, and H6 was not supported. The study found that NB has a significant positive impact on INT in both countries. Thus, H1 was supported. This finding falls in line with the results of previous studies that have also found that NB have a significant impact on behavior intention (e.g., Bock et al., 2005; Chen et al., 2009; The et al., 2015). Given the collectivist societies of Thailand, the members of those societies rely heavily on the social cues provided by those in their referent groups. While NB is also important to American consumers in the heavily individualistic society, the reason for the significance has to do with ‘keeping up with the trend’. Many Americans tend to closely watch what members of their referent group do and they follow suit so as not to be ‘left out’ and not to be considered ‘less trendy’. Businesses are in an excellent position to capitalize on this behavior by incentivizing customer referrals.

This study also found support for H2 by finding a significant relationship between TC and PEOU for both countries. This result was also found in a study by Venkatesh and Davis (1996) who reported TC’s direct effect on PEOU. The presence of existing technology skills does have an impact on PEOU. The more direct experience that an individual has with web browsers and e-commerce technology, the easier they will find it to use social commerce. Browser technology and e-commerce have been around for more than 20 years. So, the typical online shopping demographic is likely to already have direct experience with both. Thus, a high level of TC will lead to online consumers finding social commerce easy to use.

The analysis of the data also demonstrated support for H3. For both country samples, PS was found to have a positive impact on PT. This relationship was also reported in past studies (Roca et al., 009; Sharma et al., 2019). As with e-commerce, personal information is required for social commerce transactions to be completed. With the frequent reports of businesses’ data being compromised, consumers must perceive that their personal data will be secure in both the transmission and storage stages before they will trust an online vendor with their personal data. Publicly available security policies and publicly displayed security seals are a way that businesses could reassure consumers that their personal data will be safe with the social commerce vendor. These simple steps assuring consumers that their data will not be used for illegal or unauthorized purposes will increase the likelihood of social commerce intention.

Data analysis also demonstrated support for H4. For both country samples, PP was found to have a positive impact on PT. This relationship was also reported in past studies. In addition to their personal data being secure, online shoppers do not want their personal data to be used for purposes outside of the original transaction. Once an online company has customer data such as an e-mail address or phone number, it is not uncommon for that information to be shared or sold to other companies. This issue is common in Thailand where online customers often receive marketing calls and emails from various other companies that were not involved in the original online transaction. While not as common, personal data is also sold by companies that sell to American consumers. For social commerce vendors to build their trust with potential customers, having privacy policies in place that detail how customer data will be used would be assuring to online consumers.

The analysis of the data also demonstrated support for H5. For both country samples, PEOU was found to have a positive impact on PU. This relationship was also reported in past studies (e.g., Adams, Nelson & Todd, 1992; Davis, 1993; Davis & Venkatesh, 1996). The easier a system is to use, the more likely a consumer will use the system and find it useful. More specifically, the easier social commerce is to use, the more likely consumers will find social commerce useful.

Analysis of the data provided no support for H6. Among the American and Thai consumers, PEOU was found not to be a significant predictor of INT. This finding is consistent with the findings in studies by Gibreel, AlOtaibi and Altmann, (2018) and Roca, Garcia and Vega (2009). A possible explanation for this finding could be that both American and Thai consumers have been shopping online for many years so, they are conversant in the use of web browser technology required to access online social commerce sites. This explanation has support in a study by Venkatesh, Morris, Davis and Davis (2003) who found that the relationship between PEOU and behavior intent only lasts until users become familiar with the new technology.

The analysis of the data also demonstrated support for H7. For both country samples, PU was found to have a positive impact on INT. This relationship was also reported in past studies (e.g., Gefen et al., 2003; Han et al., 2016; Nguyen & Cassidy, 2018). It is possible that consumers are finding the reviews and recommendations, which are available in social commerce, to be useful in finding the right combination of vendor and product for the items that they are looking to purchase. Another explanation could be that social commerce allows the process of product research and purchasing to be combined thus saving the shopper time.

Analysis of the data also found support for H8. PT was found to have a significant influence on INT among both the American and Thai consumers. This finding is similar to studies by Pavlou and Gefen (2004) and Kim, Ferrin and Rao (2008). As seen earlier, PT is partially composed of PS and PP. Those factors must be reconciled in the minds of consumers or else they may decide not to engage in social commerce. An explanation could be that both American and Thai consumers expect that their personal data will be safeguarded and that it will only be used based on the permission granted by the consumer. When this occurs, the consumers will have a higher level of PT in the social commerce vendor and will be more likely to engage in social commerce.

The analysis of the data found partial support for H9. PSP was found to have a significant influence on INT among the Thai consumers. Similar finding was reported in studies by Chiang, Lin, Huang and Yang (2019). Hofstede (2001) classifies Thailand as a culturally collective society and as such social presence is valued more in Thailand than it is in the United States. This PSP seems to fill the social aspects of shopping and is valued higher in collectivist societies. However, American consumers did not find PSP to be significant in their intention to engage in social commerce. This finding matches the findings of previous studies by Zhang, Lu, Gupta and Zhao, (2014) and Bhat and Singh (2018) who also found that PSP was not significant factor in behavioral intention. An explanation for this result could be that American consumers view the social aspects of social commerce as merely information needed to make a purchase decision and not as social connections with others.

CONCLUSIONS AND IMPLICATIONS

The purpose of this study was to investigate the antecedents that influence online shoppers' intention to engage in social commerce. The proposed model built upon the TAM by adding six additional antecedents to social commerce intention. The proposed research model was analyzed using SEM with the SPSS and AMOS statistical software applications. The antecedents NB, TC PS, PP, PU, PT, and PEOU indirectly through PU were found to be significant in both countries studied. The antecedent of PSP was found to have a significant impact on Thai consumers but not Americans. For both countries, no significant difference was found on the relationship between construct PEOU and INT.

This research empirically tests antecedents predicted to be influential in consumers decision to adopt social commerce. The study is contributing to the existing IS research by broadening the TAM to include the additional antecedents of NB, TC, PSP, and PT along with PS and PP as antecedents to PT. In addition, this study examined social commerce in both a developed economy (U.S.A.) and developing economy (Thailand). The findings from this study made a step in identifying similarities and differences in social commerce adoption in developed and developing economies.

The scientific and practical insights provided by this study will benefit both the social commerce literature and businesses currently participating in social commerce and those businesses planning on entering the social commerce market. The social commerce literature is expanded with this empirical study that tests additional antecedents that contribute to the social commerce intention of consumers. It is this behavioral intention that has been linked to actual technology usage (Davis, 1993).

The practical insights from this study arrive in its revelation of the antecedents that online consumers find important in their decision to use social commerce. By using the findings from this study, online businesses can improve the design of their existing or future social commerce sites to better fit with the expectations of online consumers. A big take away is the importance of NB. Thus, businesses could benefit by offering incentives to existing customers that refer family and friends to their social commerce site. Stronger privacy and security policies would also go a long way in assuring the trust of prospective social commerce customers. Additionally, with the trend of web access quickly moving to smartphones and tablets, it would benefit businesses to ensure the ease of use of their social commerce sites on these mobile devices.

Most empirical studies have an innate limitation due to the sample used. The participants for this study were recruited mostly via social media posts. Thus, non-social media users may not be fully represented in this study. Additionally, most of the participants were under 46 years old. Thus, those consumers older than 46 may not be fully represented. The study also relied on self-reported data by the participants. Therefore, the generalizability of this study's results may be limited. Future studies could focus on obtaining more participants to represent those 46 years old and above and can use other recruitment methods instead of heavily relying on social media posts to find participants. Future studies could also bring more cultural characteristics into the research model.

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Some like it hot: using lean six sigma to improve QSR service operations

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ABSTRACT

Six Sigma methodology was uniquely applied to improve service operations management at Bewley's Cafe. Bewley's is an upscale quick service restaurant located on Grafton St. in Dublin, Ireland. Research results included an improvement of hot beverage service arrival time by 82% with the usage of 5S and statistical methods.

KEYWORDS: Six sigma, Service Operations Management, Restaurants, Cafes, Customer satisfaction

INTRODUCTION

What do the food service industry and the manufacturing sector have in common? Through a Six Sigma project conducted at Bewley's Café in Dublin, Ireland we will illustrate common use of variation reduction tools and techniques. This work applies to quick service restaurants (QSR) of various size and scale.

Bewley's is a leading coffee and tea company with a mission to delight the senses. They are a customer focused business who strives to provide excellent service and food to customers in an environment that allows them to receive a full Bewley's experience. The Bewley's team strives to meet their hot food and beverage metrics established in their steps of service documentation. Upon an initial meeting with management, the following items were identified as specific problems:

- Speed of hot food and beverage delivery
- Large portion of total revenue spent on labor costs
- Inability to analyze data collected due to time constraints

With those problems identified, our goal became to decrease the delivery/manufacturing time of hot food and beverages to customers, while maintaining the Bewley's experience and decreasing labor costs. The scope of this project consisted of the full-service dining experience at Bewley's and we determined that the Takeaway portion of the operations was out of scope. We hoped to determine a realistic benchmark for food and beverage times given the current business conditions, in addition to delivering hot food and beverage within the specified target statistically and practically, utilizing the established benchmark.

LITERATURE REVIEW

Six Sigma is a process improvement methodology which has been incorporated by companies throughout the world. The interest in Six Sigma comes from the level of quality associated with the methodology.

In brief, the goal of Six Sigma is to improve a process in which the process outputs 3.4 defects per million (Zare Mehrjerd, 2011). In order to reach this standard, Six Sigma contains five phases:

- Define
- Measure
- Analyze
- Improve
- Control

The Define phase is focused, as with most projects, on establishing project goals and scope to ensure resources can be appropriated to root problems. With boundaries established, the Measure phase begins to gather data on current process procedures, baseline information, and problem areas. As scope is refined, the goal of the Analyze phase is to examine the data collected in the previous phases and determine root causes. Once identified, the Improve phase involves generating solutions for the root causes and implementing them into the process. Finally, the Control phase monitors and validates the process post-improvement to ensure output performance (iSixSigma, 2017).

While Six Sigma is commonly associated with the manufacturing industry, it has also started to become an integral part of the service industry (Kwak and Young, 2006; Gamal, 2010; Srinivasan et al., 2016; Tsironis and Psychogios, 2016; Karout and Awasthi, 2017). Specifically, this paper aims to explore the role of Six Sigma in the food service industry and the benefits, as well as the drawbacks that come with it. Six Sigma has proven itself in its ability to improve many structured, behind the scenes processes in the service context, but little research has been done on the role that Six Sigma can play in a customer-facing process (Noone et al., 2010; Antony et al., 2017). In the food service industry, the focus is primarily on using Six Sigma to improve the quality of the customer experience (Nakhai and Neves, 2009). This is due to the high expectations of today's consumer that is warranted from the substantial number of entities in the market. Consumers expect great taste, as well as high quality and value for their money, while their main complaints derive from three main areas: poor design, improper execution, and low capability (Kovach and Cho, 2011). Six Sigma can be leaned on to curb the complaint derivatives, even though this can be a difficult feat due to the gap between service performance and customers' expectations as a result of the ambiguity of customer expectations. This may cause customer dissatisfaction even though the product and or service is delivered according to Six Sigma bounds (Nakhai and Neves, 2009).

Most relevant to the research shown in this paper, a Six Sigma project was conducted in a college campus restaurant where they were able to reduce the service time from 21.49 minutes to 18.64 minutes through offering pre-made takeout meals and creating a better atmosphere in the waiting area to reduce the perceived wait times (H. Chen and K. Chen, 2016). This decrease in wait time increased overall customer satisfaction and created a better consumer experience. While this paper focuses on the food service industry, there are several other instances of Six Sigma playing an important role in the general service industry and cases in which other industries implementing Six Sigma projects directly impacts customers. For example, Six Sigma has been used in improving processes in areas like healthcare, utility companies, and banks (Sehwail and DeYong, 2003; Oliya et al, 2012; Islam, 2016; Shokri, 2017; Antony, 2019; Sreedharan et al., 2018; Abdallah, 2021; Vanichchinchai, 2021). The processes in these areas can all be standardized as there is no true human element. In the case of healthcare, results can be quantified by seeing the amount of throughput of patients, in turn seeing more customers in less time (Antony, 2006). To highlight another relevant example where customers are directly impacted, we take a look at Reducing the delivery lead time in a food distribution SME through the implementation of six sigma methodology: IMS written by Farhad Nabhani and Alireza Shokri (2009). They conducted a Six Sigma project in a warehouse (manufacturing setting) to decrease overall delivery time, which directly affected the customer. The overall goal of increasing customer satisfaction was achieved through this project, showcasing that Six Sigma can be used in both manufacturing and service sectors of the industry and still have an impact on customers.

There are many implications to consider when implementing Six Sigma in the manufacturing industry, but it becomes more complex when implementing it in the service industry. The service industry has a set of different requirements for improving a process. Picking the right project to implement Six Sigma takes time and thoughtful consideration, due to the amount of time, energy, and resources that are used during the process improvement (Ray and Das, 2010; Albliwi, et al., 2015). It is important to note that not all processes can be applied to the Six Sigma method, in both the service industry and manufacturing industry, but picking the correct project is important so that the project leads to a large return on investment (Raisinghani et al., 2005; Bumblauskas and Meyer, 2015). Some criteria to take into consideration include financial impact, duration of project, probability of success and customer needs and expectations. The differentiating factor between implementing Six Sigma in the manufacturing and service industry is customer satisfaction (Antony, 2006). For example, Six Sigma may be useful in standardized processes for the customer like reading a script when presenting a menu at a restaurant, but this is not always useful because customers may expect differing levels of service. The underlying focus of implementing Six Sigma in the service industry should be customer-centric, and improvements will only work when improvements of customer satisfaction fits the needs of the customer (Noone et al., 2010). Even if the approach is customer-centric and fits the needs of the customer, there still lies the issue of each customer's level of service being based on pure subjectiveness. Each customer may have a different level of expectation of customer service (Found and Harrison, 2012). Therefore, selecting the correct project is so important in order to quantifiably show how the process was improved and customer satisfaction increased at the end of the project (Antony, 2006). As discussed previously, quantifying customer satisfaction is a challenge, but to get a better understanding on how to measure it, creating standardized measurement to identify the root cause of the problem or process variation is very important (Nabhani and Shokri, 2009).

While there are implications of Six Sigma being in the food service industry, there are an abundance of benefits that outweigh the implications. Lean, Six Sigma and Lean Six Sigma in the Food Industry: A Systematic Literature Review cited that the main benefits could be categorized into four areas: cost (43%), time (27%), value (21%), and defect (10%). Those categories, which do not sum to 100 percent we assume due to rounding by the authors, were broken down to determine that machine availability, financial improvement, loss reduction, lead time reduction, and process capability increase are among the most cited subcategory benefits, representing 53% (Bonome et al., 2018). This also holds true for the subcategory of equipment maintenance, such as in the QSR / café kitchen, and associated decision making (Bumblauskas et al., 2012; Kaparthi and Bumblauskas, 2020). All of these benefits and more lead to an overall increase in customer satisfaction as a result of Six Sigma's implementation in the food service industry (Nabhani and Shokri, 2009).

This information is relevant because Six Sigma in the service industry is poorly understood and researched due to the subjectiveness of each specific project and service provided. It is important to note that Six Sigma can be implemented in the service sector, just as it would be in the manufacturing sector, but capitalizing on project selection and understanding the customer expectations, while understanding its constraints, such as data availability and quality is imperative (Antony et al, 2008). There are areas in the traditional Six Sigma process that must be adapted with a few key differences as noted above (Antony, 2006). In terms of adapting the process, a simplified version of Six Sigma is an important option to consider. This takes all of the components of traditional Six Sigma, but takes an increased focus on simple tools, identifying the critical issues of each process and data driven analysis. This is not only more cost effective, but also has customer satisfaction at the forefront of the project, for example reducing lead time to the customer (Nabhani and Shokri, 2009). When it comes to reducing lead time or the service speed to the customer and their perceived satisfaction, not only does the customer have to be satisfied with the speed, but also the quality. No matter what the speed or quality is of the overall experience, all customers have the choice of repurchasing, hence the subjectiveness of implementing six sigma in the service industry (H. Chen and K. Chen, 2016). We believe that our simplified Six Sigma project done at Bewley's allowed the best opportunity for improvement and success, which will be discussed later in this paper. We always kept the customer in the forefront of our improvements, while decreasing lead time and maintaining quality.

Also in this paper, we will show the importance of data, how changing the front-end process can lead to efficiencies, and the importance of management in Six Sigma (Bumblauskas, D. et al., 2015a). Data is essential in understanding where the root cause of a problem is and the quality of the data can make or break a project (Hensley and Dobie 2005; Gupta et al., 2019). It is essential that the data is clean so that it can be used for accurate data visualizations, such as Pareto Charts. Commonly, Six Sigma is thought to have more of an impact on the back-end processes, but our research goes on to show that changing front-end processes can have a big impact as well (Aminudin and Mustafa, 2014). Finally, and perhaps one of the most important elements, is management support (Heckl et al., 2010; Chakraborty and Chuan Tan, 2012; Laureani and Antony, 2015; Rodgers and Antony, 2019; Alblooshi et al., 2021). The support and backing from leadership is essential, not only in implementing a Six Sigma project, but training subordinates to understand and continue to improve and make the process more efficient (Antony, 2006; Alnadi and McLaughlin, 2021).

Methodology

Prior to implementing the DMAIC framework to improve the inefficient processes at Bewley's we went undercover and conducted a mystery dining experience. The experience was not in alignment with the Steps of Service document we had received beforehand in our preliminary meetings with management. Our entire experience lasted about one hour and forty-five minutes, contradicting the Steps of Service document, the Bewley's experience should last twenty minutes or less. Taking the knowledge that was learned from the experience, we broke down each element of the DMAIC process, using statistics, Pareto and run charts, and speaking with staff. With taking time and speaking with various managers, servers, and baristas we better understood the issues and processes that can be improved upon. This proved to be the most useful in our preliminary analysis, due to their firsthand experience and roles in the day-to-day operations of Bewley's.

Measure

Initial baselines and data

The initial baselines for service times written in the Steps of Service were determined from the management team based on studies they conducted previously. The beverage wait time baseline is three minutes from the start of an order to when the customer receives the beverage. After communication with management, these studies were conducted with three baristas behind the counter for one hour. They did not have to worry about dishes or large group orders. The goal would be customers receiving their drinks first within three minutes, then receiving their food shortly after.

After receiving the baselines, data was received from the Bewley's management team to analyze prep time and samples were collected from the barista counters to analyze the server pickup time. The former data contained the total time of the beverage process which began when a server placed the order. The time of the order would continue to accumulate as the barista continued their respective process. Once the beverage is completed, the barista would hit a "bump" button to end the timer for that specific item, this entire process is defined as order time. As for the wait time, the sample times were defined as the time a barista fulfills a drink order to when the item is picked up for delivery by a server. With the company's baselines and integral data, several visualizations were created for each respective category:

- Run Charts: Visualize order times consecutively
- Histograms: Create bins to group transactions together and form a frequency plot

We collected data building off factual understanding of existing process conditions and problems.

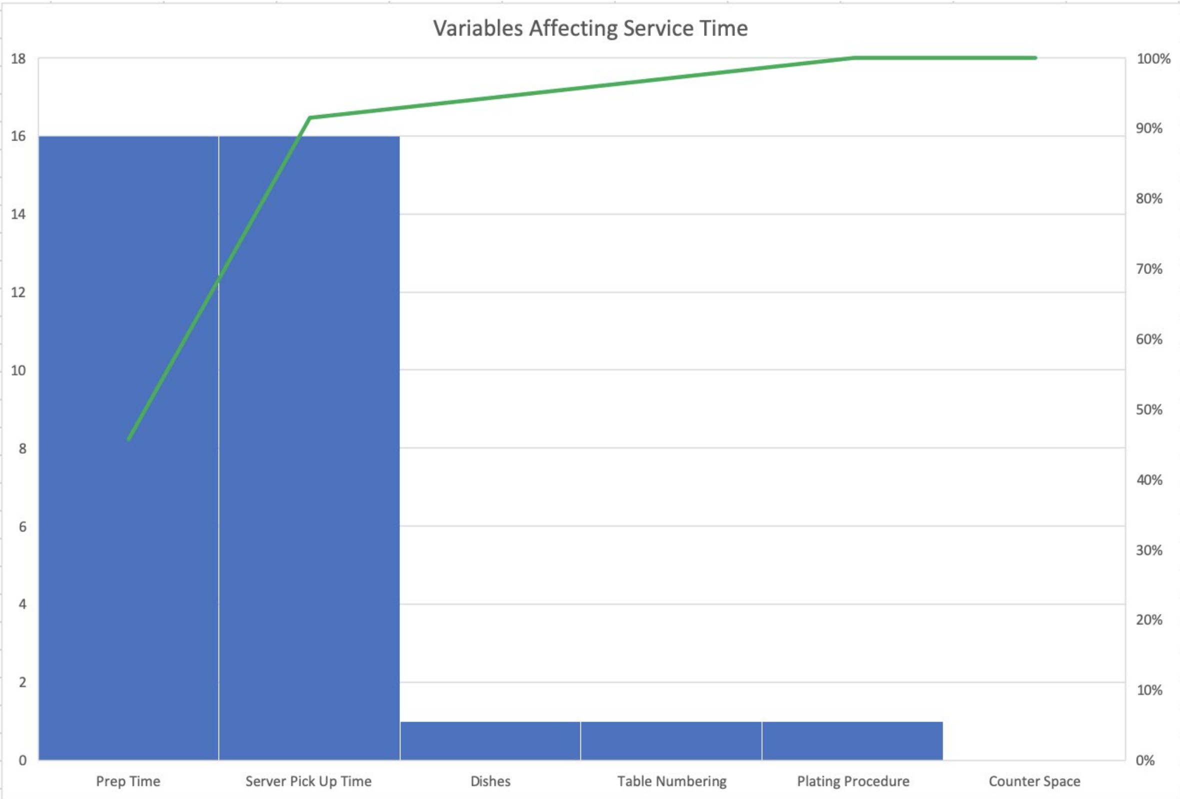
Pareto chart

To begin understanding what key processes are influencing the variation of the process, a Pareto chart was created with several variables thought to be problem categories. These include:

- Dishes: Dishes that arrived in the servery that needed to be put away

- Counter space: A queue of beverages affecting the amount of counter space available, creating limited space for more beverages
- Table numbering: Delay in service time due to server taking time to find a table to deliver the beverage to a customer
- Plating procedure: Items on the menu that took longer to prepare
- Example: Melon and Fresh Fruit Salad
- Prep Time: A need to restock pastries and prepare trays and/or plates for servers
- Server Pick Up Time: Wait time from the moment the tray was ready to the time the tray was picked up by the server

Figure 1: Pareto chart affecting service time

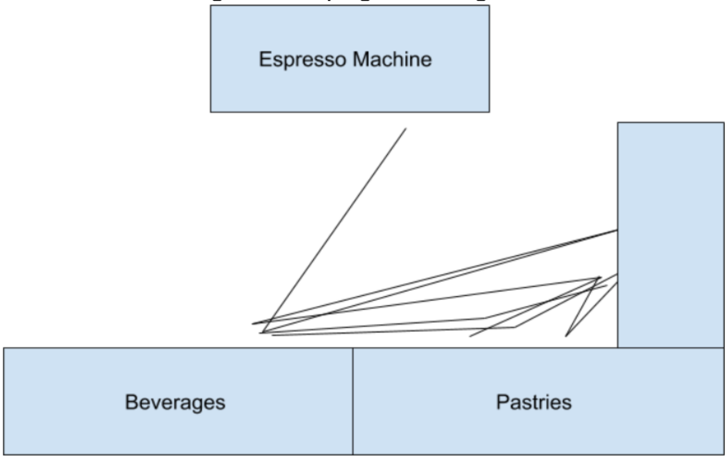


Looking at Figure 1, the two key categories of service delays were the preparation time of food and beverages as well as the server pick up time.

<u>Spaghetti diagrams</u>

Figure 2 shows the movement of the expeditor during a 15-minute time period over the course of their shift. This gives us a visualization to better understand the process and movement during any particular task. During observation, it was noted that the expeditor left their station three times to retrieve various items from the front café or downstairs. These non-value-added tasks were concerning and created a backlog of orders on the screen, which created more variation in the process. We have some recommendations based on these findings, which are explained more in depth at the end of the report.

Figure 2: Spaghetti diagram



Beverage order times

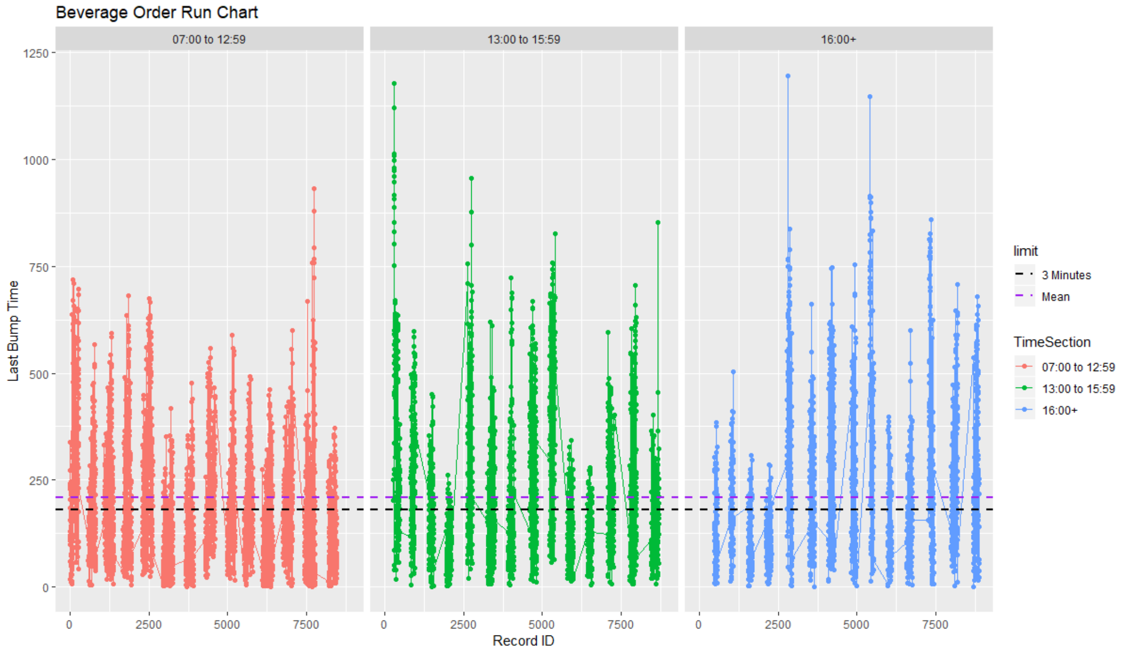
This section contains visualizations pertaining to the overall preparation time process of beverages but excludes the time a beverage sits on a tray waiting to be picked up and delivered to the customer.

Run chart – filtered via timesection

Figure 3 represents two week's worth of records broken out by TimeSection for easier comparison. The mean (purple-dotted line) is 209.89 seconds. Key data points:

- Total % Within 3 Minutes: 52.7%
- Subsetted Percentages
  - Morning: 55.9%
  - Afternoon: 50.8%
  - Evening: 48.9%

Figure 3: Beverage order times via time sections



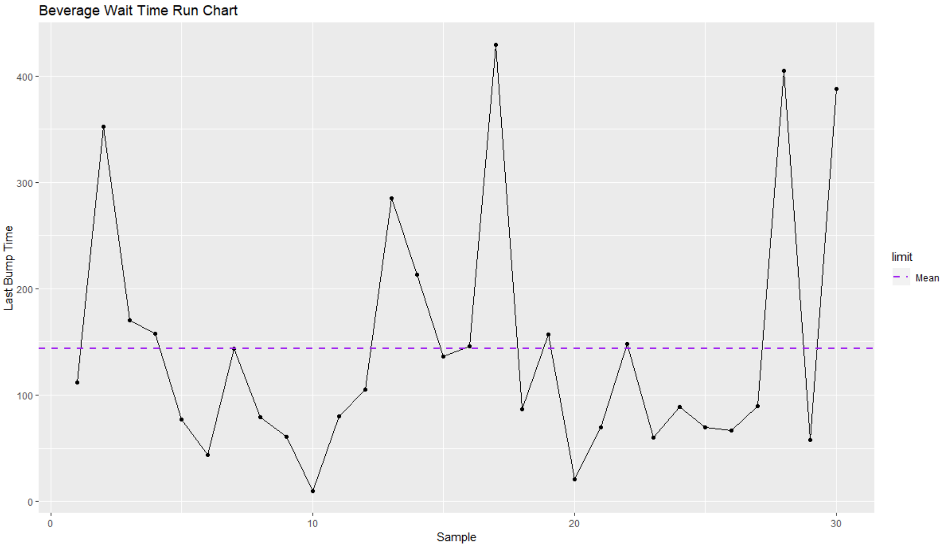
Beverage wait times

This section contains figures pertaining to the wait time of beverages, defined as the time a beverage tray is completed by a barista to when the server picks the tray up for delivery. This excludes the timing from a server physically delivering the order.

Beverage wait time run chart

Figure 4 below indicates the samples we took between 11:00 a.m. - 12:00 p.m.. The mean is 143.7 seconds or 2:23 minutes.

Figure 4: Beverage Wait Time Run Chart

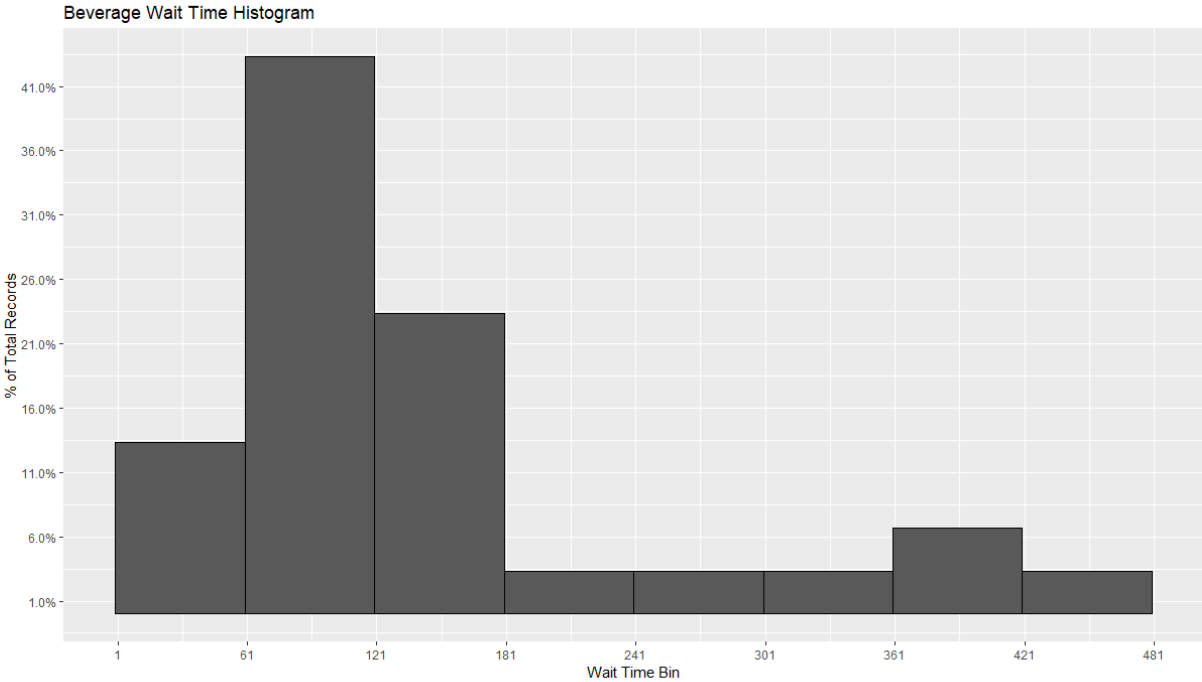


<u>Histogram</u>

Figure 5 below displays the frequency of wait times via bins. A little over 41% of the 30 samples waited on the counter between 1 - 2 minutes. Key data points:

- Only 2 drinks sat for 30 seconds or less
- 4 drinks sat for 60 seconds or less
- With the mean wait time equal to 143.7 seconds, and assuming the 3-minute metric is in play, 79.8% of the total process is spent waiting on the counter.

Figure 5: Beverage wait time histogram



Hypothesis Testing

In this project, two different tests were used to compare the two distributions at an alpha of .05: The Student's T-Test and the Z-Test.

<u>Data collection for samples</u>

Before discussing the tests, it is important to ensure fair and unbiased data collection practices. The programming language R was used to collect samples and run both the T-Tests and Z-Tests. The samples collected were from a dataset of 8,858 records. Before taking samples, the set.seed() function was used with a random integer generated from the function sample(1:1000, 1). These two functions allowed three samples of n = 500 to be collected in an impartial fashion.

<u>Student's T-Test</u>

The Student's T-Test is a method used for making inferences about the distribution mean when the population standard deviation is unknown. Although not as accurate as the Z-Test, the T-Test is useful due to not requiring the population standard deviation. In this T-Test, the null hypothesis (H_0, aka Mu) is 180 seconds. The alternative hypothesis (H_A) then becomes > 180 seconds. See Table 1 values from the 3 T-Tests conducted for this project:

Table 1: T-Test Key Metric Table			
METRIC	TEST 1	TEST 2	TEST 3
X Bar (Seconds)	206.54	213.71	204.28
St. Dev of Sample	152.51	166.17	160.88
Sample Size	500	500	500
Test Statistic	3.89	4.54	3.38
Critical Value	1.65	1.65	1.65
P-Value	5.67e-05	3.59 E-06	3.97 E-04

[p > .05]

Z-Test

The primary difference between the Z-Test and the T-Test is that the former allows Sigma (the population standard deviation) to be replaced by the standard deviation of a sample when n > 30. This allows for more powerful and accurate testing compared to the T-Test. See Figure 7 for the values from the 3 Z-Tests conducted for this project:

Table 2: Z-Test Key Metric Table			
METRIC	TEST 1	TEST 2	TEST 3
X Bar (Seconds)	206.54	213.71	204.28
Sigma (St. Dev of Sample in seconds)	152.51	166.17	160.88
Sample Size	500	500	500
Test Statistic	3.89	4.54	3.38
Critical Value	1.64	1.64	1.64
P-Value	4.99e-05	2.86e-06	3.69e-4

[p > .05]

Conclusion of Hypothesis

In conclusion of the hypothesis tests, all the samples representing the alternative hypotheses for both the T-Test and Z-Test had a p-value significantly less than alpha = .05. Therefore, we reject H_0 = 180. These tests do not mean beverages cannot be created within a 3 minute timeframe. Instead, the tests support the difference between the null hypothesis mean and the alternative hypotheses means are statistically significant. Based on the results of these tests, the team recommends creating a new baseline for beverage prep times which consider present operating conditions.

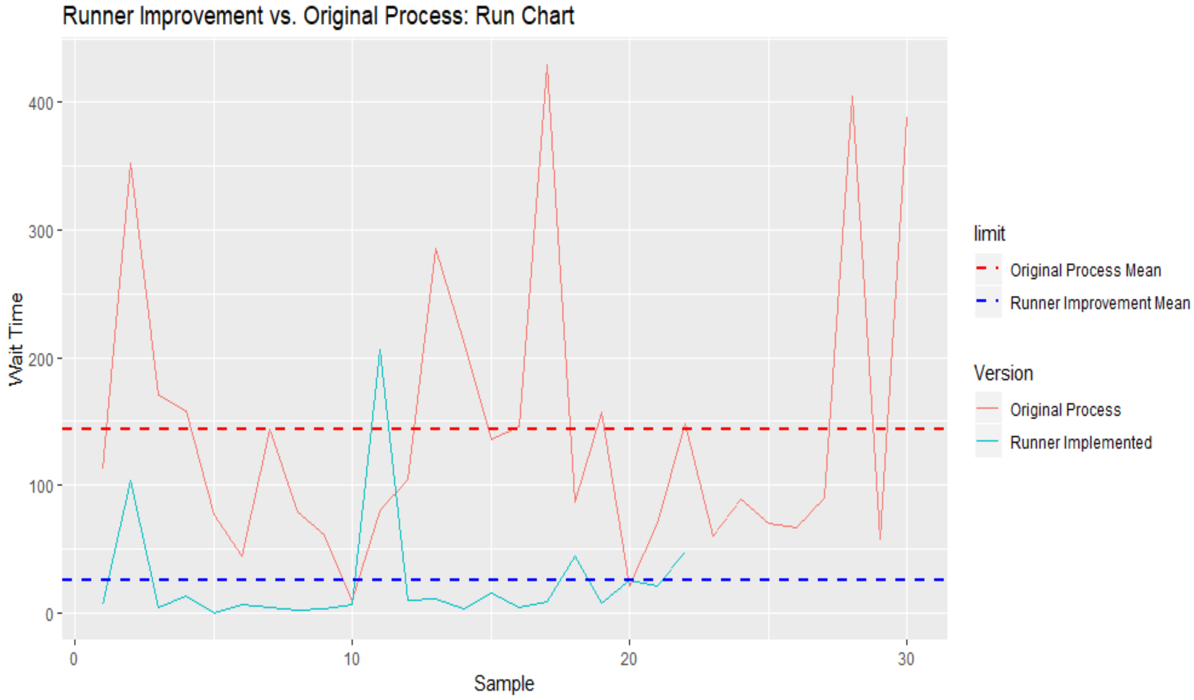
Findings, results, and recommendations

After analyzing current data given to us by the Bewley's management team, we found that often Bewley's was not meeting their three minute beverage wait time baseline which led us to believe that Bewley's may need to re-evaluate using three minutes as a baseline metric. In conducting our own evaluations and utilizing tools such as a pareto chart, we were able to determine that the two biggest reasons for a delay in service were preparation time and server pick up time. Through our statistical testing we also concluded that a new baseline should be set for the goal of beverages received in under three minutes.

The following are some recommendations that we believe can help the overall process efficiencies at Bewley's. These two recommendations were proposed to management and were tested to evaluate if they made an impact on service time. The first recommendation is utilizing the unused servery on the main level to prevent baristas from having to leave their stations for extended periods of time to restock pastries and retrieve other commonly used items from the basement. Making several trips to the basement multiple times during a shift are non-valued tasks that prevent the baristas from operating at optimal efficiency. The second recommendation consisted of reallocating a server to become a designated runner for the busy service hours at Bewley's to prevent beverage trays from waiting on the counter for extended periods of time. To incentivize the server to become a runner, our proposed solution would be to put all tips in a bucket and take out a percentage of those tips. That specified percentage would then be given to the runner and the remaining tips would be split evenly between all of the other servers. This recommendation would aid in improving the customer service experience by helping to achieve the benchmark of three minutes from order to customer. As the process evolves and changes, each of these recommendations should be changed in order to make the process become more efficient over time.

Figure 8 is displaying the data from the experiment conducted to see if service time was impacted by the implementation of a runner. The red line represents the data from the baseline time study, while the light blue line represents the data recorded from the implementation of a runner. From this chart, one can determine that service time was indeed faster when a runner was utilized. The mean decreased from 143.7 seconds to 25.08 seconds, earning a percentage change of 82.5%. The standard deviation also decreased from 115 to 46.5 seconds, boasting a percentage change of 59.6%. Note that both of the samples that were taken from the baseline study and the from the implementation of a runner were collected between 11:00 a.m. and 12:00 p.m.

Figure 8: Improvement of process run chart



Conclusion

Through our project we were able to show that Six Sigma can have a positive impact in the service industry. We also demonstrated that implementing changes in front-end execution can have just as big of an impact as changes to back-end processes. Six Sigma is commonly associated with the manufacturing industry in making changes to back-end processes, while our paper went against this norm.

We ingrained ourselves in Bewley's culture and processes by talking with not only the management, but the staff as well to get a full picture of current practices and understand pain points to help make the correct recommendations to improve their business. The support of management is critical to any successful Six Sigma project. Their management team empowered us to conduct the experiment with implementing a runner which helped us to demonstrate just how impactful making the change could be. Ultimately the decision to permanently implement our recommendation is in their hands. They will lead the change and foster the culture necessary to control the operating procedures.

Implementing Six Sigma in the service industry is possible with deep understanding and collaboration between involved parties. It can lead to enhanced customer satisfaction and, in turn, increased profitability and reduction of variation in a given process. Often, even the simplest of changes can lead to exponential results.

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DECISION SCIENCES INSTITUTE

Spatio-Temporal Effects on Green Fleet Supplier Selection

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ABSTRACT

As regulations requiring alternative fuel vehicle (AFV) adoption increase, fleet procurement agents (FPAs) must engage in the AFV supplier selection process (SSP). Best value procurement policy requires that FPAs appropriately weight non-price criteria when comparing suppliers. This study posits that a switch in procurement context from conventional fuel vehicles (CFV) to AFVs will influence criteria weightings, and that that effect is influenced by FPA geographic dispersion, and the recency in which they last engaged in the AFV SSP. An observational study is conducted to test for these spatio-temporal effects. Findings support these effects and bear significant theoretical and managerial implications.

KEY WORDS: Supplier Selection, Fleet Management, Sustainability, Procurement Policy

INTRODUCTION

As cities and urban areas evolve, passenger and freight mobility is an issue of increasing importance to business and governments alike (McKinsey and Company 2016; United Parcel Service 2018). Transportation-derived emissions have adverse effects on the environment (McKinnon et al. 2015), and account for 28 percent of GHG emissions (Zuckerman 2010; Environmental Protection Agency 2021). In the United States, 30 percent of GHG emissions are derived from transportation, with 23 percent of those transportation emissions generated by the medium- and heavy-duty transportation sector, the fastest growing transportation sector within the United States (Calstart 2016; United Parcel Service 2018). Firms in both the private and public sectors have employed various strategies to address the reduction of GHG emissions (Golicic et al. 2010; Bae et al. 2011). Among these strategies, the adoption of alternative fuel vehicles (AFVs) has been prevalent (Bae et al. 2011; United Parcel Service 2018). Adopted alternative fuels and technologies include biodiesel, cellulosic biofuel, hydrogen, liquefied petroleum gas (LPG), liquefied natural gas (LNG), compressed natural gas (CNG), fuel cells, hybrid-electric, plug-in hybrid-electric and fully electric technologies (Nesbitt and Sperling 2001; Rahm and Coggburn 2006; Tong et al. 2017; United Parcel Service 2018).

For both business and government entities, various challenges are associated with the adoption of AFVs (Rahm and Coggburn 2006; Heid et al. 2017; Cunningham et al.2018; United Parcel Service 2018). Among these challenges are dynamics associated with higher AFV purchase prices, access to charging and operating facilities, lesser degrees of AFV technology-specific organizational knowledge, unpredictability of spare part supply chains, and the increased need for technology-specific education and training (Heid et al. 2017; United Parcel Service 2018). In many instances, the capabilities and knowledge of AFV suppliers can be leveraged by organizational buyers to serve in reducing much of the technological uncertainty associated with AFV adoption (Nesbitt and Sperling 2001; Ernst 2013). Consequently, the increased adoption of AFVs augments increased technological uncertainty, as fleet procurement agents (FPAs) often have lesser degrees of familiarity with the newer vehicular technologies they are responsible for acquiring; due to differences in the advanced engineering and technological core of more recent AFV technologies (Laver et al. 2007; Ernst 2013; Heid et al. 2017; Linscott and Posner 2020). Those differences require additional considerations and management activity during the vehicle procurement process (Laver et al. 2007; Moura et al.

2008; Li et al. 2015; Heid et al. 2017; Linscott and Posner 2020). These additional considerations and activities can include more technically detailed specification development, the estimation of technology-specific life cycle and total ownership costs implications, uncertainty in negotiating warranties and liability agreements, and required changes in expectations regarding supplier capabilities and how they are evaluated (Laver et al. 2007; Moura et al. 2008; Ernst 2013; United Parcel Service 2018).

Given the organizational strategic implications, increased vehicle technological complexity, and associated regulatory compliance requirements associated with AFV procurement (Nesbitt and Sperling 2001; Laver et al. 2007; Heid et al. 2017), when FPAs begin to engage in buying contexts involving the acquisition of AFV technologies, they will conceivably possess less understanding of the technical nuances of newer technologies, leading to a decline in their ability adequately prioritize amongst salient decision variables during the vehicle procurement process; this in addition to a reduced capacity to account for the organization-wide effects of their decisions regarding these newer technologies (Nesbitt and Sperling 2001; Bae et al. 2011; Heid et al. 2017). As a consequence, the ability of FPAs to efficaciously assign the appropriate level of importance, or weightings, to the supplier selection criteria (SSC) that are most salient and critical in AFV buying contexts can be constrained, this bringing to the fore the importance of fleet procurement agents being able to leverage the supplier selection process (SSP) to identify and acquire those supplier capabilities that facilitate the reduction of AFV-induced technological uncertainty, which can have adverse effects on firm economic and environmental sustainability performance (Laver et al. 2007; Heid et al. 2017; Tong et al. 2017; McKenzie and Durango-Cohen 2012; Linscott and Posner 2020).

In extant supplier selection literature focused on supplier selection criteria prioritization (Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004; Wetzstein et al. 2016; Scott et al. 2018), prior research has established the existence of a statistically significant relationship between a change in buying contexts and variability in the importance assigned to the same supplier selection criterion, selection criteria importance (*SCI*), between those contexts (Lehmann and O'Shaughnessy 1974; Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004; Wetzstein et al. 2016). Differences in buying contexts have been represented by differences in organization size, geographic location, buyer gender, industry type, and product type (Lehmann and O'Shaughnessy 1974; Pearson and Ellram 1995; Choi and Hartley 1996; Swift and Gruben 2000; Kannan and Tan 2002). While the identification of this relationship is established and indeed insightful, much less is known about the boundary conditions or operational contexts in which the extent of that change in SCI between buying contexts varies, or what the extent of such change is dependent on, during the best value procurement process. The best value procurement process requires that both price and non-price selection criteria be adequately considered and weighted during the supplier selection process, to ensure the facilitation of improved longer term economic value, through optimized life cycle or total ownership costs over the useful life of an acquired good or service (Gransberg and Elicott 1997; Scott et al. 2006; Van de Rijt and Santema 2009). This suggests that investigating such phenomena through the lens of decision-making theories can be beneficial in explaining observations of supplier selection decision task outcomes.

Behavioral decision theory (BDT) explores de facto decision making and facilitates the prediction of decision outcomes through developing an increased understanding of how independent factors affect rational decision making in practice (Payne et al. 1993; Swait and Adamowicz 2001; Takemura 2020). The theory explores and illustrates how factors within task environments can influence decision maker choices (Payne et al. 1993; Swait and Adamowicz 2001). Various factors have been found to influence task-related decisions, among which include contextual environment, task-specific characteristics and individual characteristics; with BDT contenting that variability within these factors can lead to differences in the way decision makers make trade-offs and establish preferences when making choices (Morton and Fasolo 2009; Davis-Sramek et al. 2018; Takemura 2020). As agents make decisions between alternatives in a choice set, some of the attributes of which the alternatives comprise are perceived as being more important than others, leading to these attributes establishing dominance over other criteria (Montgomery 1983; Bettman et al. 1998). These types of attribute or criteria trade-offs occur as fleet procurement agents engage in the supplier selection process for both conventional fuel and alternative fuel buses.

Public transit agencies in the United States have often served as the organizations in which AFV technologies are first adopted and tested (CalStart 2015; Li et al. 2015; Czerwinski et al. 2016; Hughes-Cromwick and Dickens 2020), leading to significant increases in the procurement of AFVs in the industry over the past 15 years (Li et al. 2015; Liu et al. 2019; Hughes-Cromwick and Dickens 2020; APTA 2020); making the US public transportation a fitting empirical context to study AFV supplier selection dynamics. Public transit agencies have encountered significant procurement related challenges associated with the increased adoption of AFVs, among which include increased uncertainty associated with determining adequate AFV capabilities (Laver et al. 2007; McKenzie and Durango-Cohen 2012; Li et al. 2015; Linscott and Posner 2020). Due to the fact that most US transit agencies receive capital funding support from the Federal Transit Administration (FTA), they are encouraged, and often required when state stipulations mandate, to utilize the best value procurement process when procuring buses (Laver et al. 2007; APTA 2013, 2014; FTA 2016). Given the fact that the FTA doesn’t stipulate which specific selection criteria to utilize, or how to relatively weight them (FTA 2016), it is very difficult for the FTA to determine if FPAs indeed adequately consider and weight non-price criteria and, consequently, how such decisions affect its best value procurement policy objectives of optimized life cycle and total ownership costs.

Given the aforementioned, we assert that as FPAs engage in the best value procurement process as buying contexts switch from conventional fuel vehicle (CFV) to AFV procurement, observed variation in the importance assigned to both price and non-price SSCs between FPAs exists, but the extent of that existence can be attributable to other factors, among which we contend includes the geographic dispersion of FPAs and the recency with which they last completed the AFV supplier selection task. We posit these two factors influence the extent of change in SCI between these procurement contexts. Geographic location has been found to influence AFV-related environmental regulation (Laver et al. 2007; Li et al. 2015; Hsu and Baker 2016; Liu et al. 2019), access to alternative fuel infrastructure (USDOE 2002; Laver et al. 2007; USDOE 2021), operating environment conditions (Yuksel and Michalek 2015; Tong et al. 2017), and the availability of vehicle maintenance support and technician skill levels (USDOE 2002; Laver et al. 2007; Czerwinski et al. 2016; Sullivan 2018; Linscott and Posner 2020). The frequency with which transit agencies and FPAs engage in the bus AFV procurement process has been found to be influenced by FTA useful life stipulations, required supplier minimum bus order quantities, the need for transit agencies to engage in scheduled state-wide vehicle procurement programs or “piggy backing” procurement agreements with other transit agencies, and the improved life spans of diesel engines (USDOE 2002; Laver et al. 2007; Peterson 2007; Moura et al. 2008; McKenzie and Durango-Cohen 2012; Li et al. 2015; Hsu and Baker 2016; Sullivan 2018). The confluence of these dynamics and factors bear significance for best value procurement policy stakeholders and motivate the following research questions:

1. Does the importance assigned to price and non-price SSCs change between CFV and AFV best value procurement contexts?

2. Does the extent of the change in importance assigned to price and non-price SSCs between CFV and AFV best value procurement contexts differ by fleet procurement agent geographic location?
3. Does the extent of the change in importance assigned to price and non-price SSCs between CFV and AFV best value procurement contexts differ by the combined effect of fleet procurement agent geographic location and when last they engaged in the AFV supplier selection process?

The investigation of independent factors that may act as facilitators of boundary conditions to assigned SCI importance levels has not received significant focus within extant literature focused on changes in SSC importance as buying contexts switch. In seeking answers to our research questions, we respond to a call for research that explores the boundary conditions by which, or factors for which, established focal relationships are modified or altered (Fawcett and Waller 2011; Goldsby et al. 2013). This research comprises an observational study that makes novel contributions by building on work in both the AFV and supplier selection bodies of literature. We utilize the empirical context of the selection criteria weighting task during the *Develop-a-Solicitation* (DAS) stage of the best value bus procurement process, as buying contexts switch from CFV to AFV procurement in the US public transportation industry (APTA 2014; FTA 2016). Generally, after the appropriate weightings are assigned, FPAs communicate these preferences to suppliers during the *Request for a Proposal* (RFP) stage of the procurement process; to which suppliers will submit proposals in response, with the intent of being awarded the contract to supply AFVs to the soliciting transit agency (APTA 2014; FTA 2016).

BACKGROUND AND MOTIVATION

The best value procurement method requires that both price and non-price evaluation criteria be adequately considered during the supplier selection process (Gransberg and Elicott 1997; Scott et al. 2006; Van de Rijt and Santema 2009). With the goal of maximizing long term economic performance by achieving optimal cost levels, best value procurement requires that greater emphasis be placed on supplier competence and expertise, and not just price (Van de Rijt and Santema 2009; Bruno et al. 2018). The consideration of supplier competence and expertise is reflected in the use of non-price selection criteria that are assigned magnitudes of importance depending on the buying organization's objectives and needs (Dimitri 2013; Tran et al. 2016). These non-price criteria can include performance history, technical competency, financial health, delivery schedules, and environment, among others (Scott et al. 2006; Tran et al. 2016).

Comprising four components, the best value procurement process requires that buyers first determine best value parameters, followed by identifying the selection criteria to be utilized, after which the rating system to facilitate evaluation is implemented, with the establishment of the award process being the final component (Scott et al. 2006; Van de Rijt and Santema 2009; Tran et al. 2016; Bruno et al. 2018). Centrally important to the best value procurement process is the task of assigning importance, or relative weighting, to the selection criteria upon which supplier comparisons will be based. A procurement agent's ability to identify and adequately weight those criteria that are most relevant to the buying context, by making adequate tradeoffs between price and non-price criteria, enables optimal supplier choice (Gransberg and Elicott 1997; Bruno et al. 2018). Expectedly, the assignment of relative importance amongst selection criteria has been deemed as being among the most important tasks engaged in by procurement agents (Wetzstein et al. 2016; Tchokogue et al. 2017; Schutz 2020). The relative importance assigned to selection criteria signal which supplier capabilities are being prioritized, with buying organizations desirous of these capabilities becoming accessible and leverageable in the pursuit of performance goals (Wong et al. 2012; Wetzstein et al. 2016). Indeed, prior studies have found that the identification and weighting of selection criteria have an effect on buying firm financial performance (Ellram 1990; Kannan and Tan 2002; Yook et al. 2018).

Often, buying organizations' inclination to leverage supplier capabilities is driven by resource scarcity and increased uncertainty regarding specific products, operating environments or markets (Koufteros et al. 2007; Ng and Nudurupati 2010). Prior research has found that as buying contexts change, buying organizations can have an increased dependence on suppliers, exhibiting a preference for selecting the suppliers that possess those characteristics and attributes that can facilitate a reduction in the adverse effects associated with increased uncertainty (Celly et al. 1999; Ragatz et al. 2002; Oh and Rhee 2008). The advent of sustainability as a corporate responsibility has resulted in the introduction of various technological advances aimed at improving the environmental sustainability of firms' products, services, and processes (Seuring 2011; Busse et al. 2017). The introduction of new sustainability-based technologies has often induced increased levels of technological uncertainty regarding managerial practices and task completion (Seuring 2011; Busse et al. 2017; Flynn et al. 2016), among which include alternative fuel and propulsion technologies.

Increased environmental regulation and continued advancements in alternative fuel and propulsion technologies have resulted in the adoption of AFVs being a central component of organizations' sustainability strategies (Nesbitt and Sperling 2001; Bae et al. 2011; Zhang et al. 2011; Heid et al. 2017; United Parcel Service 2018). The transition from CFV procurement to AFV procurement however has resulted in a more complex procurement process, with ramifications for the supplier selection process (Nesbitt and Sperling 2001; Rahm and Coggburn 2006; Moura et al. 2008; Heid et al. 2017; United Parcel Service 2018). Fleet procurement agents, when selecting AFV suppliers, must engage in comparison that juxtaposes vehicle price with other non-price factors that include projected fuel and maintenance costs, vehicle modification requirements, distribution and refueling network dynamics, fuel supply and source locations, regulatory compliance, and life cycle costs of ownership implications (Moura et al. 2008; Heid et al. 2018). Further, the breadth and scope of AFV technologies, and the commensurate knowledge and expertise required to effectively integrate AFVs into organizational fleets, results in many fleet operators being progressively dependent on supplier capabilities and expertise (Nesbitt and Sperling 2001; Laver et al. 2007; Heid et al. 2018; Linscott and Posner 2020). Of note, the bus fleets of public transit agencies in the United States have often served as the testbeds for AFV technologies (CalStart 2015; Li et al. 2015; Czerwinski et al. 2016; Hughes-Cromwick and Dickens 2020). As such, and supported by substantial subsidies and incentives to do so, AFV procurement has increased significantly in the US public transportation industry (Li et al. 2015; Bitzan and Ripplinger 2016; Liu et al. 2019; Hughes-Cromwick and Dickens 2020).

In the United States, there are 1,187 bus systems operating a total of 71,743 buses in the public transit industry (Hughes-Cromwick and Dickens 2020). Regulatory stipulations have required that an increasing proportion of transit agency bus fleets be powered by alternative fuels or propulsion technologies (McKenzie and Durango-Cohen 2012; Li et al. 2015; Czerwinski et al. 2016; Hughes-Cromwick and Dickens 2020). The adoption of AFV technologies by US transit agencies can involve actions that range from retrofitting existing buses, to the replacement of entire fleets with electric buses (Laver et al. 2007; McKenzie and Durango-Cohen 2012; Li et al. 2015; Hughes-Cromwick and Dickens 2020). The AFVs adopted by transit agencies have included dual fuel, compressed natural gas, liquefied natural gas, liquefied petroleum gas, biodiesel, hydrogen, hybrid electric, and battery-electric technologies (McKenzie and Durango-Cohen 2012; CalStart 2015; Li et al. 2015; Czerwinski et al. 2016; Hughes-Cromwick and Dickens 2020). As of 2019, 42% of all buses in the US public transportation industry were diesel powered, down from more than 95% in 1995; and buses powered by natural gas grew from 18% in 2009 to 29% in 2019 (Hughes-Cromwick and Dickens 2020). Of note, electric drive and electric assisted buses have gained significant share in US transit operations (CalStart 2015; Sullivan 2018), where hybrid electric buses increased from one percent to 18% of share between 2005 and 2019 (Hughes-Cromwick and Dickens 2020). Electric buses represents the fastest growing segment of the electric vehicle market, experiencing an annual growth rate of more than 100 percent since 2013 (Heid et al. 2018). Of note, battery electric technologies are projected to dominate the US transit bus market by 2030 (CalStart 2015; Li et al. 2015).

With the increased adoption of AFVs, public transit agencies have encountered challenges related to the vehicle procurement and supplier selection processes (Laver et al. 2007; McKenzie and Durango-Cohen 2012; CalStart 2015; Li et al. 2015; Linscott and Posner 2020). As fleet procurement agents select bus suppliers, considerations of their respective operating environments, budgetary and cost implications, fuel and energy market dynamics, their agencies' experience with specific AFV technologies of interest, and stakeholder and institutional dynamics require that trade-offs be made (Laver et al. 2007; Li et al. 2015; Hsu and Baker 2016; Linscott and Posner 2020). Further, procurement agents must ascertain suppliers' levels of relevant experience, knowledge and capabilities pertaining to specific AFV technologies (Nesbitt and Sperling 2001; Rahm and Coggburn 2006; Laver et al. 2007; CalStart 2015; Czerwinski et al. 2016; Sullivan 2018; Linscott and Posner 2020). The advent of alternative fuel and advanced propulsion technologies presents three challenges for transit operators – higher capital investment levels, increased technological uncertainty, and the need to develop new technology-specific capabilities (USDOE 2002; Heid et al. 2018; Linscott and Posner 2020). Transit operators often move to outsource much of the uncertainty related with AFV adoption, an aspect of which is driven by their increased dependence on supplier capabilities (Heid et al. 2018). The increased adoption of AFVs has required that bus suppliers invest in capabilities and provide value-added services, in addition to delivering vehicles or infrastructure, ultimately becoming key embedded partners with transit operators (Heid et al. 2018). This evolving role of AFV suppliers makes the supplier section task in best value AFV procurement very distinct from that of best value CFV procurement.

Most, if not all, US transit agencies utilize funds provided by the Federal Transit Administration (FTA) of the United States Department of Transportation (USDOT) to purchase buses (Laver et al. 2007; Li et al. 2015; Czerwinski et al. 2016). The FTA supports transit agencies through the provision of financial and technical assistance, and invests in excess of $12 billion annually in public transit systems (FTA 2020a). The FTA provides financial support for vehicle and maintenance facility acquisition through grant programs (Mattson 2012; Li et al. 2015; Bitzan and Ripplinger 2016). For example, in 2020 the FTA announced a $455 billion dollar grant program to fund buses and bus facilities, consistent with similar announcements in the past (FTA 2020b). The FTA is headquartered in Washington, D.C. and manages grants and technical assistance programs through 10 regional offices that service transit agencies across US states and its territories; with each transit agency aligned to a specific FTA regional office. Transit agencies work with their respective FTA regional office regarding funding and technical assistance issues, among which includes activities pertaining to the procurement of vehicles (Macek 2007; Hsu and Baker 2016; FTA 2020a). Often, a condition attached to FTA vehicle procurement funding support, which generally covers 80 to 85% of net vehicle acquisition costs (Li et al. 2015; FTA 2020a), is compliance with a variety of FTA-driven procurement requirements and stipulations (Macek 2007; Hsu and Baker 2016; Czerwinski et al. 2016; Hughes-Cromwick and Dickens 2020). Transit agencies are encouraged, and often stipulated at the federal or state level (Hsu and Baker 2016; APTA 2014; Comito 2016), to utilize the best value procurement process when technical superiority of a good or service being procured is required; for which a price premium is willing to be borne to secure higher product durability while lowering long term costs (Laver et al. 2007; APTA 2013, 2014). While the FTA does not mandate the use of specific non-price selection criteria during the best value procurement process, it has indicated that such criteria can include past performance, quality of personnel, delivery schedule length, technical approach, management plan, and support services (Comito 2016; Czerwinski et al. 2016).

Increasingly, transit agencies have utilized the best value procurement process to acquire buses (Laver et al. 2007; Hsu and Baker 2016; Scott et al. 2018). Customarily driven by the need to evaluate supplier capabilities in bus design, features, and delivery schedules; the use of best value procurement has grown further in prevalence due to the increased technological complexity associated with the spectrum of available AFV technologies, and the need for commensurate supplier capabilities that can service transit agency-specific AFV-related requirements (Laver et al. 2007; Peterson 2007; Hsu and Baker 2016; Czerwinski et al. 2016; Scott et al. 2018; Sullivan 2018). These preferred supplier capabilities are often identified and prioritized by fleet procurement agents during the develop-a-solicitation stage (DAS) of the best value procurement process, and are reflected in the selection criteria utilized to compare and evaluate vehicle suppliers (Macek 2007; APTA 2013; Comito 2016; Hsu and Baker 2016).

The DAS stage of the best value procurement process involves establishing the guidelines and selection criteria on which a specific procurement instance will be based (Macek 2007; APTA 2013; Comito 2016). Key components of the DAS during bus procurement include developing the technical specifications required for the vehicle, identifying the selection criteria to be utilized when comparing bus suppliers, and assigning the relative importance amongst these criteria (APTA 2013; Linscott and Posner 2020). The ability of transit agency procurement agents to effectively detail the criteria by which selection decisions will be made is unequivocally important to vehicle suppliers, transit agencies, and government agencies. A fleet procurement agent's ability to effectively articulate the relative importance between selection criteria facilitates more effective supplier bid proposal preparation, a factor of consequential importance during the best value procurement process, as suppliers endeavor to establish competitive advantages by highlighting those capabilities that position them to be the provider of choice for AFV technology solutions (Laver et al. 2007; Peterson 2007; Czerwinski et al. 2016; APTA 2014; Sullivan 2018). Transit agencies often operate within both capital and operating budget constraints (Laver et al. 2007; Li et al. 2015), and the relative importance assigned across selection criteria is directly linked to financial performance (Hsu and Baker 2016; Sullivan 2018), with particular implications for transit agency asset life cycle and total ownership costs (Laver et al. 2007; McKenzie and Durango-Cohen 2012). Of focal importance in this research, government agencies like the FTA are particularly affected by transit agency supplier selection practices, due to suppliers' influence on transit agency attainment of both environmental and spending efficiency policy objective outcomes (Macek 2007; Li et al. 2015; Hsu and Baker 2016; Sullivan 2018). Suppliers have both direct and indirect influence on vehicle useful life and life cycle costs (Laver et al. 2007; Hsu and Baker 2016; Linscott and Posner 2020).

Life cycle or total ownership costs, refer to the economic costs associated with the capital, operating and maintenance expenses during the useful life of a transit vehicle (Cook et al. 1985; Laver et al. 2007). Life cycle costs include those costs associated with the acquisition, disposal, component replacement, mid-life overhaul, fuel, preventative maintenance, labor, parts, taxes, insurance and accessorial fees, among others, of a specific vehicle (Laver et al. 2007; McKenzie and Durango-Cohen 2012). Actualized vehicle life cycle cost levels not only signify the financial impact associated with vehicle procurement decision making (Cook et al. 1985; McKenzie and Durango-Cohen 2012; Li et al. 2015), but can also be indicative of whether or not those decisions resulted in the realization of the FTA best value procurement policy objective of maximizing economic value through efficient public funds expenditure (Laver et al. 2007; APTA 2013; Hsu and Baker 2016; Comito 2016; Linscott and Posner 2020). As such, both the containment of life cycle costs and the attainment of optimal total costs of ownership by transit agencies are outcomes that are in alignment with the FTA's best value procurement policy objectives (Comito 2016; Hsu and Baker 2016; FTA 2020b).

Prior research has found that there can be increased operational and life cycle costs associated with AFV adoption (Lowell et al. 2007; Moura et al. 2008; Ercan et al. 2015; Ally and Pryor 2016; Tong et al. 2017; Heid et al. 2018). For example, Bitzan and Ripplinger (2016) find that shifting from diesel to biofuels can result in cost increases that range from one to 12 percent, but that increase varies with transit system size. Tong et al. (2017) conducted a study in which life cycle ownership costs, relative to those for diesel propulsion technology, were found to be 1%, 2%, 5% and 18% higher for B20, CNG, B100 and LNG technologies respectively. These increased bus life cycle costs vary by AFV technology type (Laver et al. 2007; McKenzie and Durango-Cohen 2012; Sengupta and Cohan 2017; Sullivan 2018) and occur as a result of the combination of higher costs in the form of bus purchase prices, operation and maintenance costs, and infrastructure costs (Mattson 2012; Bitzan and Ripplinger 2016; Tong et al. 2017; Heid et al. 2018). Alternative fuel vehicles can cost as much as 20% to 40% more than diesel buses (USDOE 2002; Bitzan and Ripplinger 2016; Heid et al. 2018; Quarles et al. 2020). While conventional 40-foot diesel transit buses can cost between $300,000 to approximately $400,000, depending on constituent components and electronics capabilities, the cost for various other AFV types can range from $550,000 to in excess of one million dollars, with an additional cost of $100,000 per battery when procuring battery electric buses (Quarles et al. 2020). Conversely, other studies have found either similar or decreasing operating and lifecycle costs associated with AFV adoption (Clark et al. 2007; Johnson 2010; Lowell 2012; Mattson 2012; McKenzie and Durango-Cohen 2012; Bi et al. 2016; Lajunen and Lipman 2016), suggesting that various factors that are exogenous to the technological core of AFVs can also contribute to actualized life cycle costs. For example, a contributing factor may be higher levels of heterogeneity regarding how transit operators substitute factors of production, for example more skilled technicians versus facility upgrades, and how this substitutability may vary by AFV technology type (Bitzan and Ripplinger 2016; Seki et al. 2016). The existence of increased operational costs associated with AFV adoption by transit agencies, and the associated subsidizing of their purchasing (Li et al. 2015; Bitzan and Ripplinger 2016; Heid et al. 2018), requires that policy makers consider those policies, regulations and stipulations aimed at incentivizing their adoption (Li et al. 2015; Bitzan and Ripplinger 2016); where an understanding of drivers of these costs is fundamentally important input to astute policy formulation, subsidy program development, and outcome expectations; like those associated with FTA best value procurement policy objectives. Therefore, the ability of fleet procurement agents to negotiate with bus suppliers regarding specific selection criteria during the best value process leads to more accuracy and detail being articulated to suppliers, which can lead to longer-term cost containment outcomes, specifically for more technologically advanced vehicles (Laver et al. 2007; Peterson 2007; Linscott and Posner 2020). As such, the adequate prioritization of selection criteria during the best value procurement process can determine those vehicle supplier capabilities that will be acquired and subsequently leveraged and can impact actualized life cycle and total ownership costs (Laver et al. 2007; Hsu and Baker 2016; Scott et al. 2018; Linscott and Posner 2020). Indeed, supplier capabilities in the areas of technology capability, after sales service, warranty programs, parts management, engineering quality and compliance have been found to have effects on procurement and vehicle operations financial and economic outcomes (Laver et al. 2007; McKenzie and Durango-Cohen 2012; Hsu and Baker 2016; Linscott and Posner 2020). Additionally, prior research has found that differences in local economics, operating environments, regulations, and rates of technology diffusion impact the AFV market (Bae et al. 2011; Zhang et al. 2011; Yuksel and Michalek 2015; Tong et al. 2017); each having the potential to impact bus procurement agent decision making.

Prior research has found a proclivity of fleet procurement agents to make lowest-price oriented decisions and not consider the non-price factors that can significantly affect life cycle and total ownership costs when utilizing the best-value procurement process (Peterson 2007; Hsu and Baker 2016; Scott et al. 2018). The FTA expects public transit agency fleet procurement agents to act in alignment with its best value procurement stipulations when it financially supports bus acquisitions, once permitted by their respective states (Hsu and Baker 2016; APTA 2014; Comito 2016). These stipulations include that non-price criteria be duly considered along with the criteria price, and that a price premium be paid when the prioritization of specific non-price criteria can lead to technical superiority that facilitates higher durability and lower life cycle and total ownership costs (Laver et al. 2007; APTA 2013, 2014). Fleet procurement agents, acting in alignment with these stipulations can drive the attainment of FTA policy objective outcomes – increased economic value and spending efficiency of public funds (APTA 2013, 2014; Comito 2016). When fleet procurement agents do not act in alignment with best value stipulations, supplier selection decisions can lead to public spend inefficiencies, actualized through suboptimal, or higher than necessary, vehicle life cycle and ownership costs (Cook et al. 1985; Laver et al. 2007; McKenzie and Durango-Cohen 2012). Therefore, the importance that FPAs assign to selection criteria during the BVPM-driven SSP as procurement contexts switch from CFV or AFV supplier selection can serve to attain or detract from FTA best value procurement policy objectives and, additionally, supplier bid proposal strategies and capabilities development and investment programs. As such, a more nuanced understanding of the factors that have an effect on FPA decision making as they assign importance to selection criteria during the BVPM-driven SSP for buses is of significant importance to both policy and practice.

HYPOTHESES

While normative decision theory guides the development of models that establish optimal decisions that lead to highest expected value outcomes in focal choice scenarios as fully rational agents make decisions, behavioral decision theory (BDT), instead of prescribing an optimal choice, is descriptive in nature and explores de facto decision making by observing drivers of choice in practice (Nissen and Sengupta 2006; Davis-Sramek et al. 2018; Takemura 2020). BDT facilitates the prediction of decision outcomes through developing increased understanding of how independent factors affect rational decision making in practice (Morton and Fasolo 2009). The theory explores and illustrates how factors within task environments can influence decision maker choices (Payne et al. 1993; Swait and Adamowicz 2001). Among these factors include operating environment, task characteristics and individual differences; with BDT contenting that variability within these independent factors actuates differences in the way trade-offs are made as decision makers establish preferences when making choices (Morton and Fasolo 2009; Davis-Sramek et al. 2018; Takemura 2020). As agents make decisions between alternatives made up of attributes in a choice set, some attributes or criteria are perceived as being more important, or are preferred to others, leading to these criteria establishing dominance over other criteria (Montgomery 1983; Bettman et al. 1998). This dominance can be derived from previously existing values that decision makers prescribe to and can include “crystallized values” or “protected values” for which predetermined acceptable levels or trad-offs are already established (Schuman and Presser 1981; Luce et al. 2000). These predetermined levels of importance that are ascribed to specific criteria can be due to decision makers having a priori protected values, where accepting losses or tradeoffs on specific attributes or criteria is non-acceptable due to moral, societal rules, and norms constraining some tradeoffs (Luce et al. 2000). BDT contents that this prescribed importance and preference, that results in some criteria being perceived as more important than others during decision making, can be influenced by a combination of various independent factors (Montgomery 1983; Bettman et al. 1998; Swait and Adamowicz 2001). The BDT literature finds that decision-maker preferences when assigning weights or scores of importance to criteria can vary significantly across decision-making contexts (Fischer 1995; Slovic 1995; Morton and Fasolo 2009).

The task of assigning levels of importance to decision criteria has been studied (Bettman et al. 1998; Morton and Fasolo 2009), and BDT has been utilized as a lens to explain variation in decision outcomes during the task of assigning importance to selection criteria during procurement and supplier selection decision making (Nissen and Sengupta 2006; Davis-Sramek et al. 2018). Work in this literature has found that operating contexts for which there may be less available product information, or in which the purchase of a product is non-routine or less frequent, engender increased complexity during product comparisons (Hoch and Ha 1986; Frisch and Baron 1988); leading to higher variability in decision maker preferences due to the influential effect of other independent factors within these operation contexts. These product related dynamics often lead to the task of developing specifications or identifying and weighting SSCs being more challenging or less definitive (Muthukrishnan 1995; Nissen and Sengupta 2006; Davis-Sramek et al. 2018). In such instances, the procurement of less standardized purchases often does not facilitate the leveraging of comparably relevant experiential knowledge of specification or criteria selection and weighting best practices; often requiring that additional considerations and trade-off assessments be made to complete the task (Nissen and Sengupta 2006: Scott et al. 2018; cite). These additional considerations and trade-off analyses often require domain and experience with specific categories, products, or technologies (West 1996; Wright and Lynch 1995); and varying levels of their presence affect both the way trade-offs between selection criteria are assessed and the eventual weights and importance they are assigned (Ratneshwar et al. 1996). In such instances, procurement agent expectations and preferences regarding which supplier characteristics are most important can vary widely as agents are required to assess and make decisions that account for corporate, technical and stakeholder implications; and various contextual factors can affect this assessment (Ellsberg 1961; Nissen and Sengupta 2006). Further, procurement agent characteristics, like their familiarity with relevant information in a particular context, can also affect the importance they assign to specific criteria; for example, a decision maker’s familiarity with more technically complex information can reduce cognitive load when making tradeoffs between certain selection criteria (Luce et al. 2000; Scott et al. 2018). Indeed, extent procurement literature reveals that organizational- and individual-level factors affect decision making (Ferrel and Gresham 1985; Vardi and Wiener 1996; Karjalainen and Van Raaij 2011).

Utilizing BDT as a theoretical lens to study the task of assigning importance to selection criteria during the BVPM-driven SSP can facilitate a better understanding of the influences on decision making during the process (Nissen and Sengupta 2006; Davis-Sramek et al. 2018; cite); and can also provide a more nuanced understanding by identifying the independent factors that in turn affect these influences (Nissen and Sengupta 2006; Davis-Sramek et al. 2018; cite). We postulate, guided by BDT, that there will be a significant difference in the importance assigned to *Price* and *Non-Price* selection criteria by FPAs during the BVPM-driven SSP, driven by the task context change of switching from CFV to AFV supplier selection. We posit however that the extent of the differences in *Price* and *Non-Price* selection criteria assigned importance between the CFV and AFV task contexts will differ according to the geographic location an FPA's agency's fleet operates in, and when last an FPA previously engaged in the AFV supplier selection process. We suggest that the independent factors of geographic location and task recency influence the extent of the effect of a task context change from CFV to AFV supplier selection. Applying the tenets of BDT, it is plausible to posit that as FPAs engage in the BVPM-driven SSP for buses and complete the task of assigning importance scores to SSCs, the importance they assign to criteria while making trade-off assessments between them can be due to some criteria establishing dominance over others. This dominance, we argue, can be the result of FPAs having already existing "crystallized values" or "protected values" for which predetermined acceptable levels or trad-offs for certain selection criteria are already established (Schuman and Presser 1981; Luce et al. 2000) as procurement contexts switch from CFV to AFV supplier selection. We posit that FPA geographic location and the recency of when an FPA last completed the AFV supplier selection process can significantly influence FPA values and perceptions, and this effect manifests in variation in the SCI they assign to SSCs. Inferring based on BDT, we extend that the assigned SCI for the same criterion can vary among FPAs due to its relative salience across geographic locations, and the potential changes in its relevance over time. Therefore, consistent with BDT, we posit that a procurement task context change, operating environment context, and individual characteristics will have an effect on procurement agent preferences, and predict variation in these preferences, evidenced by variation in task decision outcomes during the BVPM-driven SSP for buses.

The Effect of Procurement Task Context on SCI

Prior research has found that buying behavior is context dependent (Bettman et al. 1998; Dhar et al. 2004; Friend and Malshe 2016). When buying contexts are characterized by the availability of different choices, the decision-making process becomes more complicated as buyers then compare focal features with those of comparative alternatives, all within specific contexts that influence their preferences when making these comparisons (Lynch et al. 1991; Bettman et al. 1998; Lee et al. 2017). In buying contexts characterized by advancing technologies, technological uncertainty can be a factor that influences buyer preferences, it arises due to increased levels of product technological complexity, technological innovation, or rapid rates of technological change (Celly et al. 1999; Tatikonda and Rosenthal 2000; Song and Montoya-Weiss 2001). Indeed, these increased levels of technological uncertainty have been found to impact managerial decision making, as managers have less knowledge regarding the newer focal technologies their work is related to (Tatikonda and Rosenthal 2000; Song and Montoya-Weiss 2001; Ragatz et al. 2002; Talke et al. 2011; Jean et al. 2012).

As buyers switch to contexts involving the purchase of more technologically advanced products, they make trade-offs across alternatives by considering potential uncertain future states in their respective environments, considerations than can result in them making transitions from preferences for attributes that deliver purely functional benefits to preferences for solutions-oriented attributes (Dhar et al. 2004; Worm et al. 2017). A transition to more technologically advanced and complex products regulates the expectations of buying managers regarding supplier skills and capabilities (Dhar et al. 2004; Friend and Malshe 2016), as such that suppliers' value propositions evolve due to price-based factors having diminished influence on buyer decision making (Worm et al. 2017). As such, suppliers of increasingly technologically complex products must leverage unique resources and capabilities to exhibit their ability to provide the technological solutions needed by buying organizations, taking into consideration both pre- and post-sale service offerings in an effort to enhance the probability of them securing contracts with buyers (Dhar et al. 2004; Worm et al. 2017). Therefore, as products become more technologically advanced, and requisite supplier capabilities must be commensurate with those advancements, the task of which SSCs to prioritize by assigning relative importance to them is of critical importance.

Literature focused on the task of assigning importance to SSCs indicates the need to do so for both quantitative and qualitative criteria (Hoetker 2005; Huang and Keskar 2007; Qian 2014; Babic and Peric 2014; Wetzstein et al. 2016). Further, the relative importance assigned to any of these criterion has been found to change as societal, technological, business, and product driven dynamics change between buying contexts (Kannan and Tan 2002; Cheraghi et al. 2004; Ross et al. 2006; Wetzstein et al. 2016). The magnitude of importance assigned to the same selection criterion has been found to change between buying contexts when buying contexts differ by routine to non-routine purchases (Lehmann and O'Shaughnessy 1982), by direct versus indirect materials (American Machinery Manufacturers Association 1985), by the sourcing method utilized (Swift 1995), and by the stage in the procurement process (Scott et al. 2018). Differences in any selection criterion's relative importance between buying contexts is attributable to that criterion being perceived as more relevant, or providing more utility, in one context versus another (Lehmann and O'Shaughnessy 1974; Gustafsson and Johnson 2004). Of note, environmental sustainability has been identified as a context that significantly impacts the supplier selection process (Bai and Sarkis 2010; Wetzstein et al. 2016), having particular impact on the development of new selection criteria (Handfield et al. 2002; Humphreys et al. 2006; Wetzstein et al. 2016; Bruno et al. 2018).

The advent of environmental sustainability as a central tenet of organizational operations has led firms to develop new SSCs (Humphreys et al. 2006; Lee et al. 2012; Dobos and Vorosmarty 2014), while others include and continue to utilize traditional selection criteria in new environment sustainability-based contexts (Handfield et al. 2002; Humphreys et al. 2006; Jabbour and Jabbour 2009; Wetzstein et al. 2016). The consideration of environmental-based selection criteria by procurement agents can vary by firm characteristics, industry type, and geography (Ross et al. 2006; Jabbour and Jabbour 2009; Goebel et al. 2012; Lee et al. 2012; Reuter et al. 2012). Of note, in environmental sustainability-based supplier selection contexts, the prioritization and relative importance assigned to selection criteria has been found to affect buying organizations' environmental and economic performance (Hollos et al. 2012; Wong et al. 2012; Yook et al. 2018). Further, suppliers deemed to possess those capabilities that can be leveraged to enhance the environmental sustainability-based performance of buying organizations have an increased likelihood of selection (Goebel et al. 2012; Hollos et al. 2012; Wong et al. 2012; Yook et al. 2018). Importantly, prior studies have found that in buying contexts characterized by environment sustainability-based supplier selection, price is often not the criterion assigned most importance, with its relative importance to non-price criterion decreasing as other supplier capabilities take precedence (Humphreys et al. 2006; Jabbour and Jabbour 2009; Wetzstein et al. 2016; Bruno et al. 2018). We therefore posit that while price remains of central importance to fleet procurement agents (Peterson 2007; Scott et al. 2018; Sullivan et al. 2018), and alternative fuel buses cost more than conventional fuel buses (Li et al. 2015; Czerwinski et al. 2016); as agents transition from CFV to AFV best value bus procurement, they will be willing to pay a premium to secure and have access to those attributes and supplier capabilities that serve to reduce the uncertainty associated with AFV technologies (Laver et al. 2007; APTA 2013; Sierzchula 2014); capabilities that can be leveraged to facilitate optimal levels of mid-life overhaul, life cycle and total ownership costs (Laver et al. 2007; APTA 2013; Hsu and Baker 2016; Czerwinski et al. 2016). As such, we hypothesize that:

H1: As fleet procurement agents switch from a CFV to an AFV procurement context, the change in the level of importance assigned to price versus non-price selection criteria is inverse, such that price is assigned less importance in the AFV procurement context, *whereas non-price selection criteria are assigned more importance in the AFV procurement context.*

The Effect of Geographic Dispersion on SCI

Distance and proximity between people has long been a factor of interest in research; and in business research, the geographic location in which business activities occur has been found to have organizational and market impacts (O'Leary and Cummings 2007; Gao et al. 2008). Geographic dispersion refers to the degree to which firms in a specific industry are densely or widely geographically distributed (Dess and Beard 1984), or can refer to the dispersion among members within a network (Bode and Wagner 2015). Geographic dispersion has also been represented as the distance between the subdivisions and the headquarters of a corporation, with commensurate managerial information and objectives found to change with proximity (Landier et al. 2009). Geographic dispersion has also been found to affect decision making (Gao et al. 2008; Landier et al. 2009), due to distance being a proxy for information asymmetry (Coval and Moskowitz 1999; Grinblatt and Keloharju 2001; Garmaise and Moskowitz 2004), and as such, impacts the means and nature of information acquisition and flows (Petersen and Rajan 2002; Landier et al. 2009). Geographically dispersed decision makers are imbedded in different external contexts and have less shared contextual knowledge; having more knowledge of their own operating context, referred to as "situated knowledge" (Rennecker 2001; Sole and Edmondson 2002; Gluesing et al. 2003). Prior research finds that in instances where the headquarters of a firm seeks alignment of subsidiaries to operations objectives, increased geographic dispersion requires additional expenditure of resources to attain desirable outcomes (Gligor 2017).

Geographic dispersion impacts both strategic and tactical purchasing management practices; having a significant effect on the efficacy of purchasing practices, leading to impacts on operating performance (Wiengarten and Ambrose 2017). Of note, the distribution of firms belonging to a network has been found to adversely affect practice and decision making related to innovation diffusion and adoption (Gibson and Gibbs 2006). Ecoinnovations, products and processes that contribute to sustainability through ecological improvements (Diaz-Garcia et al. 2015), are not self-enforcing in their diffusion but, due to required development time and discontinuities, may diffuse more slowly (Zhang et al. 2011). Over time, innovative technologies displace existing technologies and reshapes markets (Zhang et al. 2011; Christensen 2013), often requiring regulatory intervention to facilitate and monitor diffusion (Rennings 2000; Bae et al. 2011; Zhang et al. 2011). However, prior research findings have indicated that due to local environments, market characteristics vary; inducing significant variation in the spatial diffusion of technology (Skitti 2020). Indeed, research on innovations in alternative fuels has indicated that differences in fleet composition mix can be attributed to geographical differences (Andre et al. 2018), due in measure to regulations and incentives that are disparate across US states, directly impacting the spatial distribution of alternative fuel infrastructure, and hence AFV markets (Li et al. 2015; Liu et al. 2019).

Decision making by transit agency fleet procurement agents can be affected by their respective geographic locations for several reasons. Environmental regulation at the state level varies by geographic location, and differences in stringency can lead to AFV stipulations that range from those requiring the retrofitting of older buses, to those requiring the electrification of bus fleets (Laver et al. 2007; Li et al. 2015; Hsu and Baker 2016; Liu et al. 2019). The U.S. Department of Energy's Alternative Fuels Data Center identifies a range in the number of regulatory incentives and stipulations by state, with California having 148, the most, and Alaska having five, the least; with each state, or groups of adjacent states, incentivizing the adoption of different types of AFV technologies (USDOE 2021).

Variability in access to alternative fuel infrastructure, for example proximity to a natural gas mainline (USDOE 2002), and the related dynamic regarding alternative fuel pricing can also vary by geographic location. Depending on the selected fuel or propulsion technology, fuel availability and costs vary, requiring that transit agencies plan and partner with local fuel providers and utility companies that are geographic-specific (USDOE 2002; CalStart 2015; Linscott and Posner 2020). There is a wide disparity in the number of alternative fuel stations available by state, with California, Texas and New York having the most, in that order; and North Dakota, Delaware and Alaska having the least; not only in station count, but also in the variety of alternative fuel types and technologies available (USDOE 2002; Laver et al. 2007; USDOE 2021). Related, geographically indexed alternative fuel cost variability is driven by differences in regional, state, and local regulatory stipulations and fuel supply markets; which are both often related (CalStart 2015; Fuels Institute 2017; USDOE 2020). For instance, biodiesel prices vary significantly by region (USDOE 2002) and, both electricity rates and the emissions associated with grid electricity vary from region to region within the United States where, for example, fast-charging rates in California can range from $0.14 to $0.44 per kilowatt hour versus the same in Pittsburgh, Pennsylvania being $0.055 per kilowatt hour, due to location specific demand charges and dynamic pricing (Tong et al. 2017).

Vehicle fuel economy and tailpipe GHG emissions vary by region as a result of the influences of speed and weight limits, road grade, and weather (Yuksel and Michalek 2015; Tong et al. 2017), with prior research finding significant variations in fuel economy attributable to weather extremes (Yuksel and Michalek 2015). Colder temperatures have been observed to adversely affect the mechanical operations of certain types of alternative fuels e.g. biodiesel (Mattson 2012; Yuksel and Michalek 2015). Of note, service conditions, climate, and weather; which differ by geographic location; influence bus supplier selection decision making; as they bear significant implications for life cycle and total ownership costs (Laver et al. 2007; Linscott and Posner 2020). Consequently, the availability of maintenance support for newer AFV technologies can also vary geographically, with some suppliers having better capabilities within specific localities; leading to a preference for particular suppliers and their specific capabilities in future procurement instances; resulting in agencies training their staff on specific suppliers' equipment (Laver et al. 2007; Czerwinski et al. 2016; Sullivan 2018; Linscott and Posner 2020). Further, the level and skill of technicians varies regionally, influenced by the location of trade or technical schools, and whether or not their respective proximities facilitate transit operator access to required expertise (USDOE 2002).

Given the aforementioned, we posit that the direct and combined effects of the aforementioned geographically influenced or derived factors will not only likely dictate the type of AFV procured, but also the weighting that FPAs assign to selection criteria during the best value procurement process, as they consider these geographic-specific factors' impact on life cycle and total ownership costs. As such, we hypothesize that:

H2: As fleet procurement agents switch from a CFV to an AFV procurement context, the geographic location of their fleet operations has an effect on the importance assigned to both price and non-price selection criteria

The Combined Effect of Task Recency and Geographic Dispersion on SCI

Recency effects occur when more recent information is given more influential weight during decision making, due to it being better remembered (Laham and Forgas 2007). Recency effects have impact on decision making, as more recent events have more influence than those further in the past (Chiou et al. 2008; Lambert and Yanson 2017). An order of presentation effect, its opposite is referred as the primary effect, where earlier information has an inordinate influence on decision making (Jones and Sieck 2003; Laham and Forgas 2007). Recency effects represent a functional adaptation to elements in the decision making environment, where individuals utilize knowledge about a prior stimulus to address a current one (Jones and Sieck 2003; Jones et al. 2006). Decisional recency is the effect which occurs when decision makers weigh recent information more heavily based on recently reinforced responses or actions (Jones et al. 2006; Lambert and Yanson 2017). The perception of current stimuli has been found to also be influenced by relationships to recent stimuli (Jones and Sieck 2003; Jones et al. 2006). The magnitude assigned to a specific stimulus depends on its relationship to recently encountered stimuli (Jesteadt et al. 1977; Jones et al. 2006). Further, the strength of the recency effect depends on the similarity between the former and present stimuli (Jones et al. 2006). The manner in which tasks are performed has been found to be affected by recency effects, where the structure and presentation of a task induces a reliance on more recent exposure to task-related stimuli (Laham and Forgas 2007; Lee et al. 2017). The outcome of recency effects in task environments is dependent on the length of time that elapses until a specific task is repeated; where the longer the time, the weaker the recency effect, as less recent details are disproportionately relied on (Laham and Forgas 2007). Recency effects also impact task switching success, where success depends on decision maker capacity to re-access information on a previous task in a rapid and accurate manner (Baddeley and Hitch 1993). Of note, technological advancement has led to significant increases in the volumes of information and specialization associated with task decision making, compounding the impact of the recency effect, as decision makers must engage in more complex associative memory processes (Lee et al. 2017). Of note, recency effects have been found to impact purchasing and influence buyer preferences; where buyer responses are dependent on how recently they made a purchase (Chiou et al. 2008; Nelsin et al. 2013; Lambert and Yanson 2017).

Given the aforementioned, it is logical to posit that the recency effect can bear significant implications in the best value bus procurement context, particularly as FPAs switch from CFV procurement to the more technologically advanced context of AFV procurement. The frequency with which transit operators procure buses varies by transit agency, and that variation is driven by various factors. First, FTA regulations on the useful life of transit buses stipulate when an FTA-funded bus can be replaced, dependent on years or mileage thresholds; with the year-based useful life requirements ranging from five to 12 years according to bus type (USDOE 2002; Macek 2007; Laver et al. 2007; Hsu and Baker 2016; Seki et al. 2016). Second, to meet bus supplier minimum order quantity requirements, transit agencies must often wait until they meet these order requirements before engaging in the procurement process (Hsu and Baker 2016). Of note, when these minimum order requirements are met, both states and transit agencies often enter into contractual agreements with vehicle suppliers that stipulate their respective commitments to bus suppliers for multi-year periods, with five years tending to be the average and most often stipulated time frame (Macek 2007; Hsu and Baker 2016). Third, the need of transit operators to often engage in state-wide purchasing processes or to “piggy-back” on another transit agency’s bus procurement schedule, in order to obtain advantageous pricing or leverage the process or procedural expertise of other agencies, results in the procurement of buses being a staggered occurrence at the transit agency level (Laver et al. 2007; Peterson 2007; Moura et al. 2008; Li et al. 2015; Hsu and Baker 2016). Fourth, longer life spans of diesel engines have resulted in the staggering of bus replacement plans, and the ensuing adoption of AFVs by transit agencies (Laver et al. 2007; Sullivan 2018); a dynamic that drives an increased need for broader technical expertise and knowledge on life cycle and total ownership cost ramifications by AFV type within the procurement function, as fleets increasingly become comprised of multiple types of AFVs (USDOE 2002; Laver et al. 2007; McKenzie and Durango-Cohen 2012; Sullivan 2018). In response to the aforementioned dynamic, FPAs exhibit a preference for dispersing AFV procurement instances in a manner that facilitates spreading maintenance demand over longer periods of time, and aids in workforce planning and training, especially when considering the potential constraining effects of mid-life overhauls for purchased buses (Laver et al. 2007; Czerwinski et al. 2016; Linscott and Posner 2020).

The resulting multi-year impacts of the aforementioned factors on the variability in the frequency of bus procurement instances at the transit agency-level (Laver et al. 2007; Peterson 2007; Li et al. 2015; Hsu and Baker 2016; Czerwinski et al. 2016), along with the rapid advancement of AFV technologies within those multi-year periods (Seki et al. 2016; Heid et al. 2018; Linscott and Posner 2020), suggests that the specific AFV technology type available to FPAs when they do engage in the best value procurement process can vary significantly between those periods of time. As such, there is a likelihood that observed variability in the magnitude of importance that FPAs assign to SSCs can vary in some measure due to the type of AFV technology they most recently procured, with the type of technology procured being determined to some extent by the time period in which the last procurement instance occurred. The aforementioned will be due to the higher likelihood of there being significantly different AFV technological core compositions of buses the longer the elapsed time between the period of an FPAs' most recent AFV supplier selection experience and the current instance; where AFV technological cores may have, or have not, advanced significantly, depending on the length of time between procurement instances (Seki et al. 2016; Heid et al. 2018; Linscott and Posner 2020). Further, and central to this study's thesis, is that the factors that drive geographic location-specific dynamics for bus procurement by transit operators, also affect elements of task recency from two perspectives. First, given regulations and local economy dynamics, the prevalence of the adoption of specific types of AFV technology varies by geographic region and will have a direct effect on the AFV type most recently purchased by FPAs. Second, localized factors that influence the cadence and timing of pooled or "piggy" back procurements will affect the time that elapses between bus procurements and thus influence the amount of technological advancement, and hence level of technological uncertainty, FPAs encounter when re-engaging in the AFV supplier selection process.

When the aforementioned is considered along with the disparity in stipulations and incentives for specific AFV technologies, fuel infrastructure availability, fuel prices, service operating conditions, and commensurate maintenance expertise, that all vary by geographic location; the type of AFV technology most recently procured by a fleet procurement agent, and the frequency with which they do engage in AFV procurement, can vary based on their geographic dispersion. We posit therefore that FPA geographic dispersion interacts with FPA AFV supplier selection task recency to have a combined effect on the magnitude of importance FPAs assign to selection criteria during the best value bus procurement process, and as such we hypothesize that:

> *H3: As fleet procurement agents switch from a CFV to an AFV procurement context, prior AFV supplier selection task recency interacts with the geographic location of their fleet operations to have a combined interaction effect on the importance assigned to both price and non-price selection criteria*

The following section discusses the methodology and approach we utilize in testing the extended hypotheses.

METHODS

To test the proposed hypotheses, an observational study was conducted. A survey instrument was designed to include a representation of the task of assigning weighting to selection criteria during the DAS stage of the best value procurement process for both CFV and AFV suppliers was developed to capture the behavioral intention of FPAs, as well as capture information regarding the factors and covariates utilized in the model. The selection criteria weighting task section of the survey was followed by questions on organizational and individual characteristics. The survey was distributed electronically to study subjects, FPAs. Participants were presented with a task in which they had to assign the magnitude of importance to the SSCs *After Sales Support (A)*, *Delivery (D)*, *Integrity (I)*, *Price (P)*, *Performance History (PH)*, *Procedural Compliance (PC)*, *Quality (Q)*, *Reliability (R)*, *Technical Capability (T)*, and *Warranty and Claims Policy (W)* between a CFV versus an AFV procurement context. Participants rated each criterion across the two procurement contexts on a 10-point Likert-type scale. All participants were presented with the identical supplier selection task, with no manufacturer, supplier, or vehicle brand identifiers present (Davis-Sramek et al. 2018). Cognizant of the potential for study participants to be influenced by institutional and societal expectations regarding their perceptions of environmental sustainability procurement, a socially sensitive topic, it was reiterated to participants to be objective in responding, and that all responses will be reviewed only by the research team; this was done in order to minimize any potential social desirability bias (Fischer 1993; Davis-Sramek et al. 2018).

The 10 selection criteria utilized in the study were selected by a fleet procurement expert panel that comprised a senior procurement official at the U.S. DOT's FTA, three public transit agency executives, two management consultants that specialize in fleet procurement, and an academic whose expertise is in public transportation fleet operations. Each expert was provided a list of the 31 supplier selection criterion identified by Cheraghi et al. (2004) and rated each criterion on a 10-point Likert-type scale (1 = not at all important; 10 = very important), based on their salience to best value bus procurement in the US public transportation industry. The 10 highest rated criteria were then utilized in this research.

A finalized version of the survey was pre-tested with both the aforementioned expert panel and a group of transit procurement professionals drawn from the American Public Transportation Association's Procurement and Materials Management Committee (PMCC), none of whom where participants in the subsequently conducted main study. Interviews were conducted with participants during the pre-test, and all comments and criticisms of the survey instrument were considered, and appropriate adaptions made (Liu and Lyons 2011).

Data Collection

The population of interest for this research was fleet procurement agents at US public transit agencies. As such, the sample frame was comprised of a random sampling of FPAs at transit agencies (NAICS codes 4851 and 4852) that receive capital funding support from the USDOT's FTA to purchase buses. The sampling process utilized in this study comprised both single-stage and multi-stage sampling (Fink and Kosecoff 1985; Babbie 1990). All executives on a list of FTA-funded transit agencies, provided by the FTA, were contacted, and provided an electronic link to the survey. Recipients of the notice were asked to distribute the survey link to the personnel responsible for fleet procurement at their agency. Simultaneously, the American Public Transportation Association's (APTA) Procurement and Materials Management Committee (PMMC), the Community Transportation Association of America (CTAA), and the National Transit Institute (NTI) each provided the contact information for executives at FTA supported organizations within their respective memberships, with each identified executive asked to distribute the electronic link to the personnel responsible for fleet procurement at their agency.

We received responses from 327 FPAs after contacting 1, 000 transit agencies, resulting in a 32.7% response rate for the study. Of note, each participant in the study represented either the highest-level fleet procurement decision maker within their organization, or their most senior direct report (Pagell and Gobeli 2009). Forty-six U.S. states were represented in the research sample, having fleet sizes ranging from one to 6,354 vehicles. Of note, the representativeness of the final sample was determined by conducting an independent samples t-test to ascertain if differences in service operations characteristics existed between participating and non-participating transit agencies (Liu and Lyons 2011). Comparing both *service area* and *service area population* between the two groups of agencies, utilizing data from the FTA's NTD Agency Information database (FTA 2021), no statistically significant differences were found at α = .05. Table 1. provides a display of the characteristics of the study sample.

Table 1. Study Sample Characteristics

Sample Characteristics	
Fleet Procurement Agents(FPAs)	***n = 327***
AFV Supplier Selection Task Recency (TR)	
Within the past 5 years	172
Beyond the past 5 years	155
Geographic Dispersion (GD)	
FTA Region 1	21
FTA Region 2	26
FTA Region 3	33
FTA Region 4	64
FTA Region 5	60
FTA Region 6	31
FTA Region 7	27
FTA Region 8	14
FTA Region 9	26
FTA Region 10	25

Measures

In this study, the unit of analysis is the importance score, or rating, that each FPA decides to assign to SSCs. We posit that three factors have an effect on that decision – a switch in procurement context from CFV to AFV procurement, the geographic dispersion of FPAs, and geographic dispersion's interaction with the recency in which an FPA previously completed the AFV supplier selection task. We also include the fleet size of an FPA's transit agency as a control factor.

<u>Dependent Variable</u>

The dependent variable in this study is the magnitude of importance assigned to a specific supplier selection criterion (Ellram 1990; Pearson and Ellram 1995; Kannan and Tan 2002), referred to in this study as selection criteria importance (SCI). SCI, also referred to as supplier attribute importance (Verma and Pullman 1998; Scott et al. 2018), has been studied across extant literature, and standard operating definitions and measurements for these criteria have been established and extensively utilized (Dickson 1966; Ellram 1990; Pearson and Ellram 1995; Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004; Wetzstein et al. 2016; Scott et al. 2018). As in prior research, a direct scale rating approach (Gustafsson and Johnson 2004) was utilized to measure the SCI for each of the selection criterion utilized in this study (Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004). In this research, SCI was measured utilizing a 10-point Likert-type scale (1 = not at all important; 10 = very important) for each of the utilized SSCs. Scale validation procedures were employed to assess both reliability and validity. Reliability was substantiated with a generated Cronbach's alpha of $\alpha = 0.857$ (Nunnally and Bernstein 1994). Validity was substantiated by conducting principal components analysis (PCA) with varimax rotation, and results indicated that utilized selection criteria loaded to a single factor (Carter and Stevens 2007). However, based on the need to gain nuanced insights into selection criteria-specific implications for best value procurement, as done in prior studies (Dickson 1966; Lehmann and O'Shaughnessy 1974; Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004; Scott et al. 2018), the choice was made to analyze each selection criterion separately, to eradicate the potential for overgeneralization, misinterpretation and arbitrary conclusions based on findings (Lehmann and O'Shaughnessy 1974). Table 2. provides the definitions of the SSCs utilized in this research.

Independent Factors

Measures for the independent factors used in testing the hypotheses were developed through participant responses to questions posed after completion of the task, and for the control factor, secondary data sources were utilized. Procurement context was measured as a binary variable, with the CFV procurement context in the task exercise coded = 0 and the AFV context coded = 1, during analysis. Prior studies have utilized several measures for geographic dispersion (O'Leary and Cummings 2007; Wiengarten and Ambrose 2017; Chae et al. 2019). Among these studies, previously established geographic areas and categories have been utilized to capture geographic dispersion (Gao et al. 2008; Wiengarten and Ambrose 2017); and have included the use of the Bureau of Economic Analysis' nine census regions in the United States to determine the number of geographic regions in which a firm has operations by Gao et al. (2008), and the use of regional country categorization by the United Nations Statistics Division to determine if buyers and suppliers belonged to the same region or not by Wiengarten and Ambrose (2017). Consistent with the aforementioned studies, we measure FPA geographic dispersion (GD) by utilizing the FTA's existing regional organizational structure, where transit agencies are categorized as belonging to any of the10 geographically distinct FTA regions across the United States (Comito 2016; FTA 2020a), each dispersed from the FTA's headquarters office in Washington, D.C.; with each FPA in the sample assigned a number between 1 to 10, corresponding the FTA region to which its agency belongs.

Prior studies have utilized several measures of recency to capture the effects of time elapsing between specific defined periods of interest (Baddeley and Hitch 1993; Guiral-Contreras et al. 2007; Garnefeld and Steinhoff 2013; Plonsky et al. 2015; Lambert and Yanson 2017). Several studies have measured recency effects with respect to the completion of tasks, task switching and the task of purchasing (Sumner and Ahmed 2006; Ravindran and Iyer 2007; Nelsin et al. 2013). Amongst these studies, recency has been measured by having study participants identify whether their most recent experience was within the last 12 months; not within the last 12 months but sometime in the past; or never (Lambert and Yanson 2017).

Table 2. Supplier Selection Criteria Definitions

Supplier Selection Criteria	**Definition**
After Sales Support *(A)*	A supplier's provision of additional services after the sale of a vehicle e.g., technology support, data-management, technical consulting services
Delivery *(D)*	A supplier's ability to meet a preferred date of vehicle availability
Integrity *(I)*	A supplier's adherence to ethical principles e.g. honesty
Price *(P)*	A supplier's offering price for a vehicle
Performance History *(PH)*	A supplier's previous track record in areas important to the buyer
Procedural Compliance *(PC)*	A supplier's adherence to stipulated regulatory and buyer procedural requirements
Quality *(Q)*	A supplier's ability to reduce variation in preferred vehicle standards of design and performance
Reliability *(R)*	A supplier's dependability to meet order requirements
Technical Capability *(T)*	A supplier's understanding and willingness to share expertise concerning vehicle engineering, technology, design, and operation
Warranty and Claims Policy *(W)*	A supplier's guarantee, without charge, that any vehicle or vehicle component not meeting predetermined performance standards will be replaced or repaired

Recency has also been captured by study participants identifying the most recent month *t* in which they made their most recent purchase (Nelsin et al. 2013). Consistent with the aforementioned studies, in this study AFV supplier selection task recency (TR) is measured by participants identifying when they most recently completed the AFV supplier selection task; within the past five years, coded = 1, or beyond the past five years, coded = 0. The period of five years was chosen given various salient factors. Considering the multi-year lead times associated with bus procurements, the average length of commitment contracts being five years, the staggered impact to procurement instances due to pooled or "piggy back" bus procurement, and the intermittent rate at which AFV technologies are introduced to the market; the five year period was deemed as a realistic measure of AFV task recency (Laver et al. 2007; Macek 2007; Li et al. 2015; Hsu and Baker 2016). This approach was also validated through interviews with industry experts and practitioners during the study.

Covariates

We include four covariates in our analysis, given their potential to have an effect on FPA SCI assignment behavioral intentions. To control for the effect of agency fleet size, the number of directly operated vehicles in each agency's fleet, fleet size (FS); and the annual vehicle acquisition expenditure in the most recently completed fiscal year, fleet acquisition spend (FAS), were included as covariates in the analysis. Theoretically, firm size has been found to affect supply chain decision making in organizations, influences green purchasing practices; and is typically measured in terms of assets, sales, or number of employees (Vickery et al. 1999; Hofer et al. 2012; Touboulic et al. 2014; Yook et al. 2019). In the empirical context of vehicle fleet management, fleet size had been found to influence managerial decision making and purchasing task behavior (Macek 2007; Besiou et al. 2014; Haller et al. 2017; Scott and Nyaga 2019). We also control for fleet expenditure levels, as a proxy of size, by using FAS as a covariate, as organizational vehicle expenditure levels have been found to affect fleet practice decision making and task behavior (Macek 2007; Besiou et al. 2014; Heid et al. 2017; Islam and Lownes 2019)

The number of years of vehicle procurement experience of FPAs (EXP); and the organization type that FPAs were employed at (OGT) were also included as covariates. Theoretically, experience has been found to affect task and behavioral responses (Bode et al. 2011; Flynn et al. 2016), and procurement experience has been observed to influence managerial decision making (Stanczyk et al. 2015; Kaufmann et al. 2017); including green procurement task behavior (Meehan and Bryde 2011; Bratt et al. 2013; Grandia 2016). In the empirical context of vehicle fleet management, vehicle procurement experience has been shown to influence managerial ability to link cues in specific buying contexts to familiarities with the organizational strategic, compliance, life cycle cost, and post-acquisition effects associated with AFV procurement (Nesbitt and Sperling 2001; Hidalgo and De Vries 2006; Laver et al. 2007). Organization type has been shown to influence employee information processing behavior, perception, prioritization, and preferences during selection-based tasks (Koufteros et al. 2007; Ashenbaum et al. 2012; Tate and Ellram 2012). Structure due to organization type has been found to influence the effect of procurement decision makers (Johnson et al. 2002; Johnson et al. 2006; Johnson and Leenders 2008; Ashenbaum et al. 2012; Tate and Ellram 2012). In the empirical context of vehicle fleet management, various studies have noted the influence of organizational type and governance structure on fleet management and procurement decision making and task behavior (Laver et al. 2007; Macek 2007; Laughlin and Burnham USDOE 2014; Heid et al. 2017); particularly between transit authorities and the other types of organizations that deliver transportation services issues (Federal Transit Administration 2018; American Public Transportation Association 2018). The data for FS; EXP and OT were collected through the survey instrument utilized in the study; while the data for FAS was collected, as reported, in the FTA's NTD's Agency Information Database (FTA 2021). The values for FS and OT were also validated by drawing them from the FTA's NTD's Agency Information Database as well.

RESULTS

Prior to running the analysis to test the proposed hypotheses, bivariate correlation analysis was conducted for all variables and factors utilized in the study. Table 3. shows the results, with both descriptive statistics and inter-correlations included. To address non-response bias (Armstrong and Overton 1977; Lambert and Harrington 1990), an independent samples t-test was performed to test for differences in responses between early and late respondents; with results showing no statistically significant difference between the two groups (Liu and Lyons 2011; Rajesh et al. 2011). To address common method variance (Podsakoff et al. 2003; Podsakoff and Organ 1986), Harman's single factor test was conducted utilizing all factors included in the study. The first factor extracted in the principal components analysis accounted for only 31.9% of variance, indicating the non-existence of common method bias (Liu and Lyons 2011).

Hypotheses 1. was tested utilizing paired-sample t-tests to compare the scores assigned to SSCs between the two procurement contexts. There was a significant difference in the scores for *Quality* (SD = 1.24, t = -3.69, p < .001), *Price* (SD = 2.59, t = 3.67, p < .001), *Technical*

Capability (SD = 1.55, t = -8.29, p < .001), *After Sales Support* (SD = 1.36, t = -7.09, p < .001) and *Performance History* (SD = 1.24, t = -1.99, p = .047). The differences between scores were insignificant for *Delivery* (SD = .94, t = .69, p = .485), *Warranty and Claims Policy* (SD = 1.21, t = -1.59, p = .113), *Procedural Compliance* (SD = .98, t = -.28, p = .779), *Reliability* (SD = 1.01, t = -.49, p = .624) and *Integrity* (SD = .99, t = -.50, p = .615). Based on these findings, it can be surmised that the procurement context switch from CFV to AFV supplier selection does indeed have a significant effect of the magnitude of the importance FPAs assign to a certain SSC between those contexts. More definitively, results indicate that *Quality*, *Technical Capability*, *After Sales Support* and *Performance History* are each assigned higher scores of importance in the AFV context while, notably, *Price* is assigned a lower score in the same context. It should be noted that the aforementioned results were for modifications that were statistically significant; when observing all non-price criteria, with the exception of *Delivery*, each was assigned a higher score in the AFV context. Table 4. shows the mean scores for each selection criteria between the CFV and AFV procurement contexts.

While paired-sample t-test results do indeed support a statistically significant difference in assigned importance between AFV and CFV procurement contexts for the selection criteria *Quality*, *Price*, *Technical Capability*, *After Sales Support* and *Performance History*, a fundamental premise of the study is that the magnitude of those differences are driven to some extent by geographical and task recency differences between FPAs; that is, we posit that while the contingent context of AFV procurement will have a direct effect on SCI when assessed in isolation, we contend that that effect is itself contingent on FPA geographic dispersion and AFV task recency. To test this, a three-way repeated-measures MANCOVA was employed, utilizing each of the 10 selection criteria serving as dependent variables, and procurement context (AFV), FPA geographic dispersion (GD), and AFV supplier selection task recency (TR) serving as independent factors; with FPA organization fleet size (FS), FPA years of industry experience (EX), FPA organization type (OT), and FPA organization annual vehicle spend (AS) serving as a covariates in the model. Repeated measures MANCOVA was utilized to ensure i) that any correlation in the scores assigned to any single selection criterion between contexts is accounted for, ii) that any high levels of correlation between sets of the 10 selection criteria utilized as dependent variables are accounted for, and iii) that the effects of organization fleet size are controlled for. Table 5. shows the results for the repeated measures MANCOVA analysis. Following is a discussion on the interpretation of the results in Table 5.

Prior to interpreting results, Box's test for equivalence of covariance matrices (Box's M) was conducted and results were insignificant (Box' M = 3268, F = , p < .01), therefore Pillai's Trace was utilized in interpreting results, as opposed to Wilk's Lambda (Hair et al. 1998; Mertler and Vannatta 2010). Next, multivariate results were assessed to determine if the factors AFV, GD, and TR exhibited main effects on the combined dependent variable of SCI. Both GD (F = 1.40, p < .01, $\eta2$ = .045) and TR (F = 2.96, p < .01, $\eta2$ = .092) exhibited significant main effects on combined SCI, while, notably and in line with our proposed premise, AFV (F = 1.05, p = .403, $\eta2$ = .035) did not. Of note, at the multivariate level there were significant two-way interactions between AFV*GD (F = 1.37, p =.014, $\eta2$ = .044) and AFV*TR (F = 2.68, p <.01, $\eta2$ = .084), and a three-way between AFV*GD*TR at α = .10 (F = 1.21, p =.093, $\eta2$ = .039); all supporting the proposed hypotheses and indicating that proceeding to interpret the univariate ANOVA results for each of the 10 selection criteria included in the analysis was permissible, and would facilitate more nuanced insights for independent factor effects on specific selection criteria (Hair et al. 1998; Mertler and Vannatta 2010). Markedly, at the multivariate level the covariates FS (F = 1.68, p = .084, $\eta2$ = .054), EX (F = 1.66, p = .053, $\eta2$ = .059) and the two-way interaction of AFV*EX (F = 1.85, p = .090, $\eta2$ = .054) were shown to have an effect on combined SCI at α = .10.

Table 3. Descriptive Statistics and Variable Correlations

Variable	Mean	SD	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
A	8.8	1.6	1	10	1																
D	7.2	1.9	1	10	.26**	1															
I	8.7	1.5	1	10	.51**	.39**	1														
P	7.8	2.4	1	10	.14**	.31**	.23**	1													
PC	8.2	1.8	1	10	.35**	.41**	.42**	.23**	1												
PH	8.4	1.5	1	10	.40**	.34**	.51**	.29**	.44**	1											
Q	9.2	1.2	1	10	.37**	.28**	.35**	.09*	.30**	.33**	1										
R	9.1	1.2	1	10	.44**	.23**	.52**	.26**	.39**	.60**	.40**	1									
T	8.3	1.8	1	10	.51**	.35**	.39**	.14**	.40**	.38**	.39**	.34**	1								
W	8.7	1.5	1	10	.49**	.37**	.54**	.31**	.40**	.49**	.31**	.47**	.37**	1							
FS	339.3	749.1	1	6354	0.05	.12**	.08*	-.11**	.08*	0.03	.12**	0.02	.16**	-0.03	1						
AS	6.3	13.3	0	19.5	0.03	0.07	0.08	-0.06	0.07	0.01	.10*	-0.02	.11**	-0.04	.75**	1					
EX	18.3	11.1	0	49	.10**	0.04	.08*	-0.05	-0.05	0.01	0.04	0.02	.10*	0.04	.31**	.23**	1				
AFV	0.5	0.5	0	1	.21**	0.00	0.02	-0.07	0.01	0.06	.14**	0.04	.24**	0.05	0.00	0.00	0.00	1			
GD	5.2	2.5	1	10	.10*	0.01	0.02	0.02	-0.07	-0.04	-0.01	-0.03	0.00	-0.03	-0.01	0.02	0.05	0.00	1		
TR	0.5	0.5	0	1	-0.05	.10*	0.06	0.05	.14**	0.05	0.01	-0.03	.14**	0.05	.36**	.27**	.14**	0.00	-.12**	1	
OT	0.6	0.6	0	2	0.07	-0.05	0.03	0.07	0.05	0.01	-0.03	0.05	-0.03	0.03	-.52**	-.45**	-.15**	0.00	0.03	-.20**	1

*** Significance at p < .01; **Significance at p < .05; *Significance at p <.1

Table 4. Differences in Assigned Selection Criteria Importance between Procurement Contexts

SSC	Context	Mean	Mean Difference	SD
A	CFV	8.49	**-0.53*** **	1.64
	AFV	9.02		1.46
D	CFV	7.18	0.03	1.89
	AFV	7.14		1.96
I	CFV	8.65	-0.02	1.48
	AFV	8.68		1.52
P	CFV	8.01	**0.52*** **	2.16
	AFV	7.49		2.67
PC	CFV	8.14	-0.01	1.80
	AFV	8.16		1.85
PH	CFV	8.36	**-0.13** **	1.50
	AFV	8.50		1.54
Q	CFV	9.10	**-0.25*** **	1.21
	AFV	9.36		1.14
R	CFV	9.11	-0.02	1.11
	AFV	9.14		1.22
T	CFV	7.89	**-0.71*** **	1.80
	AFV	8.61		1.65
W	CFV	8.64	-0.10	1.47
	AFV	8.75		1.48

*** Significance at p < .01; **Significance at p < .05; *Significance at p <.1

Univariate tests for the main effect of procurement context (*AFV)* reveal that it has no effect on the level of importance assigned to any of the individual selection criteria, supporting our proposed premise and indicating that when the contingent factors of GD and TR, along with the covariates FS, EX, OT and AS, are included in the model, the direct effect of AFV on assigned SCI is reduced. This finding is notable in that it supports our assertion that as procurement contexts switch from CFV to AFV best value procurement, the magnitude of the effect of AFV is driven by its two-way and three-way interaction effect with both geographic dispersion, and AFV supplier selection task recency, as MANCOVA analysis findings reveal.

When assessing the univariate analysis for the combined effect of AFV*GD on SCI, results show significant interaction-effects for *After Sales Support* ($F = 2.65$, $p < .01$, $\eta2 = .073$), *Integrity* ($F = 3.57$, $p < .01$, $\eta2 = .097$), *Procedural Compliance* ($F = 2.33$, $p = .015$, $\eta2 = .065$), *Performance History* ($F = 2.49$, $p < .01$, $\eta2 = .069$), *Quality* ($F = 2.54$, $p < .01$, $\eta2 = .071$), *Warrant and Claims Policy* ($F = 3.02$, $p < .01$, $\eta2 = .083$), and Reliability at $\alpha = .10$ ($F = 1.67$, $p =.097$, $\eta2 = .047$); supporting H_2. When assessing the univariate analysis for the combined effect of AFV*GD*TR on selection criteria assigned importance, results show significant three-way interaction effects for *Integrity* ($F = 2.86$, $p < .01$, $\eta2 = .079$), *Procedural Compliance* ($F = 2.08$, $p = .031$, $\eta2 = .058$), *Performance History* ($F = 3.22$, $p < .01$, $\eta2 = .088$), *Quality* ($F = 2.07$, $p = .032$, $\eta2 = .058$) and *Warrant and Claims Policy* ($F = 2.75$, $p < .01$, $\eta2 = .076$); supporting H_3.

Notable non-hypothesized effects were also observed and facilitate additional insights regarding vehicle supplier selection in best value bus procurement contexts. Of note, univariate analysis indicated that GD had a direct main effect on SCI for *After Sales Support* ($F = 3.77$, $p < .01$, $\eta 2 = .10$), *Integrity* ($F = 2.49$, $p < .01$, $\eta 2 = .069$), *Procedural Compliance* ($F = 1.98$, $p = .042$, $\eta 2 = .056$), *Performance History* ($F = 2.04$, $p = .035$, $\eta 2 = .057$), *Reliability* ($F = 3.89$, $p < .01$, $\eta 2 = .104$), *Warrant and Claims Policy* ($F = 4.90$, $p < .01$, $\eta 2 = .128$); and, at $\alpha = .10$, *Price* ($F = 1.88$, $p = .054$, $\eta 2 = .053$). Findings also indicated that TR had a direct main effect on SCI for *Integrity* ($F = 4.10$, $p = .044$, $\eta 2 = .013$), *Price* ($F = 11.12$, $p < .01$, $\eta 2 = .036$), *Procedural Compliance* ($F = 6.04$, $p = .015$, $\eta 2 = .020$), *Performance History* ($F = 5.12$, $p = .024$, $\eta 2 = .017$), *Reliability* ($F = 4.34$, $p = .038$, $\eta 2 = .014$), *Technical Capability* ($F = 10.54$, $p < .01$, $\eta 2 = .034$), *Warrant and Claims Policy* ($F = 14.51$, $p < .01$, $\eta 2 = .046$) and, at $\alpha = .10$, *Delivery* ($F = 3.48$, $p = .063$, $\eta 2 = .011$). The combined effect of GD*TR was also found to have an effect on SCI for *After Sales Support* ($F = 2.21$, $p = .022$, $\eta 2 = .062$), *Reliability* ($F = 3.03$, $p < .01$, $\eta 2 = .083$), *Technical Capability* ($F = 2.08$, $p = .031$, $\eta 2 = .059$) and *Warrant and Claims Policy* ($F = 3.92$, $p < .01$, $\eta 2 = .105$). Of note, FS had a direct main effect on SCI for *Price* ($F = 8.50$, $p < .01$, $\eta 2 = .027$) and, at $\alpha = .10$, *Procedural Compliance* ($F = 3.41$, $p = .066$, $\eta 2 = .011$); while OT was found to have a direct effect on *Procedural Compliance* ($F = 6.58$, $p = .011$, $\eta 2 = .021$).

DISCUSSION

In responding to calls for research that investigates the boundary conditions or factors that determine the magnitude and direction of established focal relationships (Fawcett and Waller 2011; Goldsby et al. 2013), this research identifies both geographic dispersion and task recency as factors that affect the extent of the focal relationship between procurement context changes and variability in the importance assigned to SSCs (Dickson 1966; Lehmann and O'Shaughnessy 1974; Choi and Hartley 1996; Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004; Wetzstein et al. 2016). We find that fleet procurement agent geographic dispersion and AFV supplier selection task recency have respective direct and interaction effects on the relationship between vehicle procurement context change and the level of importance assigned to vehicle SSCs. Our findings are consistent with those found in extant supplier selection and behavioral decision theory literature, identifying a statistically significant relationship between changes in buying context and the variability in the importance assigned to SSCs (Dickson 1966; Lehmann and O'Shaughnessy 1974; Verma and Pullman 1998; Cheraghi et al. 2004). While indeed contributing to extant literature through confirming prior findings, the unique contribution of this research resides in it serving to augment overgeneralization and further enrich theory by identifying the boundary conditions or factors for which the extent of that variability differs (Fawcett and Waller 2011; Goldsby et al. 2013).

Utilizing the empirical context of the best value bus procurement process in the US public transportation industry, the extended hypotheses are supported, and we find that a buying context switch from CFV to AFV best value procurement has a significant effect on SCI for *Quality*, *Price*, *Technical Capability*, *After Sales Support*, and *Performance History*. Findings reveal that as the procurement context switches from the CFV to the AFV supplier selection process, that *Technical Capability, After Sales Support*, and *Price*, in that order, have the largest differences in assigned importance between those contexts. Both *Technical Capability* and *After Sales Support* are assigned significantly more importance in the AFV procurement context, while *Price* is assigned significantly less importance.

Table 5. Repeated Measures MANCOVA Results

	MANCOVA Results		Univariate F-Values and (Partial Eta Squared)									
Independent Variables	*Pillai's Trace*	*F-Value*	*A*	*D*	*I*	*P*	*PC*	*PH*	*Q*	*R*	*T*	*W*
Covariate												
EX	0.054	**1.66***	0.85(.00)	0.01(.00)	0.15(.00)	0.90(.00)	2.20(.01)	0.03(.00)	0.32(.00)	1.64(.01)	1.37(.01)	0.02(.00)
OT	0.035	1.05	0.67(.00)	0.05(.00)	0.57(.00)	0.27(.00)	**6.58(.02)****	0.01(.00)	0.05(.00)	0.03(.00)	0.28(.00)	0.74(.00)
FS	0.054	**1.68***	0.07(.00)	1.94(.01)	0.19(.00)	**8.50(.03)*****	**3.41 (.01)***	0.03(.00)	1.90 (.01)	0.00(.00)	1.50(.01)	0.03(.00)
AS	0.034	1.04	0.28(.00)	0.52(.00)	0.52(.00)	1.41(.01)	0.29(.00)	1.63(0.01)	0.30(.00)	0.90(.00)	0.02(.00)	0.25(.00)
Main Effects												
GD	0.401	**1.40*****	**3.77(.10)*****	.94(.03)	**2.49(.07)*****	**1.88(.05)***	**1.98(.06)****	**2.04(.06)****	.82(.02)	**3.89(.10)*****	1.35(.04)	**4.90(.13)*****
TR	0.092	**2.96*****	1.42(.01)	**3.48(.01)***	**4.210(.01)****	**11.12(.04)*****	**6.04(.02)****	**5.12(.02)****	1.13(.00)	**4.34(.01)****	**10.54(.03)*****	**14.51(.05)*****
AFV	0.035	1.05	0.34(.00)	0.02(.00)	0.34(.00)	0.18(.00)	0.10(.00)	1.04(.00)	0.50(.00)	0.39(.00)	0.15(.00)	0.48(.00)
Two-Way Interaction Effects												
AFV x GD	0.392	**1.37****	**2.65(.07)*****	.72(.02)	**3.57(.10)*****	1.32(.04)	**2.33(.06)****	**2.49(.07)*****	**2.54(.07)*****	**1.67(.05)***	1.45(.04)	**3.02(.08)*****
*AFV*TR*	0.084	**2.68*****	1.26(.00)	1.51(.01)	.48(.00)	**7.34(.02)*****	.00(.00)	1.57(.01)	.43(.00)	.00(.00)	2.17(.01)	.55(.00)
*GD*TR*	0.351	**1.23***	**2.21(.06)****	1.19(.03)	1.39(.04)	.53(.02)	1.51(.04)	1.46(.04)	1.20(.04)	**3.03(.08)*****	**2.08(.06)****	**3.92(.11)*****
*AFV*EX*	0.059	**1.85****	0.45(.00)	0.18(.00)	1.58(.01)	0.73(.00)	0.81(.00)	1.59(.00)	**3.08(.01)***	0.62(.00)	0.33(.00)	1.02(.00)
*AFV*OT*	0.034	1.02	2.41(0.01)	0.02(.00)	1.58(.01)	**4.15(.01)****	1.54(.01)	1.42(.00)	1.04(.00)	1.63(.01)	1.52(.01)	0.67(.00)
*AFV*FS*	0.036	1.1	0.53(.00)	0.15(.00)	0.26(.00)	0.53(.00)	0.11(.00)	0.30(.00)	0.60(.00)	0.10(.00)	0.27(.00)	0.33(.00)
*AFV*AS*	0.027	0.82	0.38(.00)	0.68(.00)	0.54(.00)	0.05(.00)	0.27(.00)	0.67(.00)	0.48(.00)	2.35(.01)	2.15(.01)	0.11(.00)
Three-Way Interaction Effects												
*AFV*GD*TR*	0.348	**1.21***	1.51(.04)	.54(.02)	**2.86(.08)*****	1.12(.03)	**2.08(.06)****	**3.22(.09)*****	**2.07(.06)****	1.59 (.05)	1.11(.03)	**2.75(.08)*****

*** Significance at p < .01; **Significance at p < .05; *Significance at p <.1

Of note, when accounting for the effects of geographic dispersion and task recency, we found a direct effect of a procurement context switch from CFV and AFV procurement for *Quality*, *Price* and *After Sales Support*, indicating that these two contingent factors play a role in decision making during vehicle supplier selection. Indeed, we find that the two-way interaction of procurement context switch and geographic dispersion had a combined effect on changes in SCI for *Quality*, *After Sales Support*, *Warrant and Claims Policy*, *Performance History*, *Procedural Compliance* and *Integrity*. Further, we indeed find that the three-way interaction of procurement context switch, geographic dispersion, and AFV supplier selection task recency has a combined effect on changes in the magnitude of importance assigned to the selection criteria *Quality*, *Warrant and Claims Policy*, *Performance History*, *Procedural Compliance*, and *Integrity*.

Additionally, we find that irrespective of procurement context, geographic dispersion and task recency each have direct effects on SCI during the best value procurement process for buses. Regarding the direct effect of geographic dispersion, significant effects were found for *After Sales Support*, *Warrant and Claims Policy*, *Performance History*, *Procedural Compliance*, *Reliability*, *Integrity* and *Price*; with results indicating that *Price's* relative importance varied across FTA regions, which from a best value procurement policy perspective suggests that some extent of variation in eventual life cycle and total ownership costs may be attributable to geographic location effects. Task recency was found to have a direct effect on the magnitude of importance assigned to *Price*, *Technical Capability*, *Warrant and Claims Policy*, *Performance History*, *Procedural Compliance*, *Reliability*, *Integrity* and *Delivery*. Task recency's direct effect indicates that the timing in which the completion of the task of AFV supplier selection was conducted by a fleet procurement agent not only has an effect on AFV procurement contexts, but also has spillover effects in CFV procurement contexts as well, supporting findings in extant literature on the recency effect's influence during task switching.

Theoretical Implications

At the theoretical level, we posit that BDT should predict differences in the SCI assigned to SSCs as task characteristics change, and that the extent of that change is affected by the geographic dispersion of decision makers and the recency with which they last completed a similar task. Based on our findings, we observe the potential implications of the diffusion of innovation, given that geographic dispersion and task recency are independent factors that influence the effect of a procurement context change on supplier selection task decision outcomes In positing the effect of a procurement context change on task decision outcomes, we confirm a previously established effect in extant supplier selection literature but do so in the empirical context of sustainable fleet procurement, an area of growing significance in which this effect was not previously investigated. Importantly, we engage in theory confirmation by providing support for the BDT tenet that a change in task characteristics can lead to variation in how decision makers prioritize criteria in a choice set. We further build on this contribution by identifying independent factors that affect the extent of the effect of task characteristic changes on assigned criteria importance - geographic dispersion and task recency. Particularly in markets characterized by rapidly advancing product technologies, like the AFV market, our findings can suggest that while technology is indeed advancing at an accelerated rate, its diffusion and adoption varies significantly by geography, bearing significant implications for those organizations and firms characterized by geographically dispersed units and decision makers. At any point in time, local economics, regulations, and operating environments can influence or dictate technology adoption practices and behavior in a specific locale or region, resulting in agents across a geographically dispersed network interfacing with varied technology types at the same point in time. Related, the rate at which technologies advance, and are permitted to be adopted in these localities, determines the range of technological change decision makers experience as time elapses between interfacing with new technologies. We confirm that these two factors, geographic dispersion and task recency, have an effect on the manner in which decision makers assign importance to criteria of interest, and in so doing, bring to the fore the role of behavioral decision theory in the supplier selection process across geographically dispersed networks. Of note, we contribute to this stream of work by identifying that at any particular point in time, particularly in task environments characterized by increasing product technological advances across geographically dispersed networks, the effect of a task characteristic change-based independent factor can exist on a continuum in which the intensity of technological advancement in a specific location across a network can impact the extent of a task change's effect on decision making in that location. Conversely, we also find that the way a task is performed can be time dependent, particularly when time elapses between task repetition in task environments characterized by rapidly evolving and increasingly advancing technologies, bringing to the fore the time-variant nature of independent factors' effects on decision making in specific task environments.

Limitations and Future Research

While the utilized approach and resultant findings in this study are relevant, rigorous, and facilitate significant contributions to various streams of extant literature; various considerations must be given when interpreting its findings. First, the criteria weighting task exercise utilized in this study employed a design that captured the behavioral intent, and not actual behavior, of FPAs as they assigned importance to SSCs. This approach is methodologically valid, particularly since study participants were actual FPAs that do manage the supplier selection process at their respective transit agencies; however, future research can be aimed at capturing actual FPA behavior by employing natural experiment designs, or by utilizing firm specific SSP archival data that reveal actual criteria weighting behavior. Another consideration in interpreting the findings of this study is the fact that ten SSCs identified as being highly salient to vehicle procurement are utilized and, while logically valid, future studies can incorporate a different sub-set of SSCs, or a more comprehensive list of criteria, to extract complementary or supplementary insights. Of note, the theoretical contributions of this research are articulated through the theoretical lens behavioral decision theory and while valid, they are therefore constrained by the logic and tenets on which these theories are based. To complement the theoretical contributions of this research, future studies can investigate the same empirical phenomena and context to develop complimentary, supplementary, or alternative theoretical perspectives, utilizing other theoretical lenses.

Managerial Implications

The findings of this research bear significant implications for AFV-related policy makers and regulators, as well as AFV suppliers. First, from a best value procurement policy outcomes perspective, these findings suggest that fleet procurement agents indeed assign less importance to *Price* in AFV versus CFV supplier selection contexts, in keeping with best value tenets. However, it should be noted that the increased importance assigned to both *Technical Capability* and *After Sales Support* can bear significant implications, both favorable or adverse, for bus life cycle and total ownership costs; impacting best value policy objectives and outcomes due to the prioritization of these criteria introducing additional costs that can potentially result in suboptimal total costs over the life cycle of a vehicle. For governmental entities like the U.S. Federal Transit Administration, our findings suggest that not only is the adequate consideration and prioritization of specific non-price criteria an important component of best value procurement, but that the specific criteria that are prioritized can bear significant implications to longer run costs; requiring investment in monitoring mechanisms that can categorize and evaluate respective criteria impacts to life cycle and total ownership costs over time, in order to truly measure policy objective outcomes, and provide input to subsequent policy updates and formulation. Second, our findings indicate that buying agents expect more in the area of technical capabilities and after sales service capabilities from suppliers of AFVs, as opposed to CFVs. The development of these capabilities can have significant impacts to supplier capabilities investment programs and research and development budgets, as suppliers must position themselves to bid and compete in contemporary AFV bus markets; and in the case of after sales service capabilities, the offering of such services tends to positively affect profits due to higher profit margins.

When considering the factors of geographic dispersion and AFV supplier selection task recency, additional managerial implications come to the fore for both policy makers and vehicle suppliers. First, there are implications for how the US Federal Transit Administration, and similar governmental agencies, can administer best value procurement programs and evaluate policy objective outcomes. Given the observed effect of geographic dispersion on task decision making, opportunity may lay in the FTA monitoring and evaluating best value procurement behavior and outcomes by identifying and indexing to regional norms or best practices, given the potential similarity in regulation, adopted AFV technologies and available infrastructure within FTA regions or between adjacent states. This facilitates the FTA monitoring transit agency-specific behavior and outcomes for consistency with trends in both regional criteria preferences, and levels of resultant life cycle and total ownership costs. Second, geographic dispersion-based findings bear significant implications for vehicle suppliers from various perspectives. Knowledge of region- or location-specific buyer preferences can serve to help customize supplier proposal and bid strategies for suppliers that serve across geographic regions and across AFV technology types; by highlighting those capabilities for which specific selection criteria are given higher scores in specific regions. Further, for both vehicle suppliers that service multiple regions and AFV vehicle types, and for those who serve niche technology markets or regions, knowledge on variability in selection criteria importance across regions facilitates targeted investing in research and development budgets, and in capabilities development programs. Third, transit operators within specific regions can benefit from any similarities in selection criteria preferences with other operators within or without their respective region by juxtaposing those preferences with their agency-specific preferences and using such comparisons to engage in strategically selected pooled procurement or “piggy” backing procurement initiatives with those agencies where there is observant compatibility in selection criteria rating preferences.

Findings regarding AFV supplier selection task recency bear implications for government agencies, vehicle suppliers, and transit operators alike. For government agencies like the FTA, in instances where budgetary and funding support are the key drivers behind AFV procurement frequency at transit agencies, access to timely funding can influence variability in supplier criteria importance ratings, due to its effect on the time that elapses between procurement instances and the resultant change in vehicle technological cores. Appropriate levels of funding available at optimal times can serve to reduce the adverse effects of prolonged times between procurement instances, effects that include higher variations in AFV technologies within the same fleet, which leads to required technician workforce upskilling and increased after sales service subscriptions, each impacting life cycle and total ownership costs. Thus, government agencies working to support optimal vehicle procurement cycle times through the provision of access to funding and technical assistance in a timely manner, can serve to further enhance the impact of best value procurement tenets and the realization of intended policy objective outcomes over the useful life of vehicle assets. For vehicle suppliers, knowledge of when a transit operator last engaged in AFV supplier selection can serve to enhance not only bid proposal and development strategies, but also, prior to that, information they include in their responses to request for information solicitations by transit operators, gaining competitive advantage through exhibiting knowledge regarding additional technological considerations due to advancements in technology since a specific transit agency's last engagement in AFV procurement. For transit operators, the recency effect associated with when AFV selection was last completed can inform procurement practices in two manners. First, transit operators can work to ensure that internal procurement team composition considers the recency with which each team member last completed AFV supplier selection, understanding that large differences between those times can affect how they prioritize selection criteria as they interface with more advanced technologies. Related, in the potentially probable situation that an agency has not gone to market for AFV technologies recently, it can seek best practice guidance from other geographically adjacent agencies or engage in joint procurements and "piggy backing" opportunities with adjacent agencies that more recently engaged in AFV supplier selection, as such agencies will more likely have an updated understanding of supplier capabilities needs and requirements for more recent AFV technologies.

Policy Implications

Of significance, our findings point to managerial implications regarding policy and regulatory considerations. With a multiplicity of governmental and regulatory authorities requiring, and in various instances incentivizing, the increased development and adoption of AFV technologies (Rahm and Coggburn 2006; Bae et al. 2011; Cunningham et al. 2018); regulations directly impact the diffusion and adoption rates of alternative fuel and propulsion technologies (Bae et al. 2011; Zhang et al. 2011; Li et al. 2015; Yuksel and Michalek 2015; Bitzan and Ripplinger 2016; Tong et al. 2017) and thus, impact both fleet operator and vehicle manufacturer strategies. More definitively, regulations can affect vehicle supplier capacity and production planning, vehicle supplier research and development program budgetary allocations, manufacturing capabilities investment programs, and, as such, can potentially impact the competitive AFV supplier market dynamics; causing downstream trickle-down effects (Zhang et al. 2011; Calstart 2016). Further, regulations requiring the adoption of AFVs by transit agencies, when such adoption is supported by public funding programs, have the potential to incur additional costs and demand increased support from public funding sources, potentially conflicting with best value procurement policy objectives. This suggests that the cost-effective and timely adoption of AFVs by organizations requires collaboration and joint investment initiatives between fleet operators, vehicle manufacturers, vehicle suppliers, and government agencies.

CONCLUSION

In conclusion, this research contributes to extant literature in supplier selection (Kannan and Tan 2002; Wetzstein et al. 2016; Scott et al. 2018), best value procurement (Dimitri 2013; Tran et al. 2016; Scott et al. 2018), the application of behavioral decision theory in procurement and supplier selection practice (Nissen and Sengupta 2006; Morton and Fasolo 2009; Davis-Sramek et al. 2018) , and importantly, in a novel way to extant literature on AFV fleet management (Nesbitt and Sperling 2001; Bae et al. 2011; McKenzie and Durango-Cohen 2012; Li et al. 2015; Tong et al. 2017); with no previous research at the time this study was conducted explicitly studying AFV supplier selection. Utilizing the empirical context of the best value procurement process for both conventional fuel and alternative fuel buses, findings support prior studies that posit a relationship between changes in buying context and variability in SCI (Dickson 1966; Lehmann and O'Shaughnessy 1974; Verma and Pullman 1998; Kannan and Tan 2002; Cheraghi et al. 2004; Wetzstein et al. 2016). The study then builds on this confirmatory finding, and uniquely contributes to the literature, by providing evidence that the extent of change in SCI, as best value bus procurement contexts transition from CFV to AFV contexts, is contingent on the geographic dispersion of fleet procurement agents and the recency with which they last completed the AFV supplier selection task. Importantly, utilizing the AFV supplier selection process as its empirical context, this research contributes to a further understanding of the factors that influence managerial intent as buying contexts increasingly transition from conventional to environmental sustainability contexts. Future directions of research are also suggested, given the prominence and importance of environmental sustainability in contemporary transportation, logistics and supply chain research. Of note, in addition to the passenger transportation industry, the results of this research bear significance for decision makers in the government, nonprofit, and freight services sectors, as well as private fleet operators in the private sector; all comprising organizations in which vehicle acquisition is related to the primary service provided or serves as an input factor in the production of other goods and services. This applicability also extends to decision makers in capital intensive industries, to the extent that such capital equipment is subject to regulatory or corporate stipulations that require technology conversions to more energy efficient and pollutant reducing technologies.

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DECISION SCIENCES INSTITUTE

Supply Chain Delivery Coordination Using Blockchain Smart Contracts

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ABSTRACT

This research is addressing a problem of supply chain delivery coordination by implementing penalties for untimely delivery in blockchain smart contracts. On the supplier side, delivery performance models are used to define the costs; on the buyer side, inventory models describe the costs related to delivery. Blockchain smart contracts can be developed to automate supply chain delivery coordination. This research presents a conceptual framework for delivery coordination using blockchain smart contracts to aid decision making and contributes to linking and coordinating the delivery and inventory sub processes within supply chains.

KEYWORDS: Supply chain management, Delivery coordination, Blockchain, Delivery window

INTRODUCTION

Supply chain management (SCM) serves as the foundation of an organization's overall competitive strategy for attaining and maintaining competitive advantage. Three main flows need to be managed within a supply chain: product, information, and finances. Information sharing that is required for information flow is extremely important for supply chain coordination and a popular topic in SCM research (Li & Wang, 2007). Researchers agree that trust among supply chain participants is required for effective information sharing and trust is the main obstacle against information sharing (Zhang & Hou, 2013; Tejpal et al., 2013; Cachon & Lariviere, 2005; Chen, 2003).

Information sharing poses two potential problems (Oer & Zheng, 2017; Villena, et al., 2011; Kwon & Suh, 2004). First, the trust problem leads to supply chain participants questioning if information provided is reliable and trustworthy. For example, a supplier could modify a production date in order to sell an expired product. Second, the problem of undesirable information sharing is the concern that confidential information shared between participants could be shared with a third party. How can participants be sure that information provided to other participants will not be shared with a third party? For example, a company might not want its competitors to know the details of its production process.

Blockchain technology has the potential to solve information sharing problems within a supply chain (Nofer, et al., 2017; Apte & Petrovsky, 2016;). Blockchain can guarantee that data has not been modified, therefore solving the trust problem (Iansiti & Lakhani, 2017). However, blockchain cannot prevent undesirable information sharing. Moreover, in many cases supply chain contracts are short term (few deliveries) and building trust between a buyer and a supplier is infeasible. That means that even with blockchain technology companies might not be willing to share certain information. Since accurate supply chain coordination requires information from all participants, changing or substituting even one participant might be a problem. Therefore, even with blockchain technology supply chain coordination is problematic and leads to suboptimal decisions.

One possible solution might be to share a small amount of non-sensitive data. At the same time the data should provide enough information for optimal decisions within a supply chain. The paper herein discusses supply chain delivery coordination with limited information sharing using blockchain smart contracts. Blockchain technology is required to eliminate the possibility of altered data. Smart contracts are used to automate and expedite information sharing and decision making, therefore allowing short term contracts. Penalties for untimely delivery are used as a coordination mechanism that motivates a supplier to act in the buyer's best interests. At the same time, the only shared information is how much the supplier will be penalized for untimely (early or late) delivery.

The paper herein discusses a conceptual framework for delivery coordination within a decentralized supply chain and provides models to aid decision making. While the models involve limited information sharing with blockchain smart contracts, the design, architecture, and deployment of a blockchain system and the development of smart contract code are outside the scope of this research.

The rest of the paper is organized as follows. Section 2 contains a review of the literature on delivery windows, penalties for untimely delivery, and blockchain technology in supply chain management. Section 3 presents a conceptual framework for delivery coordination with blockchain smart contracts. Conclusions and directions for future research are summarized in Section 4.

LITERATURE REVIEW

Penalties for Untimely Deliveries

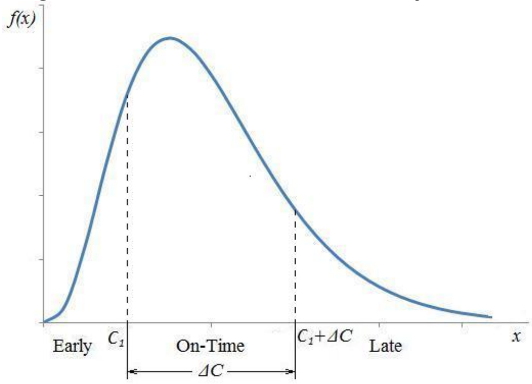
In the paper herein delivery performance models are used to coordinate delivery decisions within a supply chain.

It is common practice for a supplier and a buyer to contractually specify allowable time deviations (earliness and lateness) from an agreed upon delivery date for use in classifying deliveries as being early, on-time, and late (Guiffrida & Nagi, 2006a). The costs associated with untimely (early and late) delivery are referred to as penalty costs which are paid by the supplier to the buyer (Guiffrida & Nagi, 2006b). Therefore, it is in the best interest of a supplier to reduce the penalty costs.

Delivery windows are often incorporated into performance measurement systems when performance with respect to deadlines and/or due dates is measured. Delivery windows appearing in supply chain delivery models evolved from the general class of time window constrained models found in the operations research and operations management literature and representative examples of delivery performance models with time windows may be found in Guiffrida & Nagi (2006a), Garg et al. (2006), and Shin et al. (2009). In the context of a delivery performance model, a delivery window (see Figure 1) is defined as a time interval within which a delivery can be received. When an order is placed, the customer is typically given a fixed due date between the earliest acceptable delivery time and the latest acceptable delivery time which is called the on-time portion of the delivery window. When a delivery is made within the on-time portion of the delivery window, no penalty cost is incurred.

Models for evaluating delivery performance within supply chains can be categorized into two groups: i) index based models (Hsu et al., 2013; Nabhani & Shokri, 2009; Wang & Du, 2007), and ii) cost based models (Guiffrida & Nagi, 2006a; Bushuev & Guiffrida, 2012; Chen et al., 2018). The models differ in how they report delivery performance in terms of an overall metric. Index based models translate the probability of untimely delivery into a “delivery capability index” measure. Cost based models use partial expectations to directly translate the probability of untimely delivery into an expected cost measure. For delivery performance coordination, cost based models have a huge advantage over index based models because the effects of a managerial decision is easier to understand in cost values rather than in index values. Moreover, a decision can be easily made if an expected monetary outcome of the decision is known.

Figure 1: Illustration of a Delivery Window



Legend: *f(x)* is the probability density function (pdf) of delivery time, c_1 is beginning of on-time delivery, Δc is the width of the on-time portion of the delivery window.

A cost-based function proposed in Guiffrida & Nagi (2006a) measures the expected penalty cost per delivery when deliveries are classified as early and late according to a delivery window:

$$Y = Y_{early} + Y_{late} = QH\int_0^{c_1}(c_1 - x)f(x)dx + K\int_{c_1+\Delta c}^{\infty}(x - (c_1 + \Delta c))f(x)dx, \quad (1)$$

where Y = expected penalty cost of untimely delivery,

$Y_{early} = QH\int_0^{c_1}(c_1 - x)f(x)dx$ is the expected penalty cost of early delivery,

$Y_{late} = K\int_{c_1+\Delta c}^{\infty}(x - (c_1 + \Delta c))f(x)dx$ is the expected penalty cost of late delivery,

f(x) = the probability density function (pdf) of delivery time *x*,

QH = penalty cost per time unit early (levied by the buyer),

K = penalty cost per time unit late (levied by the buyer),

c_1 = difference between the time the delivery process is initiated and the earliest acceptable delivery time,

Δc = the width of the on-time portion of the delivery window.

Although the earliest acceptable delivery time is predefined by the contract, the supplier can define the time when delivery begins, therefore changing the value of c_1. For example, if the supplier decides to ship the product 10 hours before the earliest accepted delivery time, c_1 is equal to 10 hours. This function assumes a linear form of penalties which is the most popular but still one of many possible forms. Other forms include fixed penalty fees for earliness and lateness, penalties per time squared, etc. This function was used by researchers for delivery performance evaluation and improvement (Guiffrida & Jaber, 2008; Ngniatedema et al., 2015; Bushuev, 2018).

Using the cost based function, Bushuev and Guiffrida (2012) introduced the concept of the optimal position of the delivery window (OPDW) which defines a time when the delivery process should begin to minimize the expected penalties paid for untimely delivery by the supplier. As demonstrated in Bushuev and Guiffrida (2012), Y is a convex function of c_1 and the optimal value of c_1 (which is defined as c_1^*) that minimizes Y can be determined by evaluating

$$K \cdot P_{late} = QH \cdot P_{early}, \tag{2}$$

where $P_{late} = \int_{c_1+\Delta c}^{\infty} f(x)dx$ and $P_{early} = \int_{0}^{c_1} f(x)dx$ are the probabilities of late and early deliveries.

The cost based function used in delivery performance models investigates penalty costs for untimely delivery for a supplier; hence the models can be used as a supplier's point of view on supply chain delivery performance.

From the buyer's perspective, early and late deliveries introduce waste in the form of excess cost into the supply chain; early deliveries contribute to excess inventory holding costs while late deliveries may contribute to production stoppage costs, lost sales and loss of goodwill. Thus, delivery will affect the buyer's inventory level and inventory models (Bushuev & Brown, 2018) can represent the buyer's point of view on supply chain delivery. The first inventory model, the economic order quantity (EOQ), first introduced by Harris (1913) defines total cost as a sum of ordering and holding costs:

$$TC = S\frac{D}{Q} + h\frac{Q}{2}, \tag{3}$$

where Q = order quantity, D = demand, S = ordering (or setup) cost, and h = holding cost.

Later on, a variety of inventory models were published increasing the complexity of the initial model which includes random lead (delivery) time, stockout and overload costs, and different cost dimensions such as [$/unit/unit time], [$/unit time], and [$/unit] (Zipkin, 2000; Hadley & Whitin, 1963).

It is in the buyer's best interest to minimize inventory related costs and the buyer can potentially pass some of the costs to the supplier using penalties for untimely delivery. To date there has been only one attempt to evaluate the effect of delivery performance on buyer costs (Bushuev & Brown, 2018) that used a model with two levels of inventory and specific forms (dimensions) of stockout and overload costs that fit well to the cost-based function. Since a buyer can have other dimensions of stockout and overload costs, research linking the delivery performance model and inventory models with different cost dimensions is a potential area for future research.

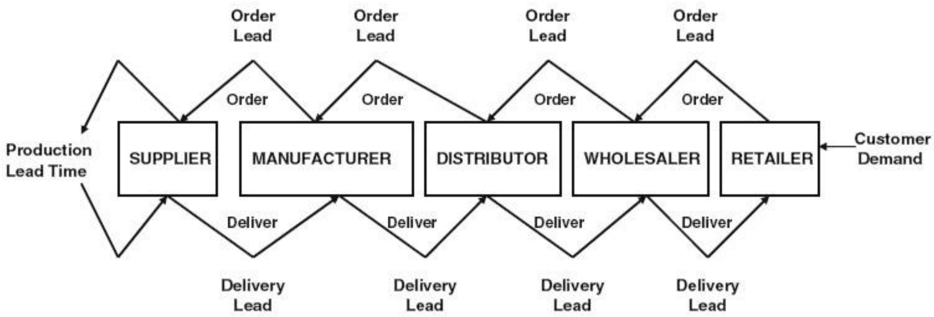
Blockchain Technology in Supply Chain Management

Use of blockchain technology in supply chain management has been drawing the attention of researchers in the last several years. Kumar et al. (2019) discussed challenges and opportunities of blockchain. Saberi et al. (2019) investigated relationships of blockchain to supply chain sustainability. Abeyratne and Monfared (2016) proposed the use of a distributed ledger in manufacturing supply chains and Dolgui et al. (2019) developed a smart contract design for supply chains. This research proposes embedding penalties for untimely delivery into blockchain smart contracts to create a supply chain coordination mechanism. A smart contract, initially described in Szabo (1996), is a computer code intended to digitally facilitate, verify, or enforce the performance of a contract (Rosic, 2020). Thus, the rules which determine when and how a supplier will be penalized for untimely delivery can be defined in smart contracts and implemented automatically. It not only saves time but also allows the ability to easily adjust the rule when necessary.

A CONCEPTUAL FRAMEWORK FOR DELIVERY COORDINATION

In this section, a conceptual framework for delivery coordination within a decentralized supply chain is introduced. The model developed in Bushuev and Brown (2018) for a 2-stage supply chain with a single buyer and a supplier is extended to a multistage serial supply chain (Figure 2).

Figure 2: Serial supply chain



Blockchain smart contracts are used to resolve a limitation that does not allow the 2-stage model (Bushuev and Brown, 2018) to be used for coordination in multistage supply chains. A contract negotiation process between a supplier and a buyer is time consuming and therefore is usually used for long-term contracts with key first-tier suppliers. Therefore, buyers cannot penalize all of their suppliers for untimely delivery. Blockchain technology allows the ordering process to automatically include penalties for untimely deliveries in all contracts. An ability to apply penalties for untimely delivery to any supplier in a supply chain allows the use of penalties as a coordination mechanism.

Assumptions and Limitations

Supply chain coordination is a broad research area. The goal of this project is to focus specifically on the delivery process. Since this is the first attempt to develop a delivery coordination mechanism within a decentralized supply chain using penalties for untimely delivery, the following assumptions will be made:

1. The supply chain is serial and each company has only one buyer and one supplier. Having more than one buyer adds complexity to the model that can be studied in future research.
2. Order quantity is fixed and is not considered a decision variable. The focus is on the time when the product should be shipped which is called reorder point in inventory management and the position of delivery window in delivery performance models. This is a reasonable assumption, since order quantity and reorder point are often selected independently (Axsäter, 2003).
3. Production rate is infinite and/or production time is zero. Thus, there is no need for production scheduling which is a separate area of research.
4. Companies in the supply chain are only using penalties for untimely delivery to motivate their suppliers to act in their interests. They are not planning to make a profit from untimely deliveries by charging the supplier more than their losses because of untimely delivery. Otherwise, game theory could be used to develop optimal strategies for the negotiation process.

Delivery coordination can be achieved if a company faces all costs incurred because of its decisions. Since a supplier is usually responsible for delivery, the supplier should compensate the buyer for all costs related to untimely (early or late) delivery. That should motivate a supplier to reduce buyer costs related to untimely delivery and act in the buyer's best interests.

Buyer and Supplier Costs

Total delivery-related costs of a company within a supply chain can be divided into buyer and supplier costs. We define buyer costs as costs associated with storing a product before it is shipped to a customer and supplier costs as penalties the company pays to a buyer for untimely delivery. As was discussed previously, inventory models should be used to measure buyer costs associated with delivery. The models are well studied in the literature (Zipkin, 2000; Bushuev et al., 2015; Wild, 2017) including models with two levels of inventory (Zhao et al., 2007; Lee & Hsu, 2009). We use a stochastic continuous review (Q, R) inventory model with two levels of storage as an example from Bushuev and Brown (2018) and similar approaches should be used for other types of inventory models.

The following notations are used to define buyer costs:

- C_O = Cost of overload (holding extra inventory when exceeding available space, \$/unit time);
- C_S = Cost of stockout (\$/unit time);
- D = Demand (units/unit time);
- H = Holding cost per unit per year (\$/unit/unit time);
- L = Lead time (unit time), random variable with probability density function (pdf) $f(L)$;
- Q = Order quantity (Lot size, units);
- Q_{max} = Size of warehouse (units);
- R = Reorder point (units);
- S = Ordering cost (\$/order).

The buyer cost per unit time is:

$$E(BC) = S\frac{D}{Q} + \frac{H}{2}\big(Q + 2(R - E(L)D)\big) + \frac{H}{2Q}(Y_{late})^2 + \frac{C_0}{Q}Y_{early} + \frac{C_S}{Q}Y_{late} \tag{7}$$

Where the first element is ordering cost, the second two elements are inventory holding cost, and the last two elements are costs of overload and stockout, respectively.

The reorder point is optimal when:

$$H\left(Q - Y_{late}P_{late}\right) + C_0 P_{early} = C_S P_{late}. \tag{8}$$

Supplier costs are defined using the delivery performance model mentioned in the section from the literature review on penalties for untimely deliveries:

$$E(SC) = QH\int_0^{c_1}(c_1 - x)f(x)dx + K\int_{c_1+\Delta c}^{\infty}(x - (c_1 + \Delta c))f(x)dx, \tag{1}$$

Thus, the total cost function that includes both inventory (7) and penalty (1) costs is:

$$E(TC) = S\frac{D}{Q} + \frac{H}{2}\big(Q + 2(R - E(L)D)\big) + \frac{H}{2Q}(Y_{late})^2 + \frac{C_0}{Q}Y_{early} + \frac{C_S}{Q}Y_{late} + QH\int_0^{c_1}(c_1 - x)f(x)dx + K\int_{c_1+\Delta c}^{\infty}(x - (c_1 + \Delta c))f(x)dx \tag{9}$$

The total cost function (eq. 9) is jointly convex on the parameter R (reorder point) that defines the time when the product is shipped from the company to the buyer and from the supplier to the company (beginning of on-time delivery c_1).

Supply Chain Coordination

This section discusses an algorithm that allows the coordination of delivery decisions within a supply chain. The algorithm assumes that decisions are made from downstream to upstream. So the company closest to the final customer acts first, then its first tier supplier, etc.

Usually, a company within a supply chain serves as a buyer (ordering products from its suppliers) and as a supplier (selling products to its buyers) at the same time. Therefore, ordering and shipping decisions made by a company should be coordinated to reduce costs. Supply chain participants can minimize these costs using blockchain smart contracts with the following procedure.

First, the company should focus on the supplier role and decide when its products should be shipped to buyers. The decision is made based on the total cost function (9) by finding the optimal value of beginning of on-time delivery (c_1). Since the width of the on-time portion of the delivery window and penalty costs per time unit (early and late) are defined by the contract, a buyer should choose a shipping time based on OPDW to minimize its costs.

Second, the company should motivate its supplier to act in the company's best interests by penalizing the supplier for untimely delivery. It requires connecting buyer costs and the parameters of the contract that define the amount of penalty paid by the supplier to the buyer. Ideally the penalties paid by a supplier for untimely delivery should cover all related buyer costs, but not exceed them, so the buyer does not benefit from untimely deliveries. If the company receives the product too early, it should be stored before it is shipped to its buyers. If the company receives the product too late, the product will be shipped later to the buyers which will increase expected penalties paid by the company for untimely delivery. In both cases, the company faces extra costs and these costs should be covered by its suppliers.

In the total cost function (9), a reorder point defines a shipping time from the supplier. Unfortunately for a buying company, they cannot directly force a supplier to ship at the time optimal for the company.

Assume the supplier chooses a time when the product will be shipped based on the concept of OPDW. How will it affect the buyer's costs? What should the buyer do to optimize its own costs? The only way a buyer can influence a supplier's delivery decision is during the contract negotiation process. Assume the buyer has enough power to choose any reasonable penalties for untimely delivery (*QH* and *K*). If a supplier has more power than a buyer, then the supplier will ask for no penalties for untimely delivery and will ship the product when it is appropriate from the supplier's production prospective. Thus, the buyer should choose the values of *QH* and *K* so that the shipping time which is optimal for the supplier is optimal for the buyer, too. Therefore, the process of setting *QH* and *K* needs to be defined.

The first step is choosing the ratio *QH/K* which is optimal for the buyer. From (2), it can be concluded that the ratio *QH/K* defines the optimal value of c_1. Thus, knowing this ratio is enough to find the optimal shipping time for a supplier. The buyer's strategy should be the following:

1. Find an optimal reorder point for the buyer.
2. Based on the optimal reorder point, calculate the ratio of probability of late to probability of early deliveries.
3. Use this ratio to define penalties (*QH/K* should be equal to the ratio).

The second step is setting the magnitude of *QH* and *K*. If the values are too low, the possible penalties are too low and will not force the supplier to delivery on-time. If the values are too high, it will affect the willingness of the supplier to sign the contract. The penalties should be reasonable and a buyer should explain why these penalties should be applied to the buyer. Therefore, a buyer can penalize a supplier based on the buyer's costs of overload and stockout. When an early delivery occurs, the supplier is penalized for early delivery and the buyer incurs an additional cost to store excess inventory. It is reasonable to assume that a buyer will ask a supplier to pay for storing this excess inventory and per the model $QH = C_o$. Late delivery will lead to stockouts for a buyer on one side and to penalties for late delivery for a supplier on another. In this case, a buyer can charge its supplier by the amount equal to its stockout costs, then the penalty per unit time is $K = C_s$. On-time delivery does not assume any penalties for a supplier and no additional costs (except inventory holding cost) for a buyer.

Assume a buyer wants its supplier to pay for overloads and stockouts choosing $QH = C_o$ and $K = C_s$. The problem is that if a buyer chooses $QH = C_o$ and $K = C_s$, the supplier's and buyer's optimal decisions will not be the same ($R_s^* \neq R_b^*$) for any $H \neq 0$ and the buyer's costs will not be minimized. Thus, the effect of holding cost on the buyer's optimal reorder point should be counterbalanced by changing the penalty costs for early and/or late delivery. How should the values of QH and K be changed? To answer this question, the effect of holding, stockout, and overload costs on the optimal reorder point is investigated in the following propositions.

Proposition 1. A buyer can decrease the supplier's optimal reorder point (R_s^*) by increasing the cost of overload (C_O).

Proposition 2. A buyer can increase the supplier's optimal reorder point (R_s^*) by increasing cost of stockout (C_S).

Proposition 3. For $QH = C_o$, $K = C_s$, and $H > 0$, the optimal reorder point for a buyer is less than the supplier's optimal reorder point ($R_b^* \leq R_s^* = R_b^*(H = 0)$).

From proposition 3, it can be concluded that the supplier's optimal reorder point (R_s^*) should be decreased to be equal to the buyer's reorder point (R_b^*). It can be done in two ways:

- Setting the penalty for early delivery higher than the cost of overload ($QH > C_O$);
- Setting the penalty for late delivery lower than the cost of stockout ($K < C_S$).

If a buyer chooses to increase the penalty for early delivery compared to the cost of overload ($QH > C_O$), it means that the supplier will have to pay more for overload than it requires to cover the excess storage costs. Thus, the penalties paid by the supplier will cover some inventory holding costs, too. If a buyer chooses to set the penalty for late delivery lower than the cost of stockout ($K < C_S$), the buyer will have to pay the difference in a case of stockout. It could also be a combination in which a buyer increases the penalty for early delivery and decreases the penalty for late delivery at the same time.

As was mentioned previously, blockchain smart contracts are required to implement the coordination process and it should work as follows:

1. A buyer defines the required delivery window, penalties for untimely delivery, and other parameters and creates a purchase order. The purchase order does not define a specific supplier, but serves as a contractual obligation for the buyer to purchase the product listed in the purchase order.
2. This purchase order is activated by the buyer in the form of a smart contract and posted to the blockchain.
3. Potential suppliers can review the purchase order and decide to sell the product to the buyer.
4. If/when a supplier agrees to sell the product to the buyer, it signs the smart contract that serves as a contractual obligation for the supplier to deliver the product to the buyer on the terms defined by the buyer in step 1.
5. The supplier will prepare and ship the product to the buyer trying to minimize related costs.
6. The buyer receives the order and the smart contract evaluates the amount the supplier should pay as a penalty if the product was not delivered on-time.

CONCLUSION

Existing research in supply chain decision making assumes that there is either a centralized decision maker or that supply chain participants coordinate their decisions with their direct buyers or suppliers. Centralized systems are well-developed in the literature, but they were not widely implemented because centralized decision making is usually unfeasible in supply chains.

Penalties for untimely deliveries is the approach that allows a buyer to force a supplier to ship in buyer's best interests by implementing penalties for untimely deliveries. Unlike other approaches, penalties for untimely delivery do not require trust among participants. A buyer and a supplier do not have to share any information except the rules on how the supplier will be penalized for untimely delivery. There is also no delegation of decision-making; each participant makes its own decisions.

However, penalties for untimely deliveries have several limitations. First, it requires a negotiation between a supplier (vendor) and a buyer. A negotiation process is time consuming and, therefore, penalties for untimely deliveries have been used only for long-term contracts. Second, penalties for untimely deliveries are designed for single-vendor, single-buyer interactions and has never been used to coordinate the entire supply chain. The proposed approach using blockchain technology for supply chain coordination addresses both of these limitations and improves supply chain coordination such that a decision optimal for a participant is also optimal for the entire supple chain. This research extends delivery performance models traditionally used for 2-stage supply chains to multi-stage supply chains using blockchain smart contracts. The proposed approach has the potential to transform supply chain coordination and to allow an expedited coordination process in which optimal decisions can be made within a decentralized supply chain without central authority and trust.

Moreover, the decision-making process can be automated such that delivery contracts will be signed and implemented with minimal human involvement. Blockchain smart contracts can potentially define optimal parameters of delivery contracts for buyers and initiate a delivery process at an optimal time for a supplier.

This research develops a general approach to modeling supply chain coordination. The approach demonstrated for delivery coordination can be applied to other forms of communication within a decentralized supply chain with low level of trust.

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Supply chain integration and mass customization capability to mitigate demand uncertainty: The case of food SMEs in Hajj

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ABSTRACT

Small- and medium-sized enterprises (SMEs) play an important role in the food chain throughout the Hajj season in the Kingdom of Saudi Arabia (KSA). This study examines supply chain strategies that can be used by SMEs to mitigate demand uncertainty during Hajj pilgrimage. Particularly, this study seeks to address the following questions: 1) how does supply chain integration (SCI) affect mass customization capability (MCC) and 2) How does the interrelationship between these two strategies mitigate demand uncertainty for food SMEs? The findings demonstrate that SCI has a significant effect on mass customization capability and on the mitigation of demand uncertainty.

KEYWORDS: Demand uncertainty; Mass customization capability; Food chains; Responsiveness; Supply chain integration; Survey

INTRODUCTION

Retailers play a key role in food provision during Hajj because of the huge numbers of foreign Muslim pilgrimages who go to Makkah during Al Hajj and who must be provided with food as they perform their religious obligation (Turban et al., 2015). The food demand by these pilgrimages and other tourists is usually very high because of the large numbers involved and retailers in food provision must therefore ensure that they meet the required demands and standards. Here, the retailers maintain low inventory levels and make frequent but smaller orders (Christopher, 2005). Although this management method is helpful in mitigating demand uncertainty effects, there remains the risk of stock-outs when demand rises quickly (Ulrich, 1995). Throughout the Hajji season, the SME food industry in Saudi faces this problem, even though it has adopted the Just- in-Time inventory management system. The SME food industry in Saudi has had to face the bullwhip effect that results from demand uncertainty (Shalaby, 2012). According to Lee et al. (2007), the bullwhip effect takes place when demand order uncertainties magnify as they move up the chain. According to these authors, distorted information from one end of the chain to the other can result in tremendous inefficiencies. These authors add that firms can effectively offset the bullwhip effect by understanding and accordingly addressing its underlying causes. This effect is based on psychology, where buyers from a company overreact to conditions where shops have stock-outs or excess inventory (Christopher, 2005). Whenever companies face this effect, they tend to over-buy after a stock-out problem and under-buy after an excess problem (Ayers, 2001). Either way, this reaction has always resulted in the opposite problem occurring. Without the adoption of adequate management techniques to mitigate the demand uncertainty, the SME food industry faces this bullwhip problem (Can, 2012). In other words, if demand uncertainty is not well mitigated, it leads to several problems in the SME food industry.

Demand uncertainty has been a burden to most SMEs in the food industry in Saudi Arabia (Turban et al., 2015). When demand uncertainty grips an organization, it affects the way the supply chain is managed. When completing inventory management, organizations strive to minimize stock outs and avoid the costs associated with holding inventory in excess. When an organization is unable to precisely predict demand, it runs the risk of over-buying and -selling at discounted rates in order to sell off excess (Christopher, 2005). At the same time, if an organization buys less in order to prevent wastage, peak times lead to stock-outs. This erodes customer confidence and can result in the loss of essential customers (Ulrich, 1995).

Several management practices have been put in place by different organizations with the aim of helping mitigate demand uncertainty. However, although extensive research has been conducted in an effort to identify the specific factors giving rise to supply chain uncertainty, most have focused on the manufacturing processes and supply-side processes, leaving demand-side uncertainties (end-customer, demand issues) under-researched (Simangunsong, 2011).Research on the mitigation of demand uncertainty amongst food SMEs is also scarce. Many sources of demand uncertainty, as well as mitigation through supply chain integration and mass customization capabilities have not received sufficient attention (Simangunsong, 2011). Specific research on SMEs in the food industry that operates during Hajj season in Saudi Arabia is yet to be conducted yet this is a key area that significantly contributes to the economic growth of the Kingdom. Studies show that demand uncertainty is the most severe type of uncertainty in the supply chain, resulting from volatile demand and inaccurate forecasts (Currie & Shalaby, 2011). Volatile demand and inaccurate forecasts are likely to characterize SMEs that operate in supplying food during the Hajj season, yet studies on how such firms manage these risks are non-existent (Currie & Shalaby, 2011). Moreover, the impact of SCI on manufacturing strategies, particularly its effect on mass customization capability to mitigate demand uncertainty has not been fully explored (Lai et al., 2012). Investigating these issues will provide more insight on how food SMES in the Hajj industry can address demand uncertainty mitigation through supply chain management practices and satisfy all customers visiting Makkah to attend Hajj, whilst at the same time leveraging their performance. Besides providing insight on management practices that can be used by practitioners in the industry, this study is also motivated by the fact that previous studies focused on SMEs in Saudi Arabia—and specifically on those operating in the food industry—are unavailable. The findings of this study therefore will contribute not only to practice but also to research and the overall body of knowledge on the mitigation of demand uncertainty through management practices for SMEs in the food industry. Considering the competitive nature of this sector, this study will also investigate the role of contingency factor (competitive intensity) in moderating the effects of SCI.

LITERATURE REVIEW

Contingency Theory and its Application in Supply Chain Management

Contingency theory which is one of the theories that have been widely used in the analysis of management practices was also will be used in the current study. Contingency theory asserts that an organization should match its processes, strategies and practices to its business environment (Donaldson, 2006). In this vein, Donaldson describes this as a behavioral theory that argues there is no best way of managing, organizing and leading a corporation or otherwise making decisions. Rather, it explains that the best course of action is dependent (contingent) on the internal and external situation. This theory maintains that the most effective organizational leadership or structural design involves the structure matching the contingencies. According to Flynn et al. (2010), this theory employs a reductionist approach, where the organization is treated as an entity that can be decomposed into various independent elements. Application of this theory for the current study stems from the realization of its importance in the study of the management of supply chains; this is in the analysis of the strategies that may be applied in supply chain management. Lai et al. (2012) also applied this theory in examination of the effect of SCI on MCC. These authors point out those previous studies have demonstrated that the value of a firm's external resources increases in an environment that is dynamic and competitive. Lai et al. (2012), provide the example of when competitive intensity and/or demand uncertainty is high, postponement, a key strategy that enables mass customization to be employed to cope with variability in the end product.

Other than having efficient coordination across the firm's internal functions, accurate and timely market-specific and component knowledge is also necessary when postponing differentiation. Improving internal integration and attaining knowledge from supply chain partners was considered more vital in this case for mass customization capability development (Lai et al., 2012). Another important study that has applied this theory in the investigation of the impact of SCI on performance is that conducted by Flynn et al. (2010). The study applied the contingency approach through the use of a hierarchical regression in an effort to establish the impact of individual SCI dimensions, namely internal, supplier and customer integration, and their interrelationships on firm performance. In their discussion of contingency approach to supply chain integration, Flynn et al. (2010) draw from the contingency theory, and accordingly explain that the processes and structures of an organization are shaped by the environment within which it operates. Organizations therefore must match their processes and structures to their environment so as to maximize performance. These authors are quick to add that customers and suppliers form an important part of an organization's (particularly manufacturer's) environment. These authors further mention structural contingency theory, which proposes that the success of how a firm performs depends on the degree to which the strategy it seeks to pursue matches or is aligned with the firm's design (Flynn et al., 2010). Literature on strategic management refers to this alignment between a firm's strategy and its performance as 'fit'. When applied to supply chain integration, this theory suggest that the individual types of SCI 'its dimensions, i.e. customer, internal and supplier integration' should be aligned for best performance in order to be achieved.

Resource-Based View and its Application in Supply Chain Management

In addition to the contingency theory, this study use the Resource-Based View (RBV) theory, which asserts that, simultaneously, valuable, rare and non-substitutable and inimitable resources can be effective sources of superior performance, which may enable enterprises to attain sustainable competitive advantage (Ambrosini et al., 2009). This theory has been used extensively in research in an effort to explain managerial practices and strategies centered on enhancing organizational performance. Important studies on the mitigation of supply chain uncertainty, such as that by Simangunsong et al. (2011), also have applied this theory in their research. In this study, the theory will be used to explain the importance of a firm's quest for integration with its customers and suppliers and also to predict the benefits of such integration. The resource perspective will provide a basis for discussing formulation of strategies to address demand uncertainty such as; the current resources to be used for mass customization as, which resources to be developed to ensure mass customization as MCC development also requires application of external resources, and the type of firms to integration links with to ensure internal and external integration. According to Vijayasarathy (2010), the RBV theory is one of the perspectives most widely adopted in supply chain studies. From the perspective of RBV, it is suggested that firms can gain sustainable advantage by developing and acquiring infrastructural resources as well as knowledge-based capabilities that are difficult for competitors to replicate. According to this author, this theory has been used by scholars to explain why organizations seek integration with their customers and suppliers, and also in predicting the rewards and benefits of such integration to organizations.

THEORETICAL DEVELOPMENT

Supply Chain Integration and Mass Customization Capability

According to Lai et al (2012), internal integration links various functions allowing firms to establish strategic resources. According to these authors, manufacturers use cross-functional coordination as well as alignment to integrate resources across the firm and to deploy them in a systematic manner. Inter-functional relationship management also makes certain that the process is cooperative and that any conflicting departmental interests are resolved. It provides a platform for different departments functions and departments to merge their opinions as well as suggestions and to integrate all resources through cooperation and working together (Lai et al. 2012). The integrated procedures and operational routines in turn facilitate creation and utilization of resources and improve problem- solving which then creates and increases organizational capability. According to Can (2008), effective internal integration therefore enables a firm to respond swiftly to customization needs of its customers and effectively address the challenges associated with product complexity, flexibility, variety as well as costs related with development of MCC.

As a supply chain management technique, integration has been most useful in cases where mass customization is used (Abdelkafi, 2008). Mass customization is a management technique whose application is mainly in areas where there is need to limit demand side uncertainty (Abdelkafi, 2008). Zhang et al. (2015) conducted a study that sought to consider two issues as regards integration and mass customization. The first study sought to examine how mass customization was influenced by integration of the suppliers, customer integration and internal integration while the second sought to establish whether certain environmental factors limited the effect of the integration of the supply chain. These authors provide insight and knowledge about mass customization. They also consider its inclusion as a supply chain management technique (Zhang et al., 2015). Zhang et al. (2015) contend that increase in competition amongst various industries and companies has necessitated the need for customization of products in order to successfully compete. This is regarded to be a differentiated strategy (Carneiro, 2012). According to this author, companies have to do this with minimal cost to improve their performance. In their paper Zhang et al, (2015) have pointed out that in order for companies to gain a competitive advantage, they must consider integration and reconfiguration of both external and internal resources. They contend that the implementation of the steps outlined in these two strategies will need to be undertaken in a way that adapts to the changing business environment (Kew & Stredwick, 2005). They used what they termed as the extended resource based view to develop a model that was used to study the economics of mass customization and the integration of the supply chain (Zhang, et al., 2015).

Zhang et al. (2015) were able to demonstrate in their study how internal and external integration may be utilized to achieve greater capabilities by companies. These thoughts contribute to the thinking of how mass customization capabilities (MCC) may be effectively achieved by companies. Zhang and his colleagues are able to indicate that internal integration and customer integration created the greatest effect on MCC. These authors came to the conclusion that the application of integration on the supply side has minimal effect on MCC according to their examination, whether this are directly or indirectly. They also show that the uncertainty in the demand in addition to the intensity of the competition may work towards negatively affecting the ability of the company to benefit from mass customization. Despite its limitations, the paper still provides knowledge that is valuable in the examination of supply chain integration and its effects on mass customization strategy (Zhang et al., 2015).
Lai et al (2012) point out that although II facilitates management of internal resources, successful MCC development also requires application of external resources which can be obtained through supplier and customer integration. Information sharing with customers and suppliers particularly enables the manufacturer to gain knowledge regarding the demand, raw materials, the market as well as components. Close relationship and engagement with suppliers and customers during product design incorporates their knowledge and voices into the manufacturing process therefore leading to more efficient and effective customization (Mikkola & Skjøtt-Larsen, 2004). Based on this discussion, it can be concluded that internal integration, customer integration and supplier integration all affect MCC in a positive manner.
2.3 The Relationship between Internal Integration and Mass Customization Capability
According Lai *et al*. (2012), the ERBV proposes that manufacturers can utilize internal and external resources towards capability development. The authors also mention that manufactures should incorporate both types of resources in an effort to come up with a hierarchy in which the extent of knowledge and resources is expanded as it shifts up the hierarchy. Therefore, the resources summed-up within the organization create a foundation for the attainment of external resources. Lai *et al*. (2012) further argue that internal integration could possibly assist an organization in facilitating external integration with both consumers and suppliers. The authors also mention that internal integration can increase the intensity of the capability and assist a manufacturer in creating a cohesive platform that breaks down internal subdivisions, tackles conflicts and reduces the obstacles facing supplier and customer participation. In this way, internal integration is presumed to have an indirect influence on MCC by enhancing external integration Lai et al. (2012). Internal integration therefore indirectly affects MCC through customer integration and supplier integration, and directly by enabling the firm to quickly respond to the customization needs of its customers and effectively address the challenges associated with product complexity, flexibility and variety, and the costs related to the development of MCC. Therefore, we hypothesize the following:

H1: Internal integration in food SMES is significantly and directly associated with their mass customization capability during Hajj
H2: Internal integration of food SMEs in Hajj has significant and indirect effect on mass customization capability through customer integration.
H3: Internal integration of food SMEs in Hajj has significant and indirect effect on mass customization capability through supplier integration

The Relationship between Customer Integration and Mass Customization Capability

CI mainly involves customer partnership, sharing customer information as well as customer involvement in design and delivery of products (Flynn et al. 2010). CI allows enables

manufacturers to access customer information, share this knowledge, speed up decision making processes, improve process flexibility, reduce lead times and pursue joint development processes and activities (Lai et al. 2012). CI is therefore important as it enables manufacturers to acquire information regarding customer requirements and also gain a better understanding of customer needs and preferences. Therefore, we hypothesize:
H4: Customer integration in food SMES is significantly and directly associated with mass customization capability during Hajj.

Relationship between Suppler Integration and Mass Customization Capability

SI mainly entails supplier partnerships, the sharing of information with suppliers, and involving them in product development (Lai *et al*., 2012). This integration enables manufacturers to gain greater inputs from suppliers, and also to include their suggestions and recommendations within their business operations. This further facilitates the smooth and timely delivery of a variety of raw materials and components for mass customization. Therefore, we hypothesize the following:
H5: Supplier Integration in food SMES is significantly and directly associated with mass customization capability during Hajj

The Relationship between Supply Chain Integration (SCI) and Mass Customization Capability (MCC) with Demand Uncertainty Mitigation (DUM)

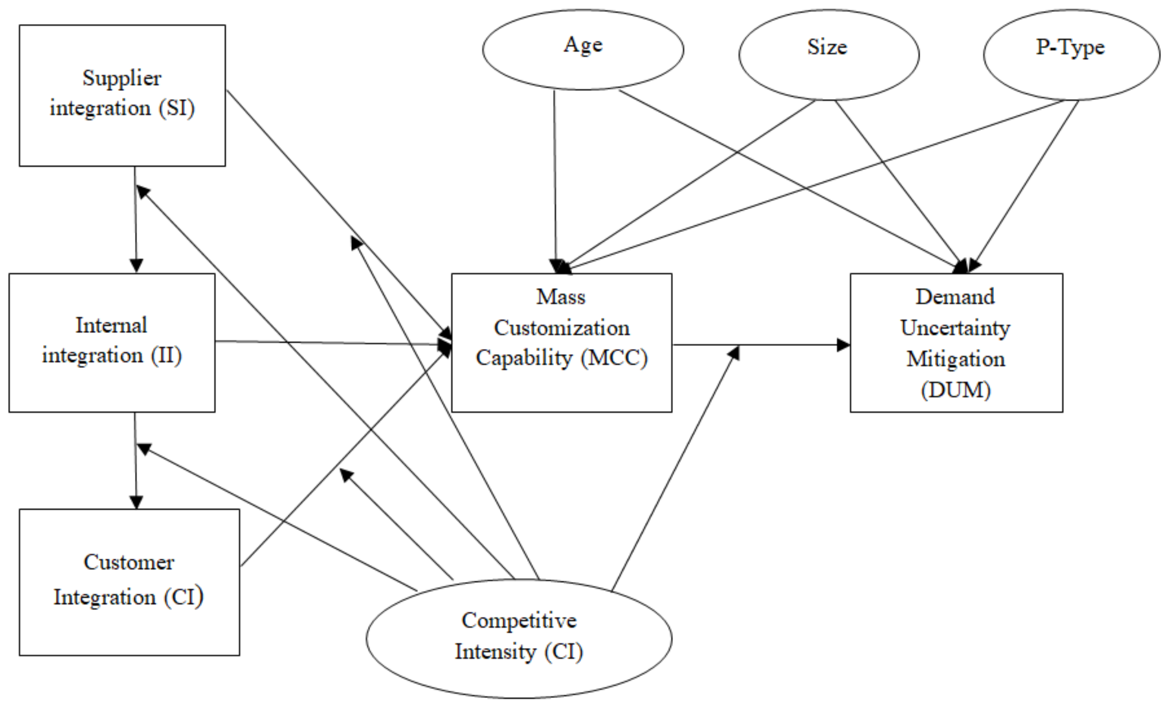
Drawing from the extended RBV of the firm, Lai *et al*. (2012) argue that all three types of supply chain integration (II, SI and CI) influence the development of MCC within a firm owing to the fact that both internal and external integration promote the strategic resources considered crucial to MCC development. The authors also mention that II can increase the intensity of capability and thereby assist a manufacturer in creating a cohesive platform that is able to break down internal subdivisions, tackle conflicts and reduce the obstacles regarding supplier and customer participation. In this way, II is presumed to have an indirect influence on MCC by enhancing external integration (SI and CI).
H6: Mass customization capability by SMEs has significant and direct effect on mitigating demand uncertainty of food during Hajj.

Contingent Effects of Demand Uncertainty (DU) and Competitive Intensity (CPI)

Demand uncertainties, in addition to competitive intensity, are presumed to be key environmental conditions designed for MCC. Lai *et al*. (2012) assert that there is empirical evidence to suggest that the influence of supply chain integration towards operating capabilities possibly could be moderated by the context of the environment. For instance, when there is a rapid shift in demand, manufactures require new knowledge to control customization owing to the fact the existing experience swiftly turns out invalid. On the other hand, however, when there is low level of demand uncertainty, manufacturers create their MCC through designs, productions, and the delivery of customized products, all of which depend on existing resources and knowledge (Lai *et al*. (2012). Tackling demands that are unpredictable and subsequently developing customized products requires the united efforts of the partners in the supply chain, such as by working together with customers. Therefore, when firms increase collaboration with their suppliers, the organization is positioned to explore and improve the variety of possible solutions for tackling customers' needs and accordingly lowering costs and lead times through improvement in joint processes (Lai *et al*., 2012). Hence, it can be concluded that in an environment characterized by competitive intensity, manufactures can improve the influence of

internal integration on external integration and consequently develop and improve MCC. Based on this, it is argued that demand uncertainty increases the indirect impact of II on MCC through customer and supplier integration.
H7: Competitive Intensity significantly enhances the indirect effect of internal integration on mass customization capability of food SMEs in Hajj through supplier integration.
H8: Competitive Intensity significantly enhances the indirect effect of internal integration on mass customization capability of food SMEs in Hajj through customer integration. Figure 1 integrates the aforementioned hypotheses into a conceptual model whereby control variables include; age and size of the firm as well as product type (or P-type).

Figure 1: Conceptual Framework



To achieve its purpose, the current study used the SMEs across Saudi Arabia that supply food to Hajj pilgrims as the population of the study. In order to validate the formulated conceptual framework, 12 CEOs who work in different food SMEs across KSA were initially interviewed. The interviewees were identified and recruited using snowball sampling. Sample size of 12 is considered to be reasonable for collecting qualitative data, as it provided enough information based on the interviewees' firsthand experience with the issues under investigation (Adler & Adler, 2012). In addition to validating the conceptual framework, the interviews sought determine the face as well as content validity of the survey tool (which explained in details in the next section). Quantitative data also collected in addition to the qualitative data by adopting convenience sampling technique because of non-availability of the sampling frame (Saunders et al., 2014).

METHODS

Measures and survey tool

The measures for the current study were developed based on information obtained from the qualitative interviews, literature review, opinions from academic experts, pilot testing and rigorous revisions. The measurements were based on a Seven-point Likert scale. The items for the different constructs are extracted from the following sources: for CI from Flynn et al., (2010); Lai et al., (2012), and Mikkola & Larsen (2004), for II from study by Lai et al. (2012); Mikkola & Larsen (2004), for CPI; (Lai *et al*., 2012); and finally for mass customisation studies; Lai et al., (2012); Mikkola & Larsen (2004); Chandra &Kamrani (2004); Can (2012); Huang et al., (2010). The items for DUM construct were partially adapted from the study conducted by Zahra and George (2002). The list of measurement items are provided in Appendix A. The survey instrument was prepared in English and translated in Arabic to connect appropriately with the local community. Direct translation approach is used to translate the questionnaire and to assess the equivalence of the questionnaire to ensure the reliability of the questionnaire (Green & White, 2000; Punnett & Oded, 2004). Accuracy of the questionnaire was established by focusing on meaning or content rather than the syntax of the language as recommended by Punnett and Oded (2004). An online questionnaire was sent to respective firms through the electronic medium.

The study respondents were asked to indicate the number of firm employees as a measure of size. Consistent with prior research, logged scores were computed and used as size variable (Swamidass & Kotha 1998). Dummy variables were used to control for firm age effects. “Younger firms may have great difficulty generating sufficient revenue while concurrently dealing with start-up costs that older enterprises have long since absorbed” (Thornhill & Amit, 2003) Thus, assessing firm’s age effects on PP and DUM is crucial. The firm’s production type (fresh meal, pre-cooked, raw material wholesale) was considered as an indicator of product variety. To validate the survey instrument, a pilot study was carried on a sample of 50 subcontractors, Hajj campaigns, pilgrimages' institutions and food suppliers to test the validity and reliability of the study’s questionnaire and its relative measures. Necessary adjustments were applied to the questionnaire after the pilot study.

Data analysis Method

Partial Least Squares (PLS) technique which is one of the important structural equations modelling (SEM) technique that is considered as second generation modelling technique that performs dual function was chosen for analyzing the collected data (Fornell & Brookstein, 1982). It functions as measurement model and assesses the quality of the research constructs and also as structural model and assesses the relationship between the outlined constructs (Fornell & Brookstein, 1982). PLS follows a soft SEM modelling approach and has no assumptions of data distribution and can be applied when: a) theory on the study’s constructs and applications is minimal, b) accuracy in predicting is high and, c) appropriate model specification cannot be guaranteed (Hair et al., 2010). Analysis through PLS although less developed, focuses on theory development and prediction with reflective/formative constructs and functions under small and large number of indicators per construct. It involves two models, measurement model and structural model, whose evaluation determines whether the theoretical model is consistent with the collected data. While the measurement model is evaluated through Confirmatory factor analysis (CFA), structural model models the structural relationships between observed variables (vs latent variables) are modelled (Vinzi, et al., 2010). The study’s assumptions are tested using multivariate analysis. Model complexity is analyzed and data is screened for missing data and outliners.

Sample size
The current study is based on PLS-SEM to validate the relationship between the study's constructs it is well-known for its power conducting research analysis based on small sample sizes. The sample size based on PLS-SEM is dependent on five crucial factors. The study's assumptions are tested using multivariate analysis. Estimation technique is identified to estimate the sample size. Model complexity is analyzed and data is screened for missing data and outliners. Average error of variance is estimated using SPSS (Hair et al., 2010). A sample size of 200 is recommended for complicated model (Kline, 2005). However, sample size of 300 is also recommended (Hair *et al*., 2010). Given the complexity of the current study, the sample size was 245 responses collected from food SMEs who operate in Hajj season and after excluding the 6 outliers, a sample size of 239 is obtained for data collection. The bootstrapping process was conducted for 5000 samples and path loadings and R2 values are estimated. While path loadings identify the strength of the relationship between independent and dependent variables, R2 measures the predictive power of the variables. SmartPLS 2.0 M3 software by Ringle et al. (2010) was used to identify the measurement and structural model. Bootstrapping estimation procedure is used to identify the significance of scale factor loadings and path coefficients of measurement model and structural model respectively (Gefen & Straub, 2005).

RESULTS

Measurement Model

Confirmatory factor analysis (CFA) was conducted using PLS-SEM to assess the reliability and validity of the multiple-item scale. The results of factor loading are summarized in Table 1. Reliability, convergent validity and discriminant validity tests are conducted in lieu with the 1982 guidelines of Fornell and Larcker (1982). Item reliability and composite reliability tests, which are superior to Cronbach's Alpha, are conducted in quantitative analysis since these tests consider actual factor loadings rather than assigning assumed equal weight for each item. Average Variance Extracted (AVE) is used to assess convergent validity, and discriminant validity is assessed in the following process. The square roots of the AVE of each construct are compared with correlations between the focal construct and each construct. Discriminant validity thus is established when a square root is higher than the correlation with other constructs. Indicator reliability refers to the square root of outer loadings and value of 0.70 or higher value validates indicator reliability (Hulland, 1999). Internal consistency reliability has been established when the composite reliability is 0.70 or higher (Bagozzi & Yi, 1988). Given that the composite reliability ranges from 0.9317 to 0.9754, which is greater than the recommended 0.70 value, internal consistency reliability is established.

Table 1: Outer model loadings (factor loading)						
	CI	II	SI	MCC	DUM	CPI
CIQ1	0.9442					
CIQ2	0.9549					
CIQ3	0.9377					
IIQ1		0.9678				
IIQ2		0.9654				
IIQ3		0.9592				
SIQ1			0.9620			
SIQ2			0.9138			
SIQ3			0.9339			
MCCQ1				0.9627		
MCCQ2				0.8768		
MCCQ3				0.9292		
DUM1					0.9396	
DUM2					0.8056	
DUM3					0.9643	
CPI1						0.9635
CPI2						0.9648
CPI3						0.9411

Note: Outer model loadings or factor loadings are extracted to conduct the CFA analysis

Average Variance Extracted (AVE) was also used to evaluate convergent validity, with the evaluation of discriminant validity in subsequent process. The presence or absence of convergent validity was established through AVE values. The AVE values should be equal to or greater than 0.5, and then the convergent validity would be determined (Baggozz & Yi, 1988). When considering that the AVE values are greater than the suggested value of 0.5 (spanning 0.8206–0.9295), as detailed in Table 2. The outer model loadings, as demonstrated in Table 1 are also found to be greater than the 0.70 values indicating that an establishment of convergent validity. The results of factor loadings from the t-statistics also exhibited significance at $p<0.01$, and communalities >0.500, which also clearly demonstrate convergent validity (Hair et al., 2010). Discriminant validity was evaluating through the contrasting of the square roots of each construct's AVE alongside the links between the focal construct and all other constructs. Therefore, the establishment of discriminant validity is achieved upon there being a greater square root than the correlation with other constructs (Fornell & Larcker, 1982). Table 3 provides clear indication as to the inter-construct correlation values of the diagonal of the matrix. On the diagonal, a contrast between the AVE square roots and the correlation values suggests discriminant validity. Note that Square root of AVE is written in bold on the diagonal of the table.

Table 2: CFA analysis					
Item **	Loading	T-Value *	C.R	AVE	
Customer Integration					(Reliability) Indicator Reliability Square each of the outer loadings to find the indicator reliability Value. 0.70 or higher is preferred. If it is an exploratory research, 0.4 or higher is acceptable. (Hulland, 1999). Internal Consistency Reliability Composite reliability should be 0.7 or higher. If it is an exploratory research, 0.6 or higher is acceptable. (Bagozzi and Yi, 1988).
CI1	0.9442	34.4739	0.9621	0.8942	
CI2	0.9549	30.0859			
CI3	0.9377	22.4917			
Internal Integration					
II1	0.9678	36.8457	0.9754	0.9295	
II2	0.9654	36.3637			
II3	0.9592	30.4638			
Supplier Integration					
SI1	0.9620	27.3363	0.9561	0.8780	
SI2	0.9138	17.3004			
SI3	0.9339	19.4477			
Mass Customization Capability					(Validity) Convergent validity It should be 0.5 or higher (Bagozzi and Yi, 1988). Discriminant validity Fornell and Larcker (1981) suggest that the “square root” of AVE of each latent variable should be greater than the correlations among the latent variables.
MCC1	0.9627	44.4393	0.9456	0.8530	
MCC2	0.8768	21.2575			
MCC3	0.9292	29.7281			
Demand Uncertainty Mitigation					
DUM1	0.9396	18.2925	0.9317	0.8206	
DUM2	0.8056	15.2333			
DUM3	0.9643	33.7083			
Competitive Intensity					
CPI1	0.9635	29.1807	0.9701	0.9150	
CPI2	0.9648	32.2481			
CPI3	0.9411	23.2297			
COMPANY SIZE	1.0000	n.a	n.a	n.a	
COMPANY AGE	1.0000	n.a	n.a	n.a	
COMPANY PRODUCT	1.0000	n.a	n.a	n.a	

Note: CR- composite reliability; AVE-average variance extracted; * all item loadings are significant at the P<0.01 level

Table 3: Criterion analysis for checking discriminant validity									
	SI	II	CI	MCC	DUM	CPI	SIZE	AGE	PRODUCT TYPES
SI	0.9370								
II	0.5105	0.9641							
CI	0.5166	0.3797	0.9456						
MCC	0.5004	0.3716	0.5145	0.9235					
DUM	0.4617	0.3440	0.5330	0.6017	0.9058				
CPI	0.2725	0.2375	0.4827	0.3940	0.4211	0.9585			
SIZE	0.7621	0.0557	0.0201	0.0016	0.1575	0.2541	n.a		
AGE	0.0720	0.0521	0.0616	0.0605	0.0165	0.0053	0.7621	n.a	
PRODUCT	0.0123	0.0521	0.0616	0.0605	0.0165	0.5106	0.0123	0.2383	n.a

Structural Model

Examination of the structural model was carried out through Smart-PLS, with the various outlined hypotheses subjected to testing. A basic model with key effects was primarily created and tested, the findings of path coefficients are superimposed on the path diagram in Figure 2 below. As can be seen from this depiction, the DUM shows a 34% variance (R2), 46% variance in MCC, 20% in SI, and 15% in CI. T-statistics of path coefficients are summarized in Table 4

Figure 2: Structural model with path coefficient estimates

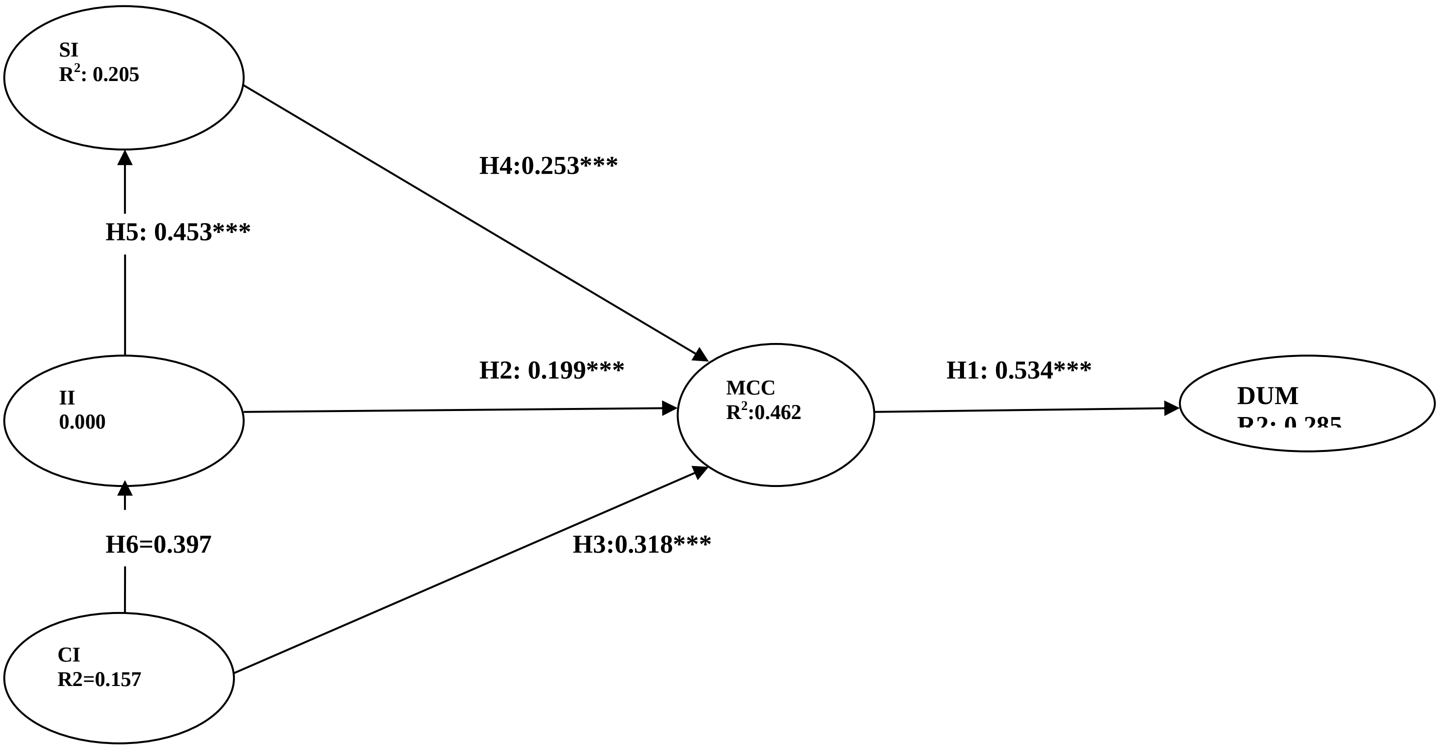


Table 4: T-Statistics of Path Coefficients	
	T-Statistics
CI -> MCC	3.9314
II -> CI	7.2749
II -> MCC	2.702
II -> SI	8.6952
MCC -> DUM	4.1138
SI -> MCC	1.6011

Note: Checking Structural Path Significance in Bootstrapping

Direct effects

The values obtained from these models may be used to determine the indirect and direct effects of the constructs of the study on one another. Direct effects are attained so as to validate the link between each supply chain integration type and mass customization capability. As per the path coefficients, internal integration (0.168, $p < 0.01$), customer integration (0.235, $p < 0.001$) are seen to have a direct effect on mass customization capability, thus validated H1: Internal integration in food SMES is significantly and directly associated with their mass customization capability during Hajj, and H4: Customer integration in food SMES is significantly and directly associated with mass customization capability during Hajj with validation, while supplier integration has no significant effect on it (0.094, ns), therefore H5: Supplier Integration in food SMES is significantly and directly associated with mass customization capability during Hajj is rejected. In addition to the direct impact of MCC on DUM is validated by the path coefficient (0.305, $p > 0.001$). H6: Mass customization capability by SMEs has significant and direct effect on mitigating demand uncertainty of food during Hajj is validated

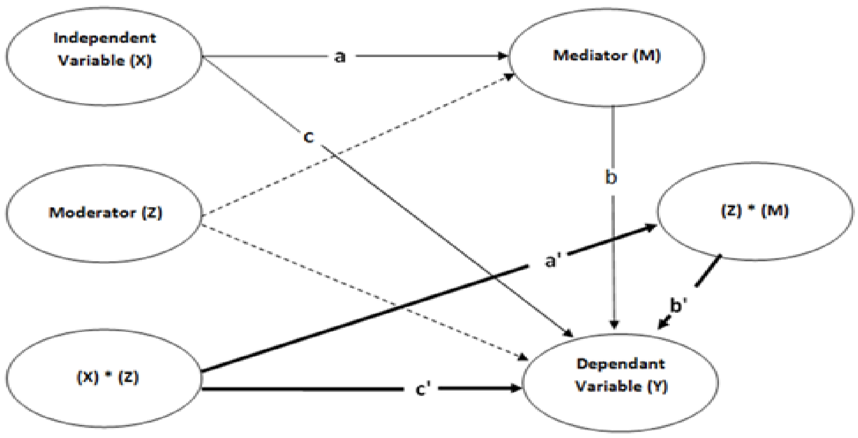
Mediating effects

In order to know whether the effect of internal integration to mass customization capability is mediated by external integration, the indirect effects were calculated through multiplying the path coefficients from integration through to external integration (a), as well as from external integration through to mass customization capability (b), where the customer integration indirect effect was found to be $0.397\times 0.235= 0.093$, ($p > 0.05$) and the indirect effect of supplier integration was $0.453\times 0.094= 0.042$, ($p > 0.001$). Accordingly, *H2 Internal integration of food SMEs in Hajj has significant and indirect effect on mass customization capability through customer integration,* and *H3*: *Internal integration of food SMEs in Hajj has significant and indirect effect on mass customization capability through supplier integration*, are validated.

4.1 Moderating effect

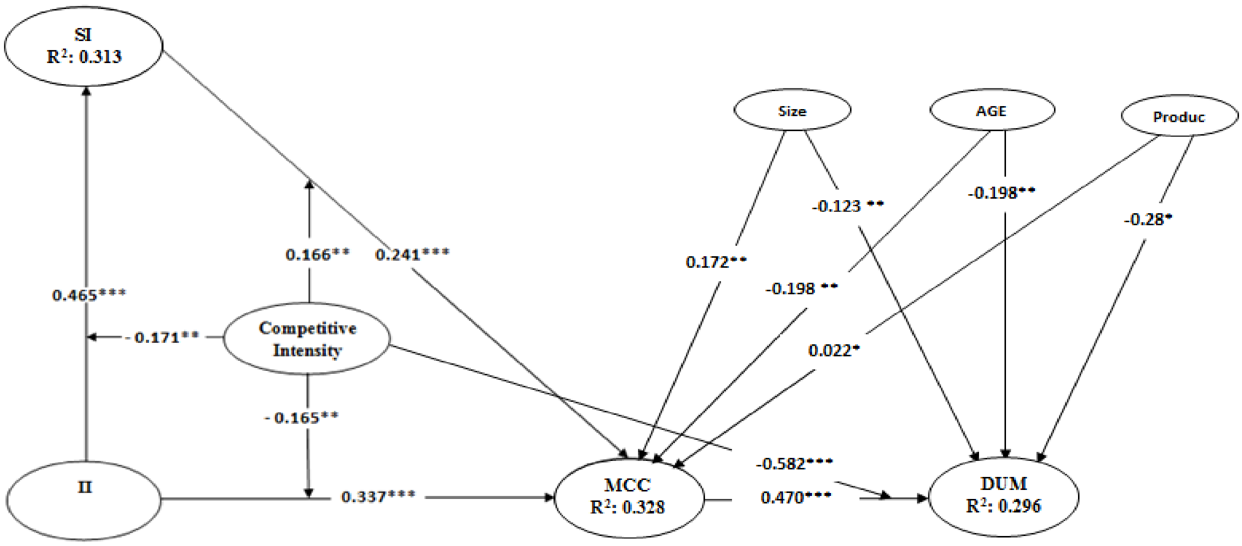
In order to complete the testing of the moderating effects relating to competitive intensity on the indirect effects of internal integration through external integration on mass customisation capability of firms, conditional indirect models were built, adhering to the process detailed by (Iacobucci, 2008). A basic model demonstrating the main effects was created and tested, the results are presented in Figure 3.

Figure3: Basic model of moderated mediation effects on study's variables (Conditional indirect effects)



In an effort to create the conditional indirect models, moderator and four interaction terms were incorporated as indicated in Figures 4 and 5. Figure 4 demonstrates that moderating effects of competitive intensity on the path from internal integration to supplier integration is negative and significant (β = -0.171; $p < 0.01$). The moderating effects of competitive intensity on the path from supplier integration to mass customization capability is significant (β = 0.166; $p < 0.01$). The products a' × b' (-0.171×0.166 = - 0.028) is negative and significant at the $p < 0.05$ level. Accordingly, H7 is validated

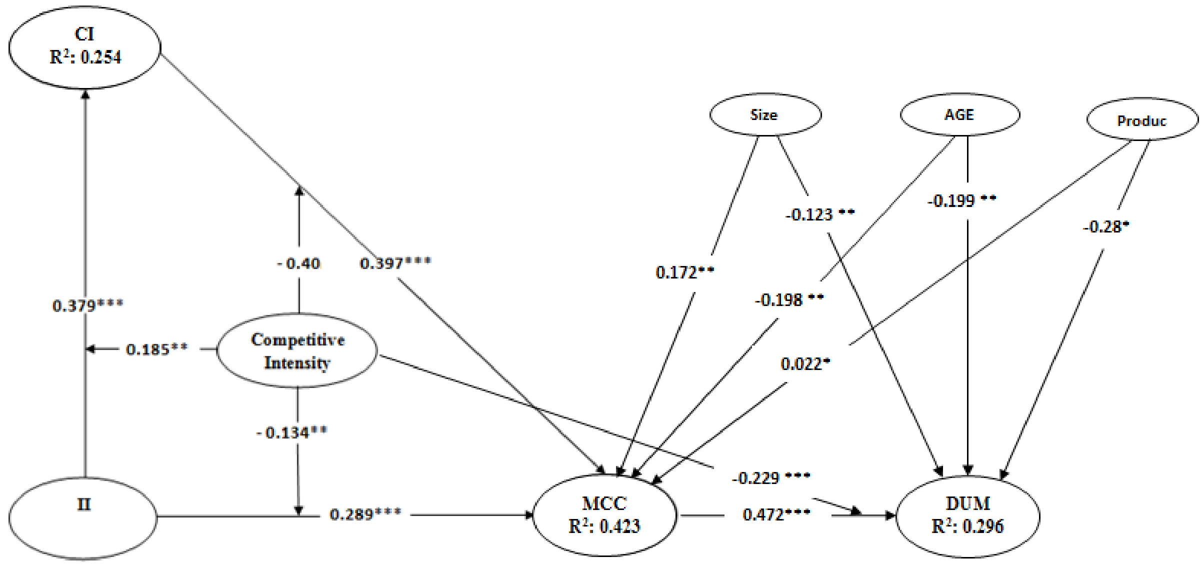
Figure 4: Conditional indirect effects



As can be seen in Figure 5, the moderating effects of competitive intensity on the path from internal integration to customer integration is significant (β = 0.185; $p < 0.01$). The moderating effects of competitive intensity on the path from customer integration to mass customization capability is negative and significant (β = -0.40; $p < 0.01$). The products a' × b' (0.185×-0.40 = - 0.074) is negative and significant at the $p < 0.05$ level. H8: Competitive Intensity enhances

significantly the indirect effect of internal integration on mass customization capability of food SMEs in Hajj through customer integration is validated.
With regards to control variables, Figures 4 and 5 demonstrate that firm size has a positive significant effect on mass customization capability (β= 0.172; p < 0.01). Moreover, a negatively significant effect is seen to stem from firm age on mass customization capability (β= -0.198; p < 0.01). Product type is also found to have significant effect on mass customization capability (β= 0.022; p < 0.01). Furthermore, firm size, age and product type have negative significant effect on demand uncertainty mitigation, β = -0.123, β= -0.198, β= -0.28 (p < 0.01) respectively.

Figure 5: conditional indirect effect
(moderation estimation of competitive intensity on the path from internal integration to customer integration and on the path from customer integration to mass customization capability)



DISCUSSION

During the six-day pilgrimage or the lesser pilgrimage, and based on the fact that most of the visitors who come for the pilgrimages are foreigners, the demand for consumer goods raises sharply (Turban et al., 2015). In essence, consumer goods retailers are faced with a huge challenge of providing all the consumer goods required and in quantities and quality that will satisfy all the pilgrims. This is quite complicated especially because it is difficult to predict the exact demands and product tastes of the pilgrims (Turban et al., 2015). These uncertainties are rife among the SMEs that supply to the pilgrims who go to Makkah to take part in the pilgrimage. Mitigating these problems is central to all prudent SMEs which not only wishes to avoid losses but also seeks to satisfy their consumers. Uncertainties in demand and tastes have adverse effects on the performance of these SMEs as would be the case for all businesses. The current study sought to explore the relationship between internal and external integration and their interaction with mass customization capability of firms to mitigate demand uncertainty faced by food SMEs during the Hajj season. The results elucidate that supply chain integration (SCI) has a significant impact on mass customization capability of firms and the interrelationship between the SCI types mitigate demand uncertainty. The key findings of the research along with implications for food SMEs who are involved in Hajj operations are summarized as follows; First, the study confirmed that mass customization capability has a significant direct and positive effect on mitigating demand uncertainty for food SMEs in KSA during the Hajj season. These findings are partly supported by Zhang et al. (2015) who found that mass customization capability helps reduce demand uncertainty by improving product innovation capability of the firm. Similar sentiments are echoed by Lai et al. (2012) who explain that mass customization capability enables firms to attain new and innovative forms of competitive advantage. Qi et al. (2014) also established that the mass customization capabilities of a firm are enabled by coordination practices of the supply chain. According to these authors, MCC enables firms to respond to survive in the today’s markets that are characterized by heterogeneous and ever changing customer demands. These sentiments are also echoed by the CEOs who were interviewed as they emphasized that SCI has a strong impact on MCC as firms need to integrate customers as well as suppliers in their processes for them to effectively customize orders to meet customer needs in a timely and efficient manner. Primary data from the survey questionnaire and the interviews indicate that MCC has a strong positive impact on demand uncertainty mitigation but is mediated by other factors and in particular supply chain integration and MCC. These findings are supported by Lai et al. (2012); Qi et al. (2014); Kull (2015); and Zhang et al. (2015).

Implementing mass customization capability as a managerial strategy for mitigating demand uncertainty in the Saudi Arabian food industry would also greatly impact the efficiency and competitiveness of the SMEs (Rudberg & Wikner, 2004). In essence, a mass customization capability allows the organization to place a lot of emphasis on the customer and his inherent needs. To be effective in mitigating demand uncertainty, a firm that an implement MCC to manage its supply chain has to create an environment where an optimal balance between productivity and flexibility is attained (Thallmaier, 2014). In essence, identifying the balancing point helps a firm to identify what decisions can be under certainty and those under uncertainty with regards to customer demand according to (Rudberg & Wikner, 2004)). The CODP model elaborates the activities that a firm can undertake as forecast driven initiatives regarding customer demand when carried under uncertainty and the activities that are purely driven by the customer’s order. It also helps in identifying the speculation point (Umeda et al., 2015).

Identifying all these parameters is of significant importance to businesses and even more so SMEs in the Saudi's food industry.

Second, this research showed that internal integration, customer and supplier integration in SMEs all have a direct and positive effect on their mass customization capabilities. Importance of CI is also illustrated by Claycomb et al. (2005) who found that for manufacturing firms to create flexibility, customer knowledge is key. The study investigated production technology routineness, compared flexibility between made-to-stock and made-to-order, and also enablers of flexibility. The study established that customer knowledge absolutely mediates the correlation between made-to-order and routineness with the firm's financial performance. This study concluded that financial success of applying mass customization extensively depends on application of customer knowledge and inventory levels of finished products. This study emphasizes on the mediating role of CI in enabling mass customization and ensuring success of the firm. These findings also collaborate those obtained by earlier studies. According to Kocoglu et al. (2011), it is worth noting that integration of supply chains through better flow of information between the supplier and firm is also critical in mitigating demand uncertainty. Such integration involves both internal and external aspects of the whole supply chain. MCC, therefore, is effective when implemented in conjunction with other managerial strategies supply chain integration (Kull, 2015). With regards to customer integration, Lai et al (2012) explain that in management of internal resources, successful MCC development requires application of external resources which can be obtained through supplier and customer integration. Information sharing with customers enables the manufacturer to gain knowledge regarding the demand and time of delivery. Close relationship and engagement with customers during product design incorporates their knowledge and voices into the manufacturing process therefore leading to effective customization (Mikkola & Skjøtt-Larsen, 2004). Lai et al. (2012) adds that for MCC to be effective in mitigating demand uncertainty there must be collaboration as well as resource integration beyond the firm's internal boundaries. According to Mikkola and Skjott-Larsen (2004), application of external resources which can be obtained through supplier integration is key to effective implementation of MCC. Information sharing with suppliers enables a manufacturer to gain knowledge regarding raw materials, the market as well as components. Close engagement with suppliers during product design incorporates their knowledge and voices into the manufacturing process therefore leading to more efficiency (Mikkola & Skjott-Larsen, 2004).

The findings of the present study are also consistent with those of the study conducted by Maglaras et al., (2015) who explored the most significant practices that are applied in the power-imbalanced dyadic supplier-to-retailer relationships in food chains in Greek. This study also evaluated how suppliers perceive these relationships as retail power is stronger in the supply chain. The study established financial goal incompatibility, dependence, behavioral uncertainty and informational asymmetry as the most significant factors that determine commercial practices in the Greek food chain. These practices are categorized into upfront. payments, negotiation pressures, and unanticipated changes of agreements. According to this study, these practices are very important to suppliers and must be taken into great consideration by the retailers. The study confirms that the practices applied by suppliers should not create unnecessary pressure to suppliers as this will have detrimental effect on their dyadic relationship. This study emphasizes on the importance of supplier integration to the success of SMEs that operate in the food industry. These findings are also confirmed by Bourlakis et al. (2014). The study conducted by Bourlakis et al. (2014) also emphasizes on the importance of suppliers in the food supply chain. According to this study, contrary to previous research findings which argue that retailers play the most powerful role in supply chains, large manufacturers who supply retailers are the champions of sustainability performance. This study emphasizes for retailers to achieve sustainable performance, they must ensure that they cooperate well with their suppliers.

This implies that supply chain integration is a mediating factor in the relationship between MCC and mitigation of demand uncertainty. By breaking down traditional silos and empowering learning across different functionalities of the firm and asset combination, internal integration activities encourage the utilization of inside firm assets and proficiencies to efficiently ensure MCC, a finding that is in accordance with the resource based view (RBV). SMEs in KSA need to collaborate coordinate and cooperate with their varied process, people and machinery that are involved in preparing, processing, and packing, storing and preserving the food during the Hajj season. SMEs can also attain vital competencies in the business sector by coordinating both interior assets and outer assets from production network accomplices, specifically from customers, consequently giving experimental validation to the extended resource based view (ERBV). Information sharing with customers enables the manufacturer to gain knowledge regarding the demand and time of delivery. Close relationship and engagement with customers during product design incorporates their knowledge and voices into the manufacturing process therefore leading to effective customization. SMEs in KSA also need to build strong relationship with their respective suppliers to maintain consistent supply of raw materials or food products based on loyalty and trust. With an understanding relationship with the suppliers, SMEs can place their varied requests and specify their requirements from various suppliers, without affecting their performance whilst managing customers' demands.

Third, the study established that internal integration of food SMEs has a positive influence on customer and supplier integration, which is in line with the findings of Zhao et al., (2008). In addition, it was found that, internal integration has a significant indirect effect on mass customization capability through enhancement of customer and supplier integration. This clearly demonstrates that the foundation of SCI begins with internal integration.

Fourth, on inclusion of competitive intensity as a contingent factor, the study established that competitive intensity significantly and indirectly enhances the effect of internal integration on mass customization capability of food SMEs during the Hajj season through supplier integration. The results show that through supplier integration, competitive intensity enhances the operational levels of the SMEs and integrate the internal functions of the organization, hence producing necessary effects on MCC. This is in line with the findings by Lai *et al*. (2012) that, when firms increase collaboration with their suppliers, the organization is positioned to explore and improve the variety of possible solutions for tackling customers' needs and accordingly lowering costs and lead times through improvement in joint processes. This study also established that manufactures can improve the influence of internal integration on external integration and consequently develop and improve MCC. The study also established that there is *competitive Intensity enhances the indirect effect of internal integration on mass customization capability of food SMEs in Hajj through customer integration. Lai et al (2012) argues that* when there is low level of demand uncertainty, manufacturers create their MCC through designs, productions, and the delivery of customized products which depend on existing resources and knowledge that requires the united efforts of the partners in the supply chain, such as by working together with customers. The findings demonstrate that competitive intensity increases the indirect impact of II on MCC through customer and supplier integration. The implication for SMEs in KSA is that in an environment characterized by demand uncertainty, the firms can improve the influence of internal integration on external integration and consequently develop and improve MCC.

Lastly, the current study demonstrated that size and age of the firm play significant roles on mass customization capability of food SMEs in Hajj. The results demonstrate positive significant effect of firm's size on mass customization capability and negative significant effect of firm's age

on mass customization capability. This implies that MCC of a firm is directly affected by the number of employees within the firm, and inversely affected by the firm's age. This correlation forces firms to consider their size and age while practicing mass customization. Generalizability in terms of MCC cannot be attained n spite of the absence of significant association between product type and MCC. However, presence of significant association between firm's size, age, product type with DUM, enables generalization of the findings across food industry in KSA.
The study provides clear understanding of the impact of supply chain integration on MCC in mitigating demand uncertainty during the Hajj operation. Bothe the primary data and literature review indicate that mass customization capability as a managerial strategy that has the capability to mitigate demand uncertainty for Saudi Arabia's food retail SMEs. The relationship between mass customization capabilities and demand uncertainty mitigation was however found to be mediated by other practices such as supply chain integration types. It is concluded that implementing mass customization capability as a managerial strategy for mitigating demand uncertainty in the Saudi Arabian food industry would also greatly impact the efficiency and competitiveness of the SMEs.

CONCLUSION

On an annual basis, the Hajj is carried out by millions of Muslims in the Kingdom of Saudi Arabia (KSA), as recognized by many scholars, including. It is recognized that, as a result of Hajj in 2012 alone, the KSA secured revenues equating to US$16.5 billion, 3% of which was acknowledged as Gross Domestic Product (GDP). Considering the global involvement of this celebration and the size of the event, it is imperative that food supply is consistent, which is one of the most pressing requirements throughout the season. Moreover, during this time, food is supplied through service offices, self-cooking and missions. Furthermore, more than half (58%) of the pilgrims are known to visit from international regions. The countless number of pilgrims in the Kingdom of Saudi Arabia therefore are recognized as having a diverse range of demands, expectations, needs and tastes, especially in regard to food. Therefore there is a need for food suppliers to ensure the deliverance of particular cuisines in order to fulfil the needs of pilgrims. It has however been established that holding optimal stocks by Saudi Arabian SMEs which operate in the food industry is complicated by demand uncertainty specifically during major festivities such as Hajj pilgrimage. The present research has centered on investigating and examining the link between external and internal integration, and its interaction with mass customization capability to mitigate the uncertainty of demand amongst SMEs throughout the period of the Hajj season. The findings from the present work show that supply chain integration has a notable effect on MCC, where the interlink between the SCI types are seen to mitigate demand uncertainty.
The study highlighted the presence of direct impact of internal integration, customer integration and supplier integration on MCC of food SMEs during the Hajj season. The moderating effects of competitive intensity on the indirect effects of internal integration through external integration on MCC were also examined. The study demonstrated the indirect capacitive effect of competitive intensity on MCC. Competitive intensity can enhance internal integration through supplier integration as well as customer integration to produce indirect effect on the MCC. .The study validated seven relationships among the eight hypothesized relationships between SCI, MCC, DUM in the presence of contingent factor CPI and control variables. The study validated the impact of MCC on DUM and determined that external integration carried the effect of internal integration to MCC. Ultimately, the study indirectly established a relationship between SCI and DUM and validated the importance of SCI practices on mass customization capability and DUM.

It is worth noting that this study was limited in scope both in regards to the recommendations provided for mitigating demand uncertainty and in the target businesses. Specifically, the research only recommended the adoption of SCI and MCC in mitigating demand uncertainty. The rationale for restricting the research scope to these managerial strategies was to reduce the ambiguity of the recommendations and was based on the specific problems that created demand uncertainty in the Saudi food industry. The recommendations were based on the contingency theory that asserts the need for an organization to align its processes and strategies to its environment and the resource based view theory which asserts that a business's competitive advantage is held in its efficient application of both its tangible and intangible resources. There are multiple other strategies that can be used to mitigate demand but the recommended strategies are the most viable given the general circumstances. The adaptability of the findings of this research are, to the same extent, limited to the case of Hajj and more information may need to be obtained before adopting the recommendation to cases other than the one used in this research. Similarly, it is vital to also do more research before adopting this strategies for firms in the same industry that do not fit into the description of a small and medium size Enterprise (SME). It is worth noting that this research did not also use a representative sample and as such the findings may suffer from statistical errors.
With regards direction for to future research, it is worth to note that the information that is currently available about mitigating demand uncertainty, mitigating demand uncertainty for SMEs and now how managerial strategies such as supply chain integration, and mass customization capabilities can help a firm to mitigate demand uncertainty is immense. However, there are still so many aspects of the study that can be explored further. This section of the research recommends the areas that future research should address regarding the subjects of mitigating demand uncertainty, using other managerial strategies recommended to mitigate demand uncertainty among other areas that fell beyond the scope of this research. During the Hajj season, it is not only the demand for food that is uncertain. In fact, this problem is experienced by all providers of consumer that are predominantly used during the season. Granted, most of the dynamics of operations may vary slightly making it possible to better focus demand. However, the problem of demand uncertainty is still rife and SMEs in these subsectors may be inefficient due to the huge costs of holding stocks or suffer from lost opportunities. Further research can be done on how SCI and MCC can be adopted for the varying situations in different industries, especially those that provide consumer goods to Hajj pilgrims. This research is also limited in scope to SMEs in Saudi Arabia's food industry. Further research can be done to identify how the supply chain management strategy can be applied to different scenarios. Further, this study also recommends the analysis of the effectiveness of these research findings to other SMEs that supply other consumer goods other than food during the Hajj season

APPENDIX A: MEASUREMENT ITEMS

Customer Integration

CI1: We are in frequent, close contact with our customers.
CI2: Our customers are actively involved in our product design process.
CI3: The customers involve us in their quality improvement efforts.
Internal Integration
II1: The functions in our plant are well integrated.
II2: Our plant's functions coordinate their activities.
II3: Our top management emphasizes the importance of good inter-functional relationships.

Supplier Integration
SI1: We maintain cooperative relationships with food suppliers.
SI2: We maintain close communications with food suppliers about quality considerations and design changes.
SI3: Our firm key food suppliers provide input into our product development projects.
Mass Customization Capability
MCC1: We can are highly capable of large-scale product customization.
MCC2: We can easily add significant food product variety without increasing costs.
MCC3: We can easily add product variety without sacrificing quality.

Demand Uncertainty Mitigation
DUM1: We mitigate demand uncertainty by providing products to our customer consistent with their nominated product specification.
DUM2: We mitigate demand uncertainty when our customers place orders consistent with their nominated delivery lead time.
DUM3: We mitigate demand uncertainty when our customers provide us reliable forecasts on their demands.
Competitive Intensity
CPI1: We are in a highly competitive industry.
CPI2: Our competitive pressures are extremely high.
CPI3: We do not pay much attention to our competitors.

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Text Data Mining to Track Information Technology Trends

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ABSTRACT

We present a technology trend analyzer that displays the frequency of demand for information technologies based on text data mining of job descriptions. It analyzes the term frequency of the leading technologies required of applicants in job descriptions scraped from job boards. This tool applies to students to determine which technology skills are in demand in the job marketplace. Faculty may use this tool to determine which technology skills the marketplace is seeking in shaping their curricula. Most importantly, it may be used by technology adopters to gauge the readiness for adoption of contemplated technologies to minimize adoption risk.

KEYWORDS: Data Mining, Text Analytics, Technology Trends, Information Technology

INTRODUCTION

Tracking technology trends is an essential activity for technology adopters. To reduce the risk of adopting technologies too early and risking adoption failures, a technology adopter needs to know what technologies are in demand in the marketplace at any given time. The adopter also needs to track the trends in adoption over time. Technology managers develop personal approaches to observing when emerging technologies have crossed the adoption chasm from bleeding edge to leading edge. Elaborate schemes have been proposed (Fortino, 2007) for such a technology watch based on the technology diffusion curve of Rogers (Rogers, 2003). For these schemes to work, the technology adopter must know the market acceptance of any one technology, thus driving the need to know the relative popularity of any one technology over another in any one sector. Seeking the opinion of technology subject matter experts and practitioners is one approach, but it is time-consuming and onerous (Fortino, 2007). This process may only be exercised infrequently. In his paper, Fortino calls technology managers to survey technology colleagues on their opinion of the bleeding/leading status of any technology they are interested in adopting. Industry surveys (Piatetsky, 2019) may be undertaken once per year, with substantial effort, and may cover one sector at a time. Piatetsky surveyed data analysts on their preference and use of various analytics languages and tools.

We contend that there is a ready-made database of market demand for technology at any one point in time: job descriptions. It is readily available and may be interrogated at any point in time. If we interrogate a database of technology jobs at the proper level (technology workers, not managers or clerks) in an industry sector for the skills and knowledge in demand at any one time, we would know what the most important technologies are. The frequency of appearance of one technology over another could provide a good indicator of the popularity of that technology at the point in time of the inquiry. It's not a perfect indicator but good enough for most business needs. Others may be able to use such quick snapshots of technology's popularity, such as H.R. managers who are seeking to train staff and arrange for technology training. They could use this as evidence to guide the trainers and arrange the proper training of their employees. Job seekers hoping to improve their preparation for the job marketplace could use this tool to look for gaps in their resumes or use it in preparing their resumes to match market expectations. It can be used in academia for faculty to decide what technology to use in their courses or what technology to emphasize in the subject matter taught.

The Technology Trend Analyzer we developed to answer this need is an R-based web application hosted on the shinyapp.io server. It scrapes 30 job descriptions from Indeed.com for 30 different job titles selected from the BLS O*NET Occupation database filtered for STEM occupations. It analyzes the frequency of technologies skills and knowledge called for in the job descriptions. It shows a bar graph of technology frequency grouped by I.T. categories from a standard technology taxonomy defined by O'Reilly's comprehensive compilation of technologies. The tool not only displays the snapshot of all the technology domains but also supports the download service of frequency tables in CSV files. It employs a keyword analysis technique provided by the standard library of R scripts. Users do not need to manually count the frequency of technologies that appeared in job descriptions anymore. Instead, they can use this tool monthly to understand the trend of technology requirements in the human resource market to prepare themselves to find a job matching their skills and create trend curves. This tool also provides opportunities for technology workers to understand the trends in I.T. to minimize the risk in technology investment.

Problem Description and Opportunity

We first envisioned this tool to be used by students graduating from our university as an aid in finding a job. The employment rate of graduates of the school is one of the vital factors of concern for students when selecting a university. With the influence of COVID-19, the unemployment rate was 4.2% in November 2021, which is higher than in the pre-COVID-19 era (Amadeo, 2021). Therefore, increasing the employment rate of graduates at our university became a problem for all university stakeholders.

A previously created tool, Job Description Compiler, that scrapes job information such as job titles, job descriptions, and other job metadata from Inddeed.com and automatically creates a CSV file for users to download, was a helpful starting point for development (Guan, 2021). This tool is convenient for users to search for jobs they are interested in and save the search results. The job descriptions provide users with information to match their resumes to job requirements.

The Job Description Compiler solves the problem of creating CSV files by hand, but users still do not know what skills are in great demand by employers. If users want to know the most recent in-demand skills, they must count the keywords in the job descriptions manually. This situation provided us with an opportunity to create a tool to automatically count the keywords in job descriptions.

We needed to obtain a comprehensive standard set of job descriptions used on a going base by the tool rather than have the user submit them. We used the database of occupation descriptions provided by the O*NET database from the U.S. Bureau of Labor Statistics. This tool scrapes job descriptions for the appropriate occupation titles culled from the O*NET occupation database from Indeed.com and analyze the technologies' frequency in the job descriptions. This tool will also produce a result in the bar graph of key technologies' frequency grouped by different categories so that users can easily visualize the most in-demand skills requirements in recent times. This tool will save the frequency data in a CSV file and provide it for downloading for users to analyze further. The tool can also be used by university faculty and administrators to help them understand the trend of technical requirements in the job marketplace and provide courses related to these technologies to help students prepare for finding a good job and performing well at the desirable jobs.

Importance of the Project

The twenty-first century is the era of technology. Since 1945, the invention of the first Electronic Numerical Integrator and Computer brought changes to the world and pushed the technology development a step forward. The main application of computers changes from initially calculating artillery firing tables for the United States Army's Ballistic Research Laboratory to process statistics data, program mobile apps, create websites, and enjoy online entertainment. Programming languages are developing at a rapid pace. With new programming languages or tools being invented frequently, employers may change their preferred programming language from the well-known programming language like C, SQL, C++, R, Java, JavaScript, Python to other new programming languages like TypeScript and Swift. Therefore, tracking the real-time dynamics of technology trends is necessary to help students find a job by learning the technology required before job hunting. It can also help students find the most suitable job opportunities by checking whether students have the technical skills companies require. Analyzing the technology trend by counting the keyword frequency by hand takes is a long and arduous process, so an automated tool could be useful to analyze technology trends.

LITERATURE REVIEW

Since 1995, search engines have provided a means of communication that allows companies to organize and diffuse information efficiently to customers (Humphreys et al., 2021). With the development of the Internet, many things are transmitting from traditional paperwork to digital work. Moret-Tatay et al. (2018) consider that, in some cases, electronic devices seem to have won the battle over traditional books because people tend to find out what has been said about a subject using Google more often than consulting an encyclopedia. This implies that analyzing online communications, like discussions and comments, can help people track the real-time dynamics of society. Therefore, to track the real-time dynamics of the trend of employers' technology requirements, analyzing the online job descriptions should be a good choice for developing a useful tool.

This project aims to create a technology trend analyzer using R with a Shiny interface to analyze technology trends by extracting information from job postings. The analyzed results will be shown as a histogram with the frequency of the number of jobs found to call for knowledge and skills in that technology.

Text analysis technology has been around for some time. This technology has been applied in many scenarios since its development. For example, a study by Humphreys & Wang (2018) used text analysis technology to analyze the consumers' desires, psychology, and process of making decisions. They stated that consumer discussions on the Internet, product reviews, and digital archives of news articles and press releases are potential insights into consumer attitudes, interaction, and culture (Humphreys & Wang, 2018). Other potential sources come from consumer-generated content, including discussions of products, hobbies, or brands on feeds, message boards, and social networking sites. Though text analysis technology has been available for a long time, there is not much agreement on the standard set of methods, reporting procedures, steps of data inclusion, exclusion, sampling, and, where applicable, dictionary development and validation. Humphreys & Wang (2018) sampled internet data, developed word lists to represent a construct, and analyzed sparse, non-normally distributed data to address the text analysis task. These procedures are employed in our technology trend analyzer project.

In Jia's (2018) study of text mining of restaurant customers' online reviews, she used text analysis tools to analyze customers' ratings and reviews to help restaurants improve their quality. Rating is easy to analyze using the statistical tool, but the review is hard to analyze without a text analysis tool. Therefore, Jia creates a text analysis tool that integrates the rating and review to reflect whether and why a customer enjoys dining in a restaurant. Other applied scenarios of text analysis technology include predicting the financial markets based on Google's search queries, analyzing annual corporate disclosures, making hotel selections based on online reviews and tourists' sentiment preferences, identifying phishing emails, and making decisions on the title of movies.

How to predict the stock market trend correctly is a hot topic for investors. In Perlin et al.'s (2017) study, they mentioned a new way to predict the stock market trend, which is analyzing the keyword that the general public searches in Google to predict the stock market trend. They consider that this way can at least analyze systematic patterns and effects on the market (Perlin et al., 2017). The result of this study also verified their ideas, which is that Google Trends data can be used to forecast the behavior of financial markets (Perlin et al., 2017). Yang et al. (2018) did a similar study with Perlin et al.'s (2017). Yang et al. (2018) use text analysis technology to assess the bankruptcy risk of companies. They extract high-frequency words, related concept links, and topics from MD&As and find that some high-frequency words appear to suggest differences between bankrupt and non-bankrupt companies regarding their financial position and ongoing status (Yang et al., 2018). However, Yang et al.'s (2018) study concluded that most of the top topics extracted merely recapture the characteristics of industries in which companies operate, and they do not provide useful information in differentiating between bankrupt and non-bankrupt companies. Yang et al. (2018) believed that one possible explanation for this result is that they conducted their topic extraction using the entire sample without classifying companies into industries. The different results of Perlin et al.'s (2017) study and Yang et al.'s (2018) study remind the importance of having and using an accurate word list.

Text analysis technology is not only used in the finance field but is also used in the tourism and cybersecurity fields. In Liang et al.'s (2019) study, they create a novel DL-VIKOR method for ranking and selecting the most suitable hotel for tourists. This method went through with online reviews and tourists' sentiment preferences and transformed them into the format of distribution linguistic with respect to sentiment levels (Liang et al., 2019). Then, they determine the ideal solution and nadir solution for the linguistic distribution evaluations (Liang et al., 2019). Finally, they determine the weight vector of the evaluation features based on the frequency of words for evaluating hotels and the distribution of linguistic evaluations (Liang et al., 2019).

The applied scenario of text analysis to the cybersecurity field includes identifying and preventing phishing emails. COVID-19 radically reshaped the global economy and accelerated the pace of digital transformation (Li, 2021). An article from Deloitte states that "the increase in remote working calls for a greater focus on cybersecurity because of the greater exposure to cyber risk" (Deloitte, 2020). The data of Deloitte shows that 47% of individuals fall for a phishing scam while working at home (Deloitte, 2020). Therefore, identify a phishing email and prevent people from being deceived by a phishing email. O'Leary's (2019) study used text analysis to explore differences between phishing emails and other emails. Furthermore, O'Leary generated a model of phishing as power based on independent variables of a friend (who they pretend to be), achievement (of their goal), (to take you) money, and (typically done at) work (O'Leary, 2019).

Text analysis technology is also used in the entertainment industry. Kim et al. (2020) studied whether a correct name can influence the success of films. The result of this study showed that it is correct to choose a title for a movie, and specific movie titles work better than others (Kim et al., 2020). In the study, Kim et al. (2020) applied the social network analysis R package applied to Hollywood movie title keywords to extract some meaningful information from Hollywood movie title keywords.

R is a well-known programming language, and it is widely used among statisticians and data miners for developing statistical software and data analysis (Wikimedia, 2021). The first official release of R was in 1995. It was first developed by Ross Ihaka and Robert Gentleman at the University of Auckland in 1991 and publicized in 1993. In 1995, they were decided to make R free and open-source software under the GNU General Public License. The Comprehensive R Archive Network (CRAN) was officially announced in 1997 with three mirrors and 12 contributed packages (Wikimedia, 2021). The first official "stable beta" version (v1.0) was released in 2000 (Wikimedia, 2021).

Until 2019, there were more than two million R users around the world (Datanami, 2020). Such a large user base makes programs written in R easier to be accepted and understood. This is one of the reasons that this technology trend analyzer project team choose to write the code in R. Nevertheless, R has many other reasons for this team to decide to use it. As open-source software, writing in R code enables anyone to access, modify and share the source code and libraries without any restrictions (Datanami, 2020). This prevents the situation that other people who want to modify the code need to buy access to read or modify the code. R also has many packages that can be an add-on. For example, ggplot2, plotly, dplyr, and tidyr provide some of the best-in-class data visualizations that are aesthetic yet insightful (Datanami, 2020). In this project, the team uses ggplot2 and dplyr to visualize the data. It is very convenient to add on these packages in R to complete a complicated project. R has extensive community support. R has an active and welcoming community for all skill levels, whereas boot camps and workshops encourage cooperative behavior (Datanami, 2020). This welcoming community can help R to perfect its loopholes and bugs. One of the essential reasons we choose R is that it is easy to understand. Workers who have some coding experience in Python or AMPL, it is easier for them to understand coding in R. All these reasons supported our choice to create the technology trend analyzer using R code

DESCRIPTION OF THE TOOL

The goal of the project was to create a technology trend analyzer using R with a Shiny interface that can analyze the trends required in job descriptions. This project is based on a previous project which collects job information from online sources. After collecting the information from websites, our tool analyzes the frequency of main words in job requirements and plots a histogram showing the recent job requirement trend of specific skills like Python or R.

This tool requires a list of technologies, a job title list, and job descriptions to create and run the analysis. The list of technologies is used to categorize the counted frequencies after the counting process completes and display histograms with categorized technologies. The job title list provides the job titles for the tool to search and define this project's scope. Based on the job titles from the job title list, this tool can scrape job descriptions from Indeed.com, then go through the analysis process and count the frequency of technologies appearing in the technology list in job descriptions.

The Technology Taxonomy

This program uses an I.T. technology taxonomy derived for a comprehensive listing of technologies compiled by O'Reilly, a prominent I.T. technology book publisher (O'Reilly, 2021). The technology list is used in this project to categorize specific technologies. The categories in the O'Reilly technology chart include (1) Methodology, (2) Security, (3) A.I./Machine learning, (4) Data, (5) Web, (6) Mobile, (7) Infrastructure, (8) Cloud, (9) Software/Architecture, and (10) Programming Languages. O'Reilly is a well-established publisher of books on information technology. Their catalog of books covers the widest variety of technology topics and does so in-depth. It is a well-regarded source of technical information in the I.T. industry. As such, O'Reilly is well-positioned to create a comprehensive taxonomy of I.T. Rather than embark on the creation of such a comprehensive taxonomy as a separate task in this project, it was expedient to use an existing taxonomy to create a proof of concept for the tool. As more comprehensive and exhaustive technology taxonomies are made available, the tool can be retrofitted and perfected.

Category	Technology
AI / Machine Learning	AutoML, Neural Networks, TensorFlow/PyTorch, Modeling, Data processing, Deployment, scikit-learn, Tuning, Math, SQL, NoSQL, Analytics, Visualization, Pipelines
Cloud	Amazon Web Services, Microsoft Azure, Google Cloud Platform, Alibaba, Oracle Cloud Infrastructure, IBM Cloud
Data	SQL, NoSQL, Analytics, Visualization, Pipelines, Cassandra, Data warehouses
Infrastructure	Kubernetes, Docker, AIOps, DevOps, SRE, VMs, Servers
Methodologies	Lean, Agile, Scrum, Kanban
Mobile	OS / iOS / Android, Caching, Toolkits
Programming Languages	Java, Go, Python, Ruby, JavaScript, React, Vue, Angular, COBOL, C, C#, R, SQL, C++
Security	Secure programming, Threat modeling, Monitoring / Alerting, Incident Response, Cloud Security, Pentesting
Software Architecture	Event-driven, Domain-driven, Microservices, Monoliths
Software Development	Coding, Pair programming, TDD, Version Control, Testing, Continuous integration / continuous delivery, DevOps, Legacy
Web	JavaScript, CSS, HTML, Monitoring / Alerting, OS / iOS / Android, Caching, Toolkits

Figure 1 – The technology domains and associated technologies used in this tool. After O'Reilly's Technology Topic Chart (O'Reilly, 2021).

Creating the list of technologies based on the O'Reilly technology chart produces the keywords for the program to extract their frequency from the job descriptions. This step also prepares for classifying technologies after counting the frequency. When this program scrapes the job descriptions based on the job title list, it will match the scraped job descriptions with the technology names in the technology list and count the frequency of the words' appearance in the job descriptions.

Job Titles from the STEM O*NET Occupation Database

The job title list used in this project was extracted from the O*NET Occupation database. The O*NET Occupation database contains over eleven hundred definitions of occupations, and job seekers in the United States use it often to find jobs. Roughly half of the occupations are considered STEM occupations. We used the STEM occupations list as a starting point to refine it further and generate the 30 most prominent I.T. occupations. We used several subject matter experts to determine which of the STEM occupations to use as I.T. job titles in scraping jobs from the job service. We focused on the most prominent and popular jobs representing I.T. staff positions, those who would be doing the technical work of I.T. and for whom one would find technologies defined at the most granular level. For example, we did not include managers or supervisors.

We limited the job titles to 30 occupations to assist in reducing the job search scope so that the search through the job board would not take an inordinate amount of time to complete the scraping task. Though having more samples can increase the accuracy of the results, it takes excessive time to finish the scraping process. Also, the job service selected for job scraping (indeed.com) employs an anti-web-crawler system. Making too many requests at one time will cause the tool to hang up. Using a maximum of 30 job descriptions is a practical operating parameter. More specifically, these occupations include Bioinformatics Scientist, Blockchain Engineer, Clinical Data Manager, Computer and Information System Manager, and other occupations are shown in Figure 2 shows the list of occupation titles used.

The tool searches for each job title on Indeed.com to get job descriptions using these O*NET occupation titles as job titles. We retrieved 30 jobs per occupation to stay within the Indeed.com anti-web-crawler system limits. This gives us a pool of 900 job descriptions which is sufficient to get a good indication of the current popularity of each technology. It is not necessary to have a high degree of accuracy since generating an imperfect indicator is sufficient for most business purposes or when looking for a job.

1	Job_Title
2	Bioinformatics Scientist
3	Bioinformatics Technician
4	Biostatistician
5	Blockchain Engineer
6	Business Intelligence Analyst
7	Clinical Data Manager
8	Computer and Information Research Scientist
9	Computer and Information Systems Manager
10	Computer Hardware Engineer
11	Computer Network Architect
12	Computer Network Support Specialist
13	Computer Programmer
14	Computer Systems Analyst
15	Computer Systems Architect
16	Computer User Support Specialist
17	Data Scientist
18	Data Warehousing Specialist
19	Database Administrator
20	Database Architect
21	Information Security Analyst
22	Information Security Engineer
23	Information Technology Project Manager
24	Network and Computer Systems Administrator
25	Penetration Tester
26	Software Developers
27	Software Quality Assurance Analyst
28	Statistician
29	Web Administrator
30	Web and Digital Interface Designer
31	Web Developer

Figure 2 – The 30 O*Net STEM occupations titles selected for scraping I.T. job descriptions from the job board.

Term Frequency Analysis

Once the 30 job descriptions for each of the 30 job titles have been extracted, the tool will analyze the specific technology by the keywords in the O'Reilly technology list and match them with the words that appear in each job description. This program uses the R function CountTech to count how many times the keyword in the technology list appears in the texts of the job descriptions. To avoid miscounting single keywords like R and C, we used space plus keyword plus period, space plus keyword plus comma, and space plus keyword plus space as keywords for single-word keywords like R and C to check the frequency of these words in the text to view. The tool also considers the situation of having a slash in keywords; it uses str_split to split the keyword with "/" and count them split and then add them together as one keyword. When all the possible keywords problems are analyzed, the tool can use for loops for R to count keywords in job descriptions.

The tool provides a good indicator of technology use because it reflects employers' current and future talent demand for that technical knowledge and skill. Online job-finding websites can reflect the real-time demand of the market. Job boards provide more immediate and recent indicators of market demand for technology knowledge than an official year-by-year statistical compilation from surveys of staff. This tool can be run once per month, for example, to track the real-time dynamics of technology use, which is more valuable than the official yearly industry statistics. Displaying the appearance of technical terms in jobs sorted by frequency can show the skills most in-demand in the technology job market. The tool also provides the function of displaying a bar graph of the data by the O'Reilly categories.

Using the tool

The tool may be found on a public Shiny app server (You, 2021). Users are provided with only two functions when the tool is run: a "TRACK" button to run the tool and a "Download CSV" button to download a table of results. Once the "TRACK" button is pressed, bar graphs of technology frequencies presented by categories will display. After running the tracking function, users can click on "Download.csv" to download the frequency table for users' further analysis.

SELECTING THE DEVELOPMENT PLATFORM

Evaluation of Alternate Solutions to R

We carefully considered the development environment for programming the tool. There are several adequate choices for the development of the program we envisioned. We limited our choice to the three most popular development environments. Two alternative solutions to using R are Python and JavaScript. After comparing all the pros and cons of R, Python, and JavaScript, we found that R was the most effective programming language to finish the project.

Positive aspects of using Python for tool development

Python is a general-purpose programming language, so it is convenient to write the whole application in Python and then include the Python-based model. Python also emphasizes code readability, making it easier for beginners to learn and understand writing code. As a general-purpose programming language, most programmers and developers know Python well. When they write code in Python, they do not need to transfer programming language syntax to a new syntax. Python is suitable for deep learning and machine learning. The deep learning and machine learning libraries like scikit-learn, Keras, and TensorFlow enable sophisticated data models that plug directly into a production system. Python supports most kinds of data formats, from CSV files to SQL tables.

Negative aspects of using Python for tool development

The primary objective of R is Data analysis and Statistics, whereas the primary objective of Python is Deployment and Production. Besides, visualization is not a strength of the Python language. Though Python can use the Matplotlib library and the Seaborn library to draw graphs, it is more complicated than using ggplot2 to draw graphs in R. The other negative point in using Python to write this project is that the project is based on previous student's work, which was written in R. To change the programming language to Python, we needed to transfer the other project code to Python first. That would have added time to the project unnecessarily. In addition, writing in Python will make it hard for other workers to develop further functions based on this tool's code. And the Python language learning curve is steep.

Positive aspects of using JavaScript for development

The second alternative solution is writing a webpage using JavaScript instead of the Shiny app. JavaScript and Shiny app are not a zero-sum situation; they can be used together in R. R has a J.S. package to implement bindings to several popular JavaScript libraries for validating, reformatting, optimizing, and analyzing JavaScript code. JavaScript can satisfy the more advanced requirements of designers. When designers have advanced features that go way beyond what Shiny can do, JavaScript can help realize the imagination. Most of the Shiny functions are JavaScript wrappers with some narrowed functionality, so using JavaScript can achieve the same effect as the Shiny app. In addition, when some loops are used, JavaScript runs faster than the Shiny app. Finally, JavaScript allows users to operate on existing DOM elements while Shiny often re-renders objects.

Negative aspects of using JavaScript for development

Many R and Shiny app developers have a data science background, not a programming background. Therefore, using JavaScript requires them to spend time learning it first. It was expected that this project was foundational to mane revisions and enhancements and that other analysts would be using the R code produced. Using JavaScript rather than R to create the web interface will make it harder for future analysts to extend the work.

Criteria for Evaluating Solutions

Time – This project was projected to be completed in three months. The work was to be accomplished by a single student analyst as part of a capstone project, and the time allocated was one academic semester. Time became a major driving factor to consider in selecting the best development approach. Any development environment and language that risks exceeding the project deadline should not be chosen. Given the state of preparedness of students (minimal), it was felt that R has the lowest learning curve of the three development languages and had the most significant possibility of bringing the project in on time.

Quality – Whether the solution can satisfy all the metrics is one factor in comparing all the solutions. The speed of running the program, the stability of the program, and the accomplishment rate of the client's requirements should be considered quality factors. A faster, more stable, and higher accomplishment rate should be preferred.

Efficiency – The amount of time and effort spent learning the development programming language to complete the project is considered the efficiency factor. The lower the learning curve, the higher the efficiency. A lower learning curve makes the project more effective and is preferred.

Continuous Improvement – Because this project will have follow-up projects, the readability of the code should be considered a factor in deciding the best solution. Easier to understand code is better because it will allow future analysts responsible to easily follow the work and build upon.

	Time	Quality	Efficiency	Continuous Improvement	Total
Using R with Shiny app	3	2	3	3	**11**
Using Python	2	3	1	1	**7**
Using R with JavaScript	2	3	2	1	**8**

Figure 3 – Scoring of the development platform alternatives.

Each criterion was scored from one to three in collaboration with a subject matter expert. One means this approach performs poorly compared to other solutions. Three means that the approach is a superior solution in that dimension. All factors were equally weighted. We see that using the R with Shiny app to complete the project is superior to the other two. Using all three solutions can complete the project by the deadline. Still, by using R with a Shiny app interface, we can finish the project faster than using Python and JavaScript because of the lower learning curve for the analyst. On the other hand, even though using R with the Shiny app can satisfy all the client's requirements, using Python can make the program run faster, and using JavaScript can make the web page look more professional. I have experience of using R before, so it is easier, faster, and more convenient for me to learn R more deeply. This project is based on a previously finished project written in the R and Shiny app. Using the R and Shiny app can make later students more convenient to understand each step in the coding and keep writing their project based on this project. In conclusion, using the R with Shiny app to create the technology trend analyzer is the best choice.

APPLICATION

We provide here some results of using the tool. The Shiny interface provides a web page for users to run the tool. The Shiny interface is Shown in Figure 4. The tool runs when users click the "TRACK" button.

Figure 4. The Technology Trend Analyzer tool start interface.

After a few seconds, the bar graph of technology frequencies divided by categories will display on the screen like in Figure 5. When users click on the "Download.csv" button, the browser will pump up a window to set the download pathways like in Figure 5 or automatically download the counted frequency file (depends on the browser the users employ).

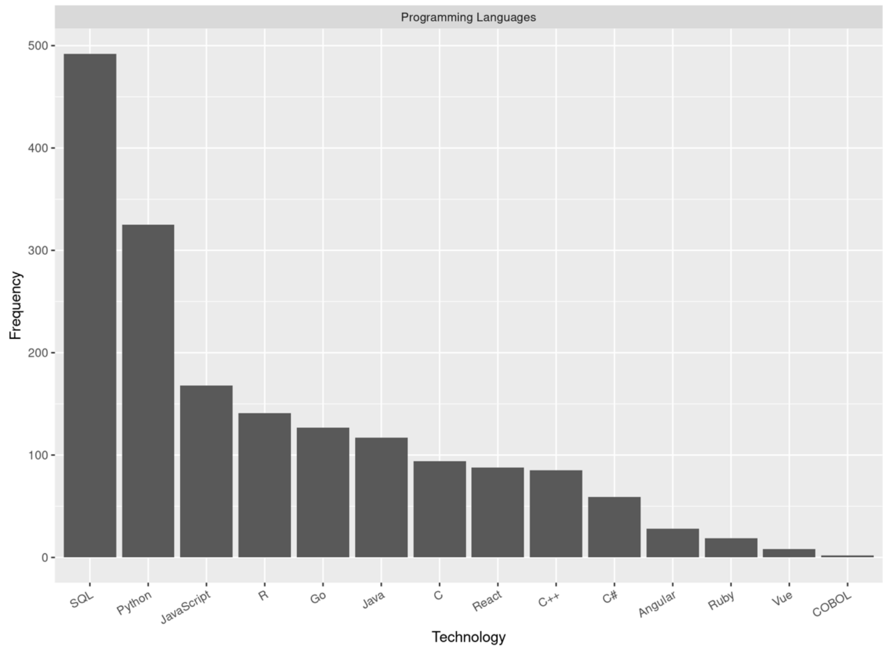

Figure 5 – Typical bar graph results of technology frequency from the 900 scraped job descriptions for the Programming Languages technology category.

As of the time and date the tool was run the most in-demand technology in the Programming Language category appears to be SQL, shown in Figure 5. The second and third in-demand technologies are Python and JavaScript. In the Methodologies category, Agile is the highest in-demand. In the Software Architecture category, the most in-demand technology is Microservices. Monitoring / Altering is the most in-demand in the Security category. In the Cloud category, shown in Figure 6, Microsoft Azure is a very close second, although Amazon Web Services appears most frequently. Therefore, Amazon Web Services and Microsoft Azure should be considered essential technologies required for job seekers in the Cloud category.

In the A.I./Machine Learning category, Modeling, Deployment, and Tuning are the top three technologies required. In the Data category, both Analytics and SQL bear watching since they both have high frequencies of appearance in jobs. Servers is the most frequent keyword in the infrastructure category, while Testing is the most frequent keyword in the Software Development category. In the Web category, JavaScript has the highest frequency, while in the Mobile category, Monitoring/Altering has the highest frequency.

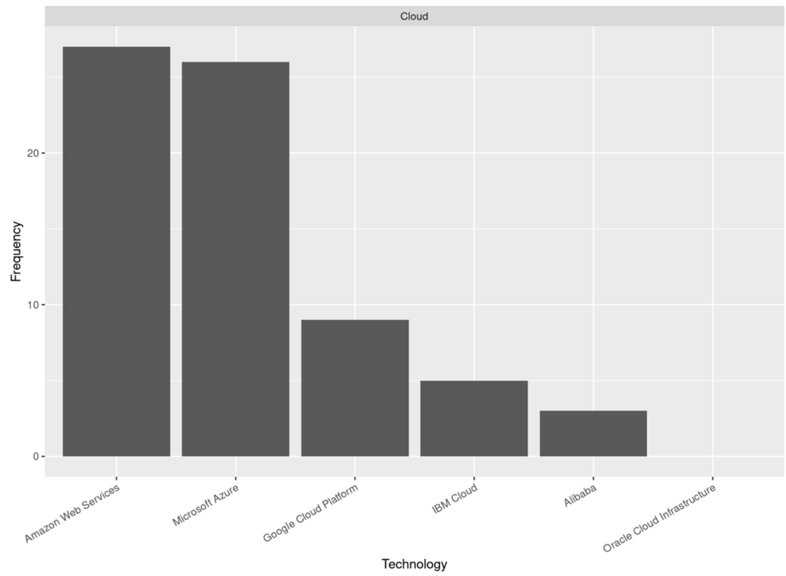

Figure 6 – Typical bar graph results of technology frequency from the 900 scraped job descriptions. – Cloud Technologies

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE WORK

Though this project is based on the work of scraping job descriptions from Indeed.com and counting the frequency of the keyword in job descriptions, it faces a problem of the anti-web-crawler system limits, which means this tool cannot scrape as many job descriptions as possible to make an analysis. Even for this project, this technology trend analyzer tool cannot scrape a more desirable 3000 job descriptions (30 job titles X 100 job descriptions) from Indeed.com at a time. It is not a problem with the code, but the problem of the website the jobs are scraped from. The anti-web-crawler system is not limitation of Indeed.com alone. Other websites, like LinkedIn, also have an anti-web-crawler system. This situation limits the number of job descriptions scraped from the website at any one tim and may lower the accuracy of the counting process.

An existing solution to this problem is running the frequency function one by one 30 minutes apart and letting R count the frequency of these job descriptions. After running the R code of main function, users can use the shiny app to see the bar graph and download the frequency table in a CSV file. However, this solution can only be useful for a limited number of job descriptions. If the number of required job descriptions increases, this solution will be very time-consuming. Therefore, the best way to find a way to solve this problem, perhaps by finding a job searching website that does not require verification to scrape job information—or applying more advanced programming techniques to develop a tool that can break the anti-web-crawler system to scrape job information from websites without any limitations.

Another future development for this project is to add the time dimension. If a person is interested in tracking technology trends over time, the program may be run repeatedly (once per week perhaps), and, with modifications, the program can accumulate the results of each run into a database. At the end of each weekly run, the program will also display a slope graph of the trend from previous runs. Thus, allowing the analyst to obtain a current snapshot for ratios of technology popularity and a slope of the trend as well.

CONCLUSIONS

The Technology Trend Analyzer is an R-based web application hosted on a shinyapp.io server. It can scrape 30 job descriptions from Indeed.com for 30 different job titles selected from the BLS O*NET Occupation database filtered for STEM IT occupations. It analyzes the frequency of technologies skills and knowledge called for in the job descriptions. It shows a bar graph of technology frequency grouped by I.T. categories from a standard technology taxonomy as defined by O'Reilly's comprehensive compilation of technologies. The tool not only displays the snapshot of all the technology domains but also supports the download of the frequency tables as CSV files. It employs a keyword analysis technique as provided by the standard library of R scripts. Users do not need to manually count the frequency of technologies that appeared in job descriptions any more. Instead, they can use this tool monthly to understand the trend of technology requirements in the human resource market so that users can prepare themselves for finding a matchable job. This project also provides opportunities for technology workers to understand the trends in I.T. to minimize the risk in technology investment.

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Text Mining and Analytics for Diversity, Equity, and Inclusion Statements in Academia and Industry

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ABSTRACT

Over the past few years, a wide range of organizations have published their commitments to Diversity, Equity, and Inclusion (DEI) on their official websites. Analyzing the information contained in these statements is of great importance for administration to make data-driven decisions regarding DEI policies. In this study, we utilize text mining and natural language processing to analyze the DEI statements issued by the top 50 universities and businesses in the United States. Our analysis may assist higher education institutions and companies in systematically comparing their DEI statement with their regional peers and making data-driven decisions regarding amending their DEI statements.

KEYWORDS: Text Analytics, Diversity, Equity, Inclusion, and Statements

INTRODUCTION

During summer of 2020, there were numerous demonstrations in support of racial justice across the United States (US) (Buchanon et al, 2020). Many higher education institutions and businesses released statements voicing their opposition towards racism and their commitment to diversity, equity, and inclusion (DEI) (Boston College, Center for Citizenship Corporation, 2021; American Talent Initiative, 2021). Organizations have pledged nearly $8 billion per year in diversity training expenditures (Hansen, 2003).
A recent survey conducted (Claeys-Kulik et al, 2019) indicates that DEI plays an important role in the mission of academic institutions. The survey highlights multiple key factors that drive DEI adoption within higher education. Several of these drivers include: “explicit value for our institution”, “institution's social responsibility”, “legal obligation”, “strategy to recruit students”, “strategy to recruit staff”, “allocation of public funding”, “quotas for students with diverse backgrounds”, and “quotas for staff with diverse background” (Claeys-Kulik et al, 2019). Furthermore, an analysis of 80 US higher education institutions in 2012 revealed that 75% of these institutions incorporated the term "diversity" within their mission statements (Wilson et al, 2012).

Beyond academia, DEI is an important characteristic of any workforce and may serve as an indication of a company's success and sustainability (Karakhan et al, 2021). The US business community has carried out diverse and inclusive initiatives to increase the representation of diverse groups within the workforce and to promote the participation and contribution of diverse individuals towards the success of the organization (Sherman et al, 2021). Organizations can make informed decisions about how to leverage resources most effectively by establishing metrics that evaluate the efficacy of diversity initiatives (Jayne et al, 2004). Not only do DEI statements reflect policy decisions of an organization but they help support DEI in the workplace (Karakhan et al, 2021).

LITERATURE REVIEW

Text mining has been widely used to analyze the mission statements of organizations (Bhaduri et al, 2017; Bayrak, 2020; King et al, 2011; Bartkus et al, 2008; Craig et al, 2016). Bhaduri et al, 2017 explored the diversity and inclusion terms in the mission statements of public and private colleges using data visualization. Bayrak, 2020 used text analytics in order to analyze the mission statement of the top universities located in five continents using the frequent words, weighting method and clustering. Another study by Bartkus et al, 2008 found that "Diversity" was the fourth most frequently used word in mission statements of the top Fortune 100 companies, following "Customer", "Employee", and "Community/society/world", where diversity concerns were lower among those companies that included the term “Diversity”. In addition, King et al, 2011 examined the mission statements of the top Fortune 100 companies based on the use of frequent words. They demonstrated how mission statements evolved over time as new terms (such as “communities” and “employee appreciation”) were added and other terms (such as “core values” and “competitors”) were reduced. Additionally, Craig et al, 2016 analyzed the mission statements of the top and bottom 100 companies on the Fortune 500 list. They found that the most frequently used words in mission statements were "products/services" and "customers". In this study we aim to 1) use exploratory data analysis to analyze the DEI statements issued by the top 50 universities and businesses in the US, 2) employ text mining methods to compare the DEI statements of academic and commercial populations, and 3) analyze implicit sentiments expressed in the DEI statements. To the best of our knowledge, our research is the first study that uses text analytics to analyze DEI statements published by higher education institutions and businesses. This may be due to a wave of DEI statements beginning primarily during the summer of 2020.

METHODS

We collected the DEI statements of the 50 top-ranked universities and companies for the year 2021. University rankings were obtained from US News (Us News, 2021) while Company rankings were obtained from the Fortune 500 list (Fortune, 2021). All universities and companies have DEI statements, apart from one company which was acquired in 2022. Note that we include the 51st company on the Fortune 500 list to have 50 companies. Moreover, we consider 55 universities due to some universities holding equal rankings in US News. Appendix provides a list of the universities and companies.

After collecting DEI statements from university and company webpages, we prepared the data for analysis. Tokenization is one of the most common pre-processing steps in Natural Language Processing (NLP) capable of dividing text into small chunks or tokens. We used the Natural Language Toolkit (NLTK) Python library to clean raw DEI statement text and tokenize, where individual words served as tokens. The following steps were taken prior to tokenization: a) text was converted to lower case, b) punctuations were removed, c) digits were removed, d) stop words were removed, e) white space was removed, f) contractions were expanded, and g) stemming/lemmatization was applied to reduce the number of similar words. The prepared data were used to create word clouds that help visualize frequent words found in DEI statements. By utilizing the SimpleTransformers Python library, we calculated the similarity values between DEI statements within universities and companies:

$$\text{Cosine Similarity } (A_j, A_k) = \frac{A_j.A_k}{||A_j||\ ||A_k||} = \frac{\sum_{i=1}^{n} A_{ji}A_{ki}}{\sqrt{\sum_{i=1}^{n} A_{ji}^2}\sqrt{\sum_{i=1}^{n} A_{ki}^2}} \tag{1}$$

where A_j and A_k are vectors *j* and *k* in the bag-of-words model for the DEI statements while *n* represents the total number of unique words as shown in Equation 1. Additionally, we used Multidimensional Scaling (MDS) (Borg et al, 2005) to visualize the distances, similarity, and dissimilarity between the DEI statements in a two-dimensional space. MDS is a non-linear method of embedding data in a lower dimensional space. Additionally, we used sentiment analysis to analyze the social (positive, neutral, and negative) sentiments expressed in DEI statements. A positive sentiment indicates that the DEI statement has a positive context, a negative sentiment indicates that the DEI statement has negative polarity, and a neutral sentiment indicates that a DEI statement does not express any opinion or is neutral for the audiences. It should be noted that these techniques are widely used in text mining literature (Zucco et al, 2020).

RESULTS

Figures 1 and 2 present DEI statement word clouds related to academia and industry. Note that the larger the size of the words, the more frequently they appeared in the DEI statements. The ten most commonly used words in academic DEI statements are *diversity, community, university, inclusion, student, create, value, environment, member,* and *mission.* Comparatively, the top ten words used in commercial DEI statements are *diversity, inclusion, culture, work, community, commitment, create, people, employee,* and *value*. The most common words that appear in both university and company DEI statements are *diversity, community, inclusion*, and *create*. Additionally, companies refer to *culture* and *commitment* more frequently in their DEI statements compared to academia. Universities, on the other hand, use the word *environment* more frequently than companies in their DEI statements. Moreover, companies refer to *employee* or *workforce* more frequently than *customer* in their DEI statements. In contrast, universities refer to *student* more frequently than *faculty* or *staff* in their statements.

Figure 1: World cloud for top-ranking university DEI statements

Figure 2: World cloud for top-ranking company DEI statements

Figure 3 visualizes the similarity of DEI statements between top universities using a heat map. In order to de-identify similarity values, universities are grouped into general regions: Northeast, Midwest, South, and West. It should be noted that the universities are arranged randomly within each region. The intersection between each row and column provides the similarity value between two DEI statements, where similarity values range from 0 (disparate) to 1 (identical). Higher (lower) similarity values between two DEI statements are marked in darker (lighter) colors in the similarity matrix. As illustrated in Figure 3, several universities possess DEI statements that differ significantly from the majority of universities, visually observed as light strips in the similarity matrix. In order to gauge the degree of similarity between academic DEI statements across different US regions, we computed the average (standard deviation) of distinct similarity scores within and between regions as shown in Table 1. For the top ranked schools, average similarity values range from 0.583 to 0.639. Universities residing in the Midwest have the most similar DEI statements with a similarity value of 0.639 (marked in **bold**) and universities in the Northeast have the most dissimilar DEI statements with a similarity value of 0.583 (marked in **bold**).

Figure 3: Similarity matrix (heat map) for top-ranking university DEI statements

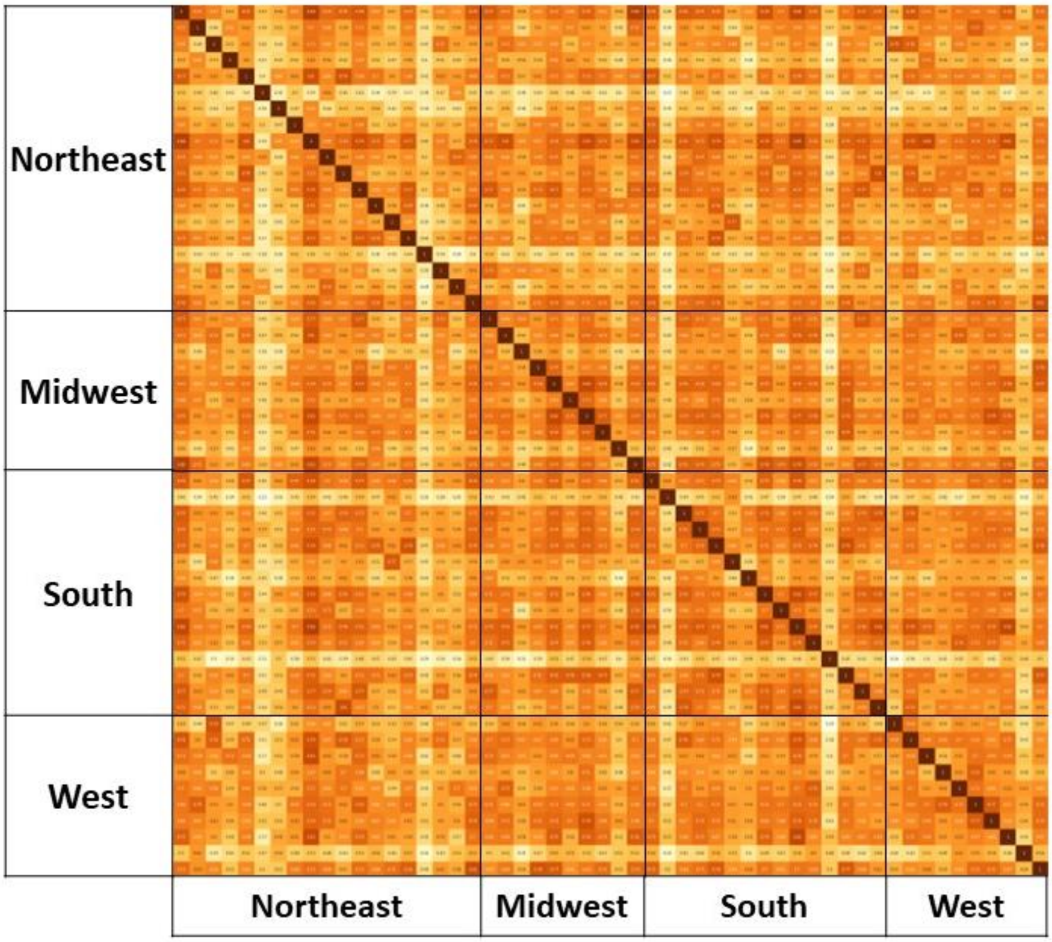
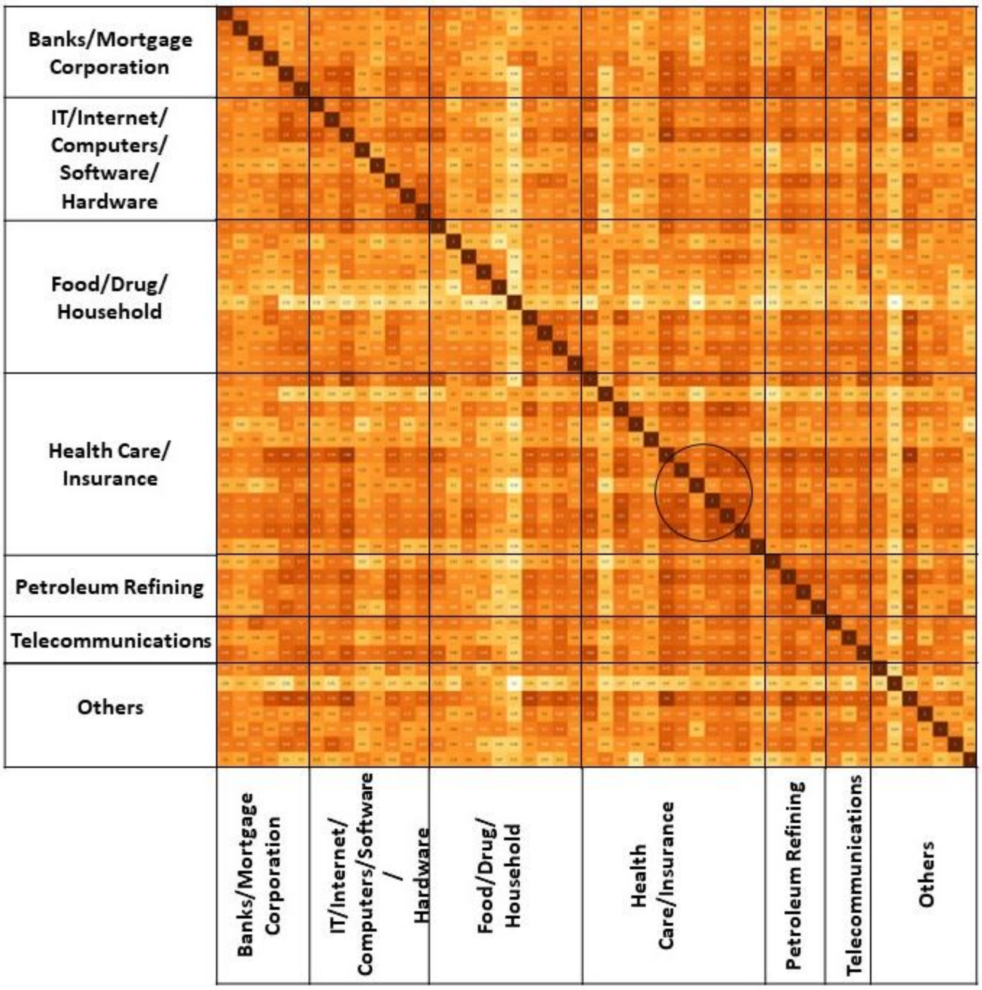


Table 1: Average (standard deviation) DEI statement similarity scores across four academic regions

	Northeast	Midwest	South	West
Northeast	**0.583 (0.112)**	0.612 (0.096)	0.597 (0.115)	0.603 (0.100)
Midwest	0.612 (0.096)	**0.639 (0.086)**	0.627 (0.104)	0.633 (0.084)
South	0.597 (0.115)	0.627 (0.104)	0.623 (0.116)	0.612 (0.104)
West	0.603 (0.100)	0.633 (0.084)	0.612 (0.104)	0.622 (0.083)

Similar to above, Figure 4 visualizes the similarity of DEI statements between the top 50 US companies using a heat map. Similarity values are again de-identified by grouping companies into sectors: Banks/Mortgage Corporation, IT/Internet/Computers/Software/Hardware, Food/Drug/Household, Health Care/Insurance, Petroleum Refining, Telecommunications, and Others. In order to ensure de-identification of companies, we combined sectors with low frequencies and arranged companies randomly within each sector.

Figure 4: Similarity matrix (heat map) for top-ranking company DEI statements



As seen in Figure 4, a block of companies within the healthcare industry (marked within a circle) share similar DEI statements. Based on the similarity matrix and averages found in Table 2, DEI statements appear more similar between companies in corresponding sectors like IT/Internet/Computers/Software/Hardware, Health Care/Insurance, Petroleum Refining, and Telecommunications. Furthermore, the DEI statements of the top 50 companies appear to have closer messaging than the top-ranking universities based on overall averages of the similarity matrices. The similarity matrix for the top 50 companies appears darker, with an overall average similarity of 0.635, compared to academia with an overall average similarity of 0.610.

In Table 2, we present the average (standard deviation) DEI statement similarity scores between different commercial sectors. For the top 50 companies, average similarity values range from 0.587 to 0.722. The companies in the Petroleum Refining sector have the highest similarity value of 0.722 (marked in **bold**), while companies in the Food/Drug/Household and Others sectors have the lowest similarity value of approximately 0.588 (marked in **bold**).

Table 2: Average (standard deviation) DEI statement similarity values in seven industry sectors

Sector	Banks/ Mortgage Corporation	IT/Internet/ Computers/ Software/ Hardware	Food/Drug/ Household	Health Care/ Insurance	Petroleum Refining	Telecommunications	Others
Banks/Mortgage Corporation	0.649 (0.048)	0.649 (0.064)	0.621 (0.080)	0.651 (0.084)	0.656 (0.083)	0.676 (0.065)	0.638 (0.095)
IT/Internet/Computers/ Software/Hardware	0.649 (0.064)	0.669 (0.063)	0.607 (0.096)	0.644 (0.093)	0.668 (0.089)	0.674 (0.069)	0.619 (0.090)
Food/Drug/Household	0.621 (0.080)	0.607 (0.096)	**0.588 (0.101)**	0.621 (0.100)	0.603 (0.099)	0.642 (0.087)	0.599 (0.101)
Health Care/Insurance	0.651 (0.084)	0.644 (0.093)	0.621 (0.100)	0.681 (0.104)	0.658 (0.097)	0.677 (0.078)	0.625 (0.104)
Petroleum Refining	0.656 (0.083)	0.668 (0.089)	0.603 (0.099)	0.658 (0.097)	**0.722 (0.047)**	0.691 (0.053)	0.628 (0.117)
Telecommunications	0.676 (0.065)	0.674 (0.069)	0.642 (0.088)	0.677 (0.078)	0.691 (0.053)	0.701 (0.036)	0.642 (0.095)
Others	0.638 (0.095)	0.619 (0.090)	0.599 (0.101)	0.625 (0.104)	0.628 (0.117)	0.642 (0.095)	0.587 (0.101)

Figures 5 and 6 visualize the similarity values of the DEI statements in a two-dimensional space using MDS for the top universities and companies, respectively. In this approach, each university (company) is assigned a pair-wise distance matrix. Similar to what was found in Figures 3 and 4, Figures 5 and 6 demonstrate how the DEI statements of companies are more uniform (similar) than those found in academia.

In order to measure overall sentiment in DEI statements issued by universities and companies, we analyzed neutrality and positivity scores. The polarity scores (neutrality, positivity, and negativity) range from zero to one (the higher the score, the greater the polarity) and the sum of the polarity scores is one. We note that DEI statement negativity scores are either zero or near zero. Table 3 presents average (standard deviation) neutrality and positivity scores in DEI statements issued by universities in the Northeast, Midwest, South and West. Based on the results in Table 3, DEI statements from southern universities possess the highest average neutrality score of 0.806 (marked in **bold**). Consequently, the top southern universities generally use more neutral language in their DEI statements compared to Northeast, Midwest, and West universities. Moreover, top universities in the West have DEI statements with the highest positivity score of 0.257, implying that universities in the West use more positive language in their DEI statements compared to those in the Northeast, Midwest, and South.

Figure 5: MDS for the top-ranking university DEI statements

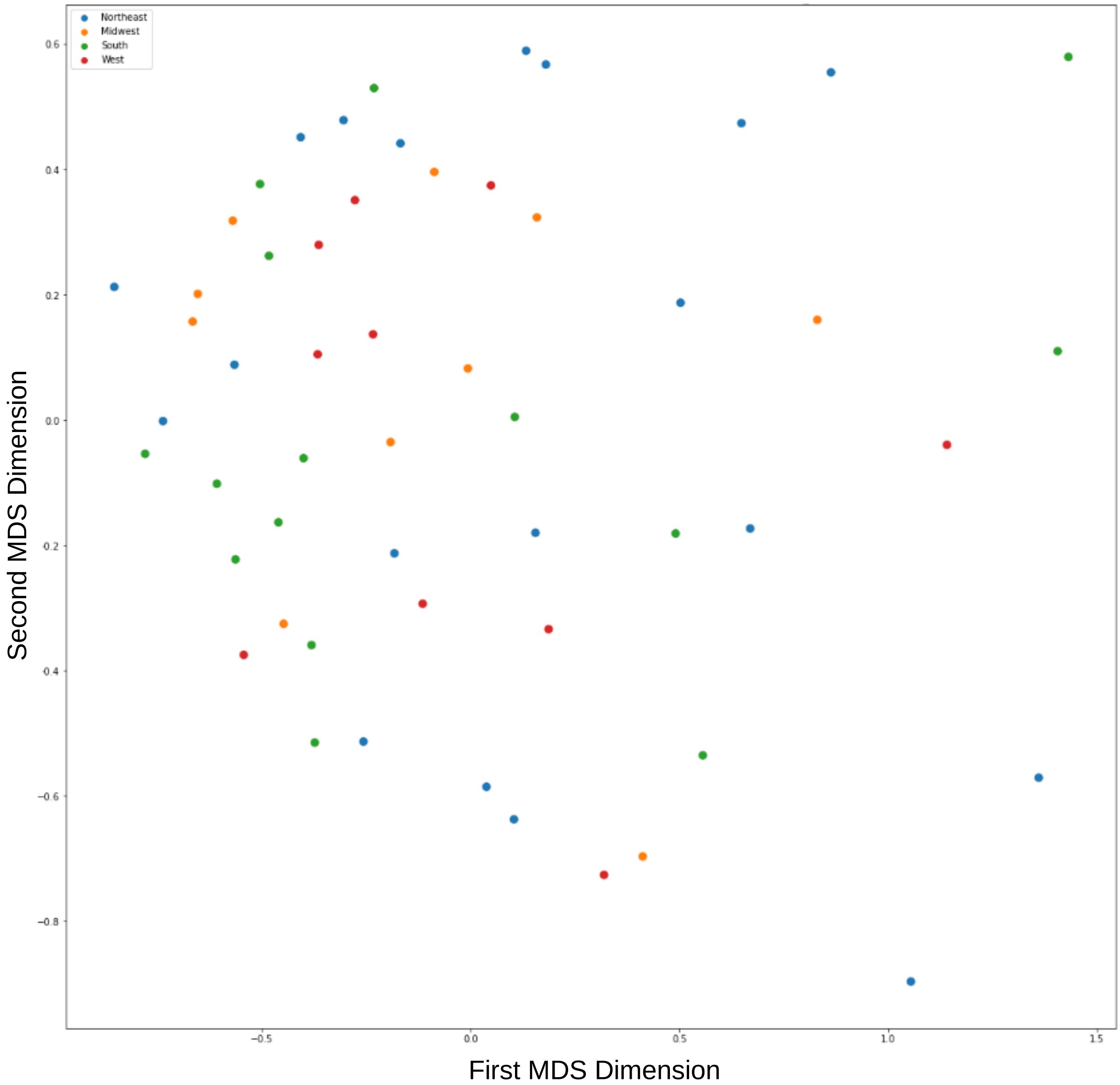


Figure 6: MDS for the top-ranking company DEI statements

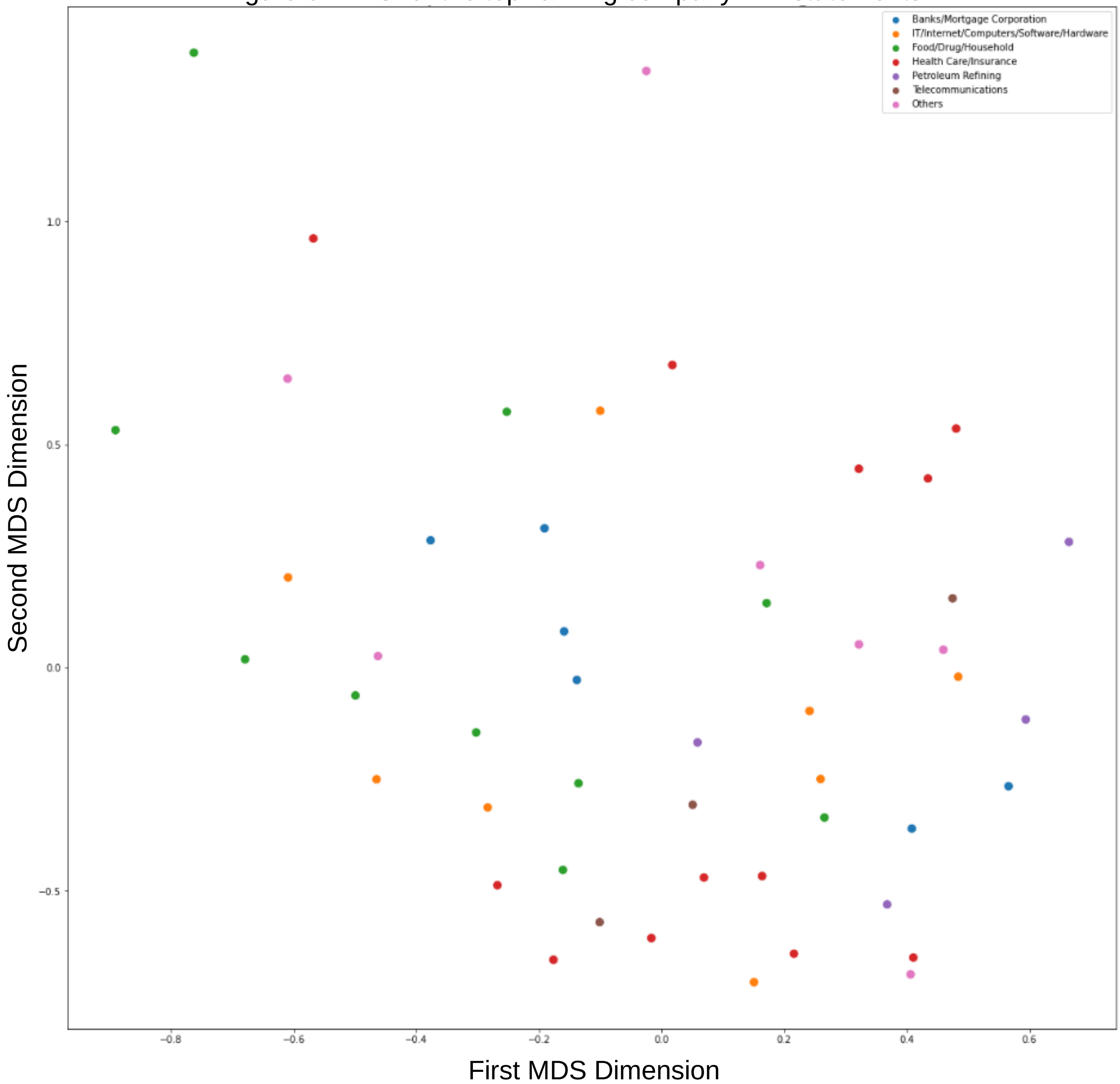


Table 3: Average (standard deviation) DEI statement neutrality and positivity scores in academia

Region	Neutrality	Positivity
Northeast	0.781 (0.075)	0.213 (0.072)
Midwest	0.741 (0.076)	0.249 (0.085)
South	**0.806 (0.066)**	0.185 (0.068)
West	0.730 (0.096)	**0.257 (0.101)**

Table 4 presents average (standard deviation) neutrality and positivity scores in DEI statements issued by top companies across seven sectors. Among the top ranked companies, the

IT/Internet/Computers/Software/Hardware sector has the highest neutrality sentiment score of 0.812 (marked in **bold**), while the Petroleum Refining sector has the highest positivity sentiment score of 0.258 (marked in **bold**).

Table 4: Average (standard deviation) DEI statement neutrality and positivity scores in industry

Sector	Neutrality	Positivity
Banks/Mortgage Corporation	0.766 (0.062)	0.215 (0.072)
IT/Internet/Computers/Software/Hardware	**0.812 (0.055)**	0.185 (0.056)
Food/Drug/Household	0.775 (0.048)	0.220 (0.051)
Health Care/Insurance	0.765 (0.102)	0.219 (0.098)
Petroleum Refining	0.739 (0.089)	**0.258 (0.088)**
Telecommunications	0.767 (0.124)	0.211 (0.105)
Others	0.764 (0.078)	0.227 (0.083)

To compare the top universities and companies, we calculated general neutrality and positivity sentiments from DEI statements across academia and industry. The average (standard deviation) neutrality scores for the top-ranking universities and companies are 0.771 (0.081) and 0.773 (0.076), respectively. Additionally, the average positivity scores for DEI statements in academia and industry are 0.220 (0.082) and 0.217 (0.075), respectively. These finding show that top ranking universities and companies issue DEI statements with comparable levels of neutrality and positivity on average. Table 5 presents the proportion of universities and companies whose DEI statements are above and below average neutral or positive sentiment. Based on the results in Table 5, a slightly larger proportion of companies (48.00%) tend to use neutral language in their DEI statements compared to the top-ranking universities (46.30%). Similarly, a greater proportion of companies (54%) tend to use positive language in their DEI statements compared to universities (51.85%).

Table 5: Percentage of universities and companies with DEI sentiments above and below the average

	Neutrality		Positivity	
	Universities	Companies	Universities	Companies
Above average	46.30%	48.00%	51.85%	54.00%
Below average	53.70%	52.00%	48.15%	46.00%

DISCUSSION AND CONCLUSIONS

An analysis of the DEI statements using text mining is of great importance for administration since it reveals university or business beliefs and policies in creating and maintaining an environment that supports diverse individuals, offers equal opportunities, and creates an inclusive community for both internal and external customers. In this study, we utilized text mining to examine the DEI statements for the top 50 universities and companies in order to gain a better understanding of commitments made by top academic and commercial influencers. We found that academic messaging emphasized students (customer base) more so than industry which preferred to place emphasis on its workforce. DEI statements in industry were also found to be more uniform (similar) compared to statements in academia, which are slightly more varied in terms of word composition. Moreover, slight variations in DEI statement sentiment were identified between different academic regions and industry sectors. Our analysis can assist universities (companies) finetune their DEI statements by comparing word composition and sentiment found in statements issued by their regional (sector) peers. As a result of our study, we believe that higher education and business administrations can benefit from having DEI statements systematically analyzed from a focus, target, and sentiment perspective. In addition, this type of analysis enables administrations to understand how DEI statements differ based on factors such as geographic location and target audience. To facilitate DEI statement comparisons and adjustments, we share techniques that quantify DEI statement differences. For future work, we intend to expand upon this research by incorporating additional higher education institutions and businesses, which will be subdivided into subgroups. In addition, we aim to apply machine learning techniques in classifying these DEI statements.

APPENDIX

Ranking	Company
1	Walmart
2	Amazon
3	Apple Inc.
4	CVS Health
5	UnitedHealth Group
7	McKesson Corporation
8	AmerisourceBergen * (acquired in 2022)
9	Alphabet Inc.
10	ExxonMobil
11	AT&T
12	Costco
13	Cigna
14	Cardinal Health
15	Microsoft
16	Walgreens Boots Alliance
17	Kroger
18	The Home Depot
19	JPMorgan Chase
20	Verizon Communications
21	Ford Motor Company
22	General Motors
23	Anthem
24	Centene
25	Fannie Mae
26	Comcast
27	Chevron Corporation
28	Dell Technologies
29	Bank of America
30	Target Corporation
31	Lowe's
32	Marathon Petroleum

Ranking	University
1	Princeton University
2	Columbia University
2	Harvard University
2	Massachusetts Institute of Technology
5	Yale University
6	Stanford University
6	University of Chicago
8	University of Pennsylvania
9	California Institute of Technology
9	Duke University
9	Johns Hopkins University
9	Northwestern University
13	Dartmouth College
14	Brown University
14	Vanderbilt University
14	Washington University in St. Louis
17	Cornell University
17	Rice University
19	University of Notre Dame
20	University of California--Los Angeles
21	Emory University
22	University of California--Berkeley
23	Georgetown University
23	University of Michigan--Ann Arbor
25	Carnegie Mellon University
25	University of Virginia

33	Citigroup
34	Meta Platforms, Inc.
35	United Parcel Service
36	Johnson & Johnson
37	Wells Fargo
38	General Electric
39	State Farm
40	Intel
41	Humana
42	IBM
43	Procter & Gamble
44	PepsiCo
45	FedEx
46	MetLife
47	Freddie Mac
48	Phillips 66
49	Lockheed Martin
50	Walt Disney
51	Archer Daniels Midland

27	University of Southern California
28	New York University
28	Tufts University
28	University of California--Santa Barbara
28	University of Florida
28	University of North Carolina--Chapel Hill
28	Wake Forest University
34	University of California--San Diego
34	University of Rochester
36	Boston College
36	University of California--Irvine
38	Georgia Institute of Technology
38	University of California--Davis
38	University of Texas at Austin
38	William & Mary
42	Boston University
42	Brandeis University
42	Case Western Reserve University
42	Tulane University
42	University of Wisconsin--Madison
47	University of Illinois--Urbana-Champaign
48	University of Georgia
49	Lehigh University
49	Northeastern University
49	Ohio State University--Columbus
49	Pepperdine University
49	Purdue University--West Lafayette
49	Villanova University

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The choice of financial advisors in M&As: does the counterparty's earnings management matter?

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ABSTRACT

This study explores the role of financial advisors in merger and acquisition deals when a firm is concerned about earnings manipulation in its merger counterparty. We show that the likelihood of a firm hiring advisors increases as the merger counterparty engages in a higher level of earnings management. This association is strongly supported in the analyses on the acquirer's advisor choice but is weak for the target's advisor choice. Furthermore, acquirers prefer hiring informed advisors who are the target's relationship banks, especially when the concern of target's earnings manipulation is heightened. Moreover, acquirers hiring informed-advisors pay lower premiums to targets.

KEYWORDS: earnings management, financial advisors, M&As

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The Clock is Ticking: The Role of DC Operations and Transportation in Avoiding Late Orders in Online Retailing

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ABSTRACT

On-time delivery represents a key challenge for online retailers. Differently from prior literature, this study employs Theory of Swift and Even Flow and Queue Length Visibility to examine the flow of the order fulfillment process in its entirety. Using data relative to 11,241 orders of an online retailer, we empirically tested how process speed, order focus, and bottlenecks in the order fulfillment process affect on-time deliveries. We find a curvilinear relationship between speed and operational performance, a moderation effect of order focus, and a reduction of delays by expediting transportation. A post-hoc analysis further investigates the role of transportation.

KEYWORDS: online retail, order fulfillment process, theory of swift and even flow, last-mile logistics

INTRODUCTION

As Business-to-Consumer (B2C) e-commerce expands, on-time deliveries represent an increasingly important service quality outcome of the order fulfillment process (Dayarian and Savelsbergh 2020; Shang and Liu 2011). Yet online retailers (or retailers hereafter) continue to struggle with on-time delivery (Liu et al. 2021). Recent statistics showcase the relevance of on-time deliveries: more than 60% of consumers are less likely to repurchase from a retailer if the delivery is late (Victor 2021), and 87% of shoppers expect retailers to take ownership of late deliveries (Convey 2018). These concerns are expected to continue as post-pandemic trends show a surge of online orders that increase the pressure on retail operations (Zimmermann et al. 2021) to increase fulfillment processing, expedite deliveries, and satisfy customers (Dolan 2022).

However, in many instances, retailers' effort to deliver on-time is insufficient (Awaysheh et al. 2021; Gryta 2021; LateShipment.com 2020).

The order fulfillment process forms the core of online retailing operations. Prior research independently investigates activities making up order fulfillment processes, focusing on how each activity influences overall performance. The literature suggests that better management of activities within distribution center operations can improve last-mile delivery performance (Apte and Mason 2006; Camdereli and Swaminathan 2010; DeVries et al. 2016; Agatz et al. 2021; Awaysheh et al. 2021; Liu et al. 2021) and increase overall productivity for retailers. However, while it is useful to study how singular factors in the order fulfillment process affect performance, these activities do not occur in isolation (Rabinovich and Bailey 2004). In other words, a process-view of how key order fulfillment activities contribute to on-time deliveries in e-commerce can bring forth important insights for scholars and practitioners (Zhang et al. 2020), as fulfillment delays occurring DCO can propagate to delivery delay at the final stage (Salari et al. 2022).

We ground our study in the Theory of Swift and Even Flow TSEF (Schmenner and Swink 1998) and incorporate ideas from Queue Length Visibility (Shunko et al. 2018). Following TSEF, we first conceptualize the order fulfillment process as a flow constituted of two main activities, distribution center operations delivery transportation. Then, we empirically investigate how speed of distribution center operations affect on-time performance, the moderating role of process focus, and the relationship between distribution center speed and transportation time. We test our hypotheses using a unique dataset containing 11,241 observations of online orders that we retrieved from a large online retailer.

This study offers many contributions to theory and practice. First, we address the call for theory testing of TSEF's main predictions (Boer et al. 2015). Relatedly, we hypothesize and find a concave relationship between distribution center operations speed and delay, extending the logic from TSEF that would reasonably predict a linear relationship. Further, we contribute to TSEF literature on service design by arguing that the effects of swift and even flows are influenced by workers' performance relative to the queue. Third, we reveal the key role of complex orders (those containing higher product variety) in achieving on-time deliveries. This allows us to unpack the effects of focus in the process. Finally, we contend that expediting transportation time can resolve bottlenecks in distribution center operations. We offer online retailers guidance on how to look at order fulfillment as a process flow that meets e-commerce customer expectations. Finally, the unique dataset of this study identifies potentially important contextual differences from traditional order fulfillment operations, namely e-commerce customers have now higher expectations for delivery (Nguyen et al. 2019), and the last mile of the online retailer does not follow the same delivery schedule constraints as traditional delivery models do. For example, the online retailer in our study adopts cargo-motorcycles for urban delivery, which enable improved operations service design (Janjevic et al. 2021).

LITERATURE REVIEW

This study investigates an operations management perspective of the order fulfillment process, specifically, factors impacting on-time deliveries. The order fulfillment process is defined as a set of interrelated activities from the point of a customer's purchase decision to the point a product is delivered to the customer (Croxton 2003). The order fulfillment process for online retailers (or e-fulfillment process) encompasses five distinct activities, namely, order capture, order processing, pick and pack, ship, and after-sales service (Pyke et al. 2001). We focus on the first four activities as after-sales services do not affect on-time deliveries. Our analysis of the literature reveals that research has focused on examining individual factors impacting each e-fulfillment activity.

Order processing, picking, and packing include the activities of creating the pick items list, physically selecting the correct items, and packing and preparing for shipment (Croxton 2003;

Pyke et al. 2001). These activities experience delays when inventory is misplaced (Camdereli and Swaminathan 2010) or not optimally positioned (Acimovic and Graves 2015). Retailers can improve the distribution center operations when the pre-sorting and picking process flows more regularly (Apte and Mason 2006; Batt and Gallino 2019; Chen et al. 2010; DeVries et al. 2016). The literature also suggests that the product type affects complexity in order selection and fulfillment. Fisher (1997) suggested an efficient supply chain for functional products, as stable demand and low margins call for bulky orders and cheaper operations, and a responsive strategy for innovative products, characterized by unstable demand yet higher margins, that requires higher standards on product selection and fulfillment. In addition, literature has also investigated the impact of different product types, namely convenience, shopping, and specialty goods, on customer's expectation of fulfillment operations (Thirumalai and Sinha 2005), finding that customized fulfillment operations has a positive effect on customers' outcomes, but also increase complexity to it (Nguyen et al. 2018; Thirumalai and Sinha 2009).

Finally, order shipping or delivery relates to last-mile delivery of orders to their final destination (Pyke et al. 2001). This process may suffer delays due to delivery drivers' errors (Awaysheh et al. 2021), and increased service standards of same-day delivery (Dayarian and Savelsbergh 2020; Stroh et al. 2021). While transportation time has compressed, expectations relative to service standards have increased, and disruptions often occur in the final leg of the order fulfillment process. This is important because consumers' willingness to pay shipping fees (Gümüş et al. 2013) can be contingent upon retailers balancing the trade-off between delivery time and service quality (Shang and Liu 2011). In addition, the adoption of incentives related to delivery time slot choices is emerging as key issues (Agatz et al. 2021). Research also studied new technologies and innovations to improve on-time performance, for example, parcel lockers (Lyu and Teo 2022), autonomous vehicles (Reed et al. 2022), drone delivery (Perera et al. 2020), and sharing economy platforms (Benjaafar and Hu 2020; Tian and Jiang 2018), while using predictive analytics to assess the best route and avoid failed deliveries (Praet and Martens 2020) and forecast real-time delivery time (Salari et al. 2022), based on travel time predictors (Liu et al. 2021).

Overall, the literature review highlights that prior research focused either on service quality standards or individual factors impacting the order fulfillment process and on-time deliveries. We contend that the activities within the order fulfillment process are interdependent and consequential (Rabinovich et al. 2008). Thus, we argue that on-time delivery performance depends on the entire flow of the order fulfillment process, from the moment in which the order is placed to the moment in which it is delivered. As such, we take the process flow perspective to contribute to the literature by accounting for the complexities occurring in the entire process flow.

THEORY AND HYPOTHESIS

We study the order fulfillment process combining the Theory of Swift and Even Flow (TSEF) and notions from the behavioral literature on Queue Length Visibility (QLV) to explore how the process flow impacts online retailers' operational performance.

Theory of Swift and Even Flow

TSEF explains how managing the flow of a process improves the productivity of the process (Devaraj et al. 2013; Schmenner 2015; Schmenner and Swink 1998). Indeed, TSEF proposes that the productivity of a process increases the more swift and even the flow of the process (Schmenner and Swink 1998). TSEF was first introduced by Schmenner and Swink (1998) and initially employed to investigate the productivity of manufacturing processes (Schmenner 2001; 2009; Yin et al. 2017). Its predictions have proven useful to study a variety of operations contexts, including services (Karwan and Markland 2006; Schmenner 2004). For example the process flow of patients in hospitals' operational performance (Devaraj et al. 2013; Fredendall et al. 2009; Johnson et al. 2020; Venkataraman et al. 2018) and the process flow of order fulfillment process (Garn et al. 2020). TSEF can be applied to investigate efficiency and productivity at different organizational levels, including workers and supply chain productivity, also across organizational boundaries (Germain et al. 2008; Modi and Mabert 2010; Sartal et al. 2020). Hence, according to TSEF, productivity can refer to labor productivity, machine productivity, and total factor productivity (Schmenner and Swink 1998). In addition, productivity includes performance dimensions of manufacturing throughput time and delivery speed (Schmenner and Vastag 2006). In this study, productivity centers on service delivery Lateness, which manifests as a diminishing of service productivity in the order fulfillment process (distribution center operations) due to mismatching between the actual to planned delivery time (Atan et al. 2016; Rabinovich 2004).

TSEF identifies five basic laws: the law of variability, the law of focus, the law of bottlenecks, the law of scientific methods, and the law of quality (Schmenner and Swink 1998). Given our aim to assess the impact of the order fulfillment process on on-time performance, we do not investigate the law of quality, nor the law of scientific method (Schmenner and Swink 1998). This is because the quality of the order fulfillment process constitutes an outcome of interest and scientific method commonly focuses on individual distribution center operational activities (i.e., improving order picking). Our study examines the collective flows of distribution center operational activities focusing on the speed of process flow, the law of variability, the law of focus, and the law of bottlenecks

Queue Length Visibility

QLV refers to an aspect of queue design that represents the availability of feedback about the length of the queue (Shunko et al., 2018). QLV suggests that workers adjust the speed of their service rate when they receive feedback about their performance, such that workload visibility affects workers' effort (Powell & Schultz, 2004; Schultz, McClain, & Thomas, 2003). In a process flow in which workers can see the work build up, workers increase their processing speed when congestion occur (Doerr & Gue, 2013). Hence, the available feedback (queue length) will result in workers adjusting their service rate by speeding up to reduce the queue as an attempt to avoid becoming idle (Schultz et al., 1998; Schultz, Juran, & Boudreau, 1999). These arguments have found ample support in the literature analyzing how queue-length and increasing workload levels impact worker's service time and productivity (Doerr & Gue, 2013; Ergün‐Şahin et al., 2022; Jaeker & Tucker, 2017; KC & Terwiesch, 2009; Schultz et al., 1998, 1999; Tan & Netessine, 2014). For example, Wang and Zhou (2018) found that service times increase at a diminishing rate as the queue length continues to increase, and Ashkanani, Dunford, and Mumford (2022) found that workers adjust their service rate by speeding up or slowing down depending on the workload and the expected service quality.

Hypothesis development

In this section, we develop three hypotheses by incorporating logic of QLV and contextual aspects to TSEF. The constructs of interest are also the result of the theory elaboration process, as we combine aspects of the empirical context with TSEF. In this study, the constructs of interest are *Lateness*, *Fulfillment Center Operations*, *Transportation Time*, and *Focus*.

Lateness is the outcome variable related to delivery performance, which is crucial in the order fulfillment process (Fisher et al., 2019) and links to the process productivity. TSEF understands productivity in terms of the input of resources for a given output. Productivity has been studied at different levels within and across organizations, including labor, machine, total factor, and supply chain productivity (Germain, Dröge, & Christensen, 2001; Modi & Mabert, 2010; Sartal, Rodríguez, & Vázquez, 2020; Schmenner & Swink, 1998). In service contexts, productivity can refer to service provision' quality and service' value for the customer, thus as customer valued output over resource inputs (Johnson et al., 2020; Yin et al., 2017). In this sense, productivity reflects the performance of the service delivery. In order fulfillment, for less productive processes, more resources (e.g., expediting process) are required to deliver or preserve the value of the output. Following this reasoning, in this study, productivity centers on service delivery *Lateness*, which manifests as diminishing service productivity in the order fulfillment process. For each resource input in the order fulfillment activities, *Lateness* decreases customer valued output. *Lateness* indicates the mismatch between the actual vs planned delivery time (Atan et al., 2016; Rabinovich & Bailey, 2004).

Based on TSEF, literature on the order fulfillment process, and contextual aspects, we identified three factors of productivity: *Fulfillment Center Operations Time* (FCOT), *Transportation Time* (TT), and *Focus*. FCOT and TT reflect the speed at which operations within the order fulfillment process are executed. Specifically, FCOT refers to the activities of picking, sorting, and packing customer orders (Salari et al., 2022) while indicating the proportion of order processing time to the promised lead time. That is, it represents the elapsed time between order placement and packed, divided by the elapsed time between order placement and planned delivery time. TT refers to the activities of dispatching and delivering, and indicates the elapsed time between order processing time and actual delivery time. Finally, *Focus* reflects FCO task complexity, and refers to the difficulty in transforming task inputs into outputs because of the interdependency or diversity among task elements (Kang, Hahn, & De, 2017). In FCO, task complexity refers to the complexity of processing an order depending on the intrinsic characteristics of the order. *Focus* indicates a reduction of task complexity due to the concentration of the order in a product type.

<u>The impact of speed of the order fulfillment process on lateness</u>

According to TSEF, the efficiency of a process increases with the speed of material flow and declines with the increase in variability of flow (Modi and Mabert 2010). As such, two key factors are essential to improve the productivity of a process, namely speed and variability or evenness (Schmenner 2015).

According to TSEF, “the more swift […] the flow of materials through a process, the more productive the process is” in a linear fashion (Schmenner and Swink, 1998, p. 102). Speed is conceptualized in terms of lead time, such as the delivery speed of manufacturing throughput time, from the point where materials for a unit of the product are first worked on until that unit is completed (Schmenner and Swink 1998; Schmenner and Vastag 2006). As such, TSEF predicts that delivery speed decreases uncertainty in the lead-time and safety stock, hence maintaining a constant service level by shortening the transaction time by reducing the product cycles (Devaraj et al. 2007; Germain et al. 2001). TSEF has also been used to conceptualize speed in terms of rapidity of service delivery and information flow (Karwan and Markland 2006; Schmenner 2004). For example, swiftness has been conceptualized as the speed at which a physician treats patients, operationalized as the patient’s length of stay (Johnson et al. 2020). Similar to prior research (Rabinovich 2004), in the context of this study, Distribution Center Operations (DCO) refers to the speed at which the distribution center processes an order, namely, the time between the moment a customer places an order and the moment in which the order is packed.

In the retail supply chain, the speedy distribution represents a key element of competitiveness (Garn et al. 2020; Schmenner 2015). Within the distribution center, retailers often focus on expediting the process through automation (Douglas 2018) or individual picking (Ryder.com 2021). As such, retailers try to improve the speed of operations to improve process productivity, hence delivering on time and reducing the mismatch between the promised delivery and the actual performance (i.e., earliness or lateness) (Rabinovich 2004; Salari et al. 2022). However, developments in QLV augment this prediction by focusing on workers' service time (Shunko et al. 2018). Indeed, QLV suggests that workers adjust the speed of their service rate when they receive salient feedback about their performance, such that workload visibility affects workers' effort (Powell and Schultz 2004; Schultz et al. 2003). Similarly to Shunko et al. (2018), we suggest that queue length likely affects a worker's pace: a longer queue stimulates workers to work faster and more efficiently to reduce the queue, thus, increasing the service rate. Hence, the relationship between speed and productivity could be curvilinear (Jaeker and Tucker 2017). For example, Wang and Zhou (2018) show that service times increase at a diminishing rate as the queue length continues to increase, following a concave function.

Following the literature, in the context of this study, we expect that as Distribution Center Operations increase (i.e., the time it takes for the order to be packed and ready for shipment), the queue in the activities of the process increases, thus suggesting a linear relationship between. As such, according to TSEF, an increase in DCO reduces productivity, which in turn increases Lateness. However, QLV suggests a curvilinear relationship between DCO and Lateness. Reconciling TSEF with QLV, we predict a concave relationship between DCO and Lateness. As DCO increases, productivity will decrease, thus increasing the Lateness up to the point in which workers will increase their work speed to reduce the longer queue, marginally increasing the productivity and reducing the Lateness. As such, we posit that:

Hypothesis 1 (H1). DCO has a diminishing positive association with Lateness.

<u>The moderating role of focus on the impact of speed of the order fulfillment process on Lateness</u>

Focus is of key importance when considering process flows and performance (Schmenner and Swink 1998). It can be viewed as the reduction of differentiation in product and service categories, as well as the reduction of unevenness across categories (McLaughlin et al. 1995). Focus has referred to the range of tasks to be accomplished in the process, and it serves as means to understand task assignments (division of labor) among individuals (Huckman and Zinner 2008). The reasoning is that a focused process improves productivity because repetition and concentration on a specific area allow its workforce to become more effective (Diwas Singh and Terwiesch 2011). For example, in hospitals or airlines, focusing on a specific activity or customers will increase productivity and efficiency (Johnson et al. 2020; Tsikriktsis 2007). Similarly, many retailers focus on selling specific product categories (e.g., groceries or electronics), leveraging their expertise to improve the productivity of retail operations. However, the expansion of online retailing offered opportunities to expand the offering of product categories, ranging from functional to innovative products (Fisher 1997), distinguishing between categories such as convenience, shopping, and specialty products (Thirumalai and Sinha 2005). Consequently, as we study focus in the order fulfillment process, focus depends on the set of tasks involved in DCO to process an order and reflects the intrinsic characteristics of the order in terms of the presence of different product categories. Hence, Focus is defined as the degree to which an order is focused on a product category.

According to TSEF, the law of factory focus states that the greater the focus is on a limited set of tasks, the more productive the process is (Schmenner and Swink 1998). As such, productivity depends on the policy used to process orders (Chen et al. 2010) and specify work methods (DeVries et al. 2016). For example, grouping like products together improves the speed of the process as it standardizes the flow of materials. Hence, as the process flow is more focused on a specific product category, productivity can increase. However, similarly to the development of H1, focus affects such a concave relationship by altering the magnitude of the curvilinear effect. Indeed, when operations are focused on lesser products, workers can improve their productivity and the service rate, ultimately reducing the amount of Lateness (Batt and Gallino 2019).

Conversely, workers processing a greater variety of product categories – i.e., lower focus, will experience difficulties in increasing their productivity, potentially increasing the total Lateness. Thus, we expect that considering the nature of the worker involved in the distribution center operations process, an order focused on fewer product categories, the curvilinear effect of speed on Lateness will be mitigated as compared to when the worker processes an order with many product categories. As such, we posit that:

Hypothesis 2 (H2). Focus will moderate the relationship between DCO and Lateness, such that DCO will have a diminishing effect on Lateness for focused orders, while less focused orders will continue to increase to be late as DCO increases (linear effect).

The impact of bottlenecks of the order fulfillment process on Transportation Time

A bottleneck represents the slowest stage of a process resulting in excessive cost and reduced efficiency (Germain et al. 2008; Li et al. 2019). Considering TSEF, the law of bottlenecks suggests that better management of a bottleneck improves the process productivity (Schmenner & Swink, 1998). Furthermore, aligning the pace of process activities with the speed of a bottleneck makes the flow more consistent (Venkataraman et al., 2018). This law applies when operations managers aim to reduce the effect of bottlenecks in FCO (queue) by managing order fulfillment activities. Indeed, operations managers discretionally expedite delivery operations (TT) when FCOT increases to make up for the delay and reduce the queue length. However, by adopting a process flow perspective, operations managers aim to reduce the bottlenecks depending on how they respond to the queue length feedback.

Following the logic that in retail operations, transportation time can complement – not substitute – operations lead time (Cachon, 2001), operations managers can respond to the queue until the speedup costs exceed the congestion costs (Ashkanani et al., 2022). Hence, depending on the effort (cost) it takes to expedite an order, the likelihood that on-time delivery occurs, operations managers respond to the increasing queue length. In other words, managers accelerate delivery operations when an order's FCOT consumes a portion of the planned lead time that can realistically ensure on-time delivery (and avoid lateness). However, as an order is more likely to become late because the FCOT consumes a larger portion of the planned lead time, managers lack the incentive to expedite transportation, which is a resource-intensive activity presenting higher costs for the retailer (Chen et al., 2016; Jain, 2018). Therefore, we expect that as FCOT increases, TT first decreases, then increases. As such, we posit that:

Hypothesis 3 (H3). The relationship between FCOT and TT is curvilinear with a U-shape.

RESEARCH AND METHODS

Data source

To test our hypotheses, we retrieve archival data from a fast-growing Vietnamese online retailer operating exclusively in the domestic market since 2010 – that we name Ecom1. This online retailer is one of the most prominent and fast-growing in Southeast Asia, accounting in 2021 for 10% of Vietnam's total online market share with total revenues of over $370 million.

We selected Ecom1 because its operations resemble those of world-class giants, such as Amazon.com and Alibaba.com, yet includes unique characteristics that support the notion that DC operations are idiosyncratic, spanning from fully automated systems to manually-based operations (DeVries et al. 2016). This is particularly true in developing countries (Caro et al. 2020), such as Vietnam, in the context of this study. Similar to well-established retailers, Ecom1 offers a wide range of products, spanning from textbooks to electronics, holds inventories from third-party vendors in its facilities to fulfill on their behaves, sources items with an extended shelf life from international vendors (e.g., Cosmetics), and grounds its operations on a multi-city network (i.e., Hanoi, Danang, Hochiminh) that requires network-level optimization to minimize transshipments. Ecom1 also presents idiosyncratic characteristics of its fulfillment operations. First, Ecom1 pick and pack activities in all DCs are manually performed by workers backed by optimization technologies. Each DC utilizes staggered scheduling to ensure that workforce levels remain consistent during each 24-h period. This allows to assume a constant level of workers and, as such, productivity within the DC. Second, Ecom1 combines a private fleet and third-party logistics providers for its deliveries. The private fleet is constituted of cargo-motorcycles that deliver small or medium-sized parcels in the city. Like many other developing countries, Vietnamese retailers must design delivery operations to handle underdeveloped public transportation systems (Zhao et al. 2019), cash on delivery, and direct handover to customers. The transportation time starts when each motorcycle box is filled, and it has a cut-off every 10 minutes from 8 am to 8 pm, inferring that the night shift does not dispatch for last-mile delivery. Third-party logistics is only used for rural areas and for transshipments between DCs located in different cities. In such instances, delivery lists and routes are autogenerated at the dispatch door through an interconnected system between Ecom1 and its 3PL partners.

Dataset description

Due to trade-secret reasons, Ecom1 could not offer its entire historical database. We mitigated such drawbacks by asking Ecom1 for operations and order data on its fastest delivery service in a randomized period. This service offers customers the option to pay to expedite a singular order or subscribe to have all qualified orders delivered faster. This service is available only for addresses located in one of the three Urban contexts. Indeed, Ecom1 uses customers' registered addresses to report the availability of products for its fastest service from the closest DC. Therefore, we selected orders in which items were available at the local DC, did not require transshipment, and were delivered through the private fleet. This data selection strategy followed theoretical reasons and common best practices. First, this service prioritizes on-time performance. Hence, it offers more precise insights into our hypotheses' variable of interest and a more conservative hypotheses testing. Second, we specified the timeframe and the variable of interest to prevent Ecom1 from providing data that could bias our results. Indeed, examining only one firm ensures consistency in the dataset and enables to obtain cleaner results (Lu et al. 2022).

The original dataset includes a sample of 13,592 online orders purchased between August 2015 and September 2017, with the unit of analysis at the order level. For each order, the dataset includes five time stamps, a unique identifier for the DC that fulfilled the order, and order attributes, namely the number of items per sku, unique identifiers of product category, and the selected shipping option with the associated shipping fees. The sample of orders is limited to non-perishable products that can be parceled (e.g., phones, small appliances, T-shirts).

Variable construction

The variables operationalization followed the theoretical conceptualization, prior literature, and common practice.

Dependent Variables: The dependent variable *Lateness* L_n is the Lateness of the orders, often used as indicator of service quality (Dayarian and Savelsbergh 2020), and computed the difference, expressed in hours, between the actual delivery date and the planned (or promised) date of order n (Atan et al. 2016; Thürer et al. 2020). *Lateness* takes positive values when the order was delivered late, negative values when the delivery occurred prior to the deadline, and zero when the delivery date and time coincide with the scheduled one. In the sample used for the analysis, late orders were about 16%, in line with prior literature (Awaysheh et al. 2021; Salari et al. 2022) as well as industry benchmarks (Gryta 2021; LateShipment.com 2020).

The dependent variable *Transportation Time* (*TT*) was computed as the difference in hours between the delivered and packed date and time. Thus, this operationalization captures how long it took for each order to be delivered once DCO was completed.

Key Independent Variables: We operationalized *Distribution Center Operations* (*DCO*) as the ratio between packed-to-purchased time and planned lead time. Specifically, packed-to-purchased time corresponds to the difference between packed and purchased date and time, and planned lead time is the difference between scheduled delivery and purchased date and time. As such, this operationalization captures the time consumed for DCO as a percentage of the total lead time available to the online retailer for processing and delivering the order. Ratio approaches have long been used in computing similar operational time measures (Kilbridge and Wester 1961; Salari et al. 2022).

The moderator *Focus* was operationalized as a Herfindahl-Hirschman Index (HHI) (Hirschman 1964); for the order n, *Focus* is the sum of squared ratios between the number of items (*qty*) of product category c and the total number of items. The dataset identifies seven product categories, namely books, consumer electronics, cosmetics, fast-moving consumer goods, fashion clothing, lifestyle products, and new baby products. As such, for the total number of units included in the order, this measure reports the concentration of units relative to each product category. *Focus* scores close to one imply greater focus of the order on a product type and lower complexity in processing the order. This operationalization aligns with operations management literature that used the HHI as a proxy of product category concentration in a consumer' online order (Patel et al. 2021), and that defines product category at article level (Jain and Tan 2022).

Control Variables: We also computed several control variables capturing order intrinsic characteristics that may influence the order fulfillment process. First, we included *Order Size*, computed as the total number of items i in the order, because it can affect service time (Liu et al., 2021). Indeed, prior literature suggests that order size negatively affects the timeliness performance of online retail (Rabinovich & Bailey, 2004). Second, we included control variables to capture the characteristics of the retailer's delivery services. Thus, we included *Shipping Fees*, which captures the total shipping fees paid by the customer for the shipment of order n, because research found that such indicators directly or indirectly influence the order fulfillment process (Gümüş et al., 2013; Lewis, Singh, & Fay, 2006). Since this variable was specified in foreign currency – Vietnamese Dong (VND), to facilitate the readability of the results, prior to the analysis, we converted *Shipping Fees* (*SF*) to US Dollar using the Wall Street Journal daily historical series of exchange rates (Wall Street Journal, 2021). In addition, the retailer provides customers paying the subscription the 2-hour delivery service. As such, similar to prior literature (Peinkofer, Schwieterman, & Miller, 2020), we included a binary variable, *Expedite Delivery* (*ED*), that takes the value of one when the customer required the two hours delivery, zero otherwise, to control for the shorter promised lead time that an order can have. We also included a dummy variable, *Prepack*, to control for the items packed in advance. Prepacking is the practice of grouping multiple units of one or more stock keeping units (SKU) to reduce distribution and handling costs while increasing the productivity in warehouses (Gao, Thomas, & Freimer, 2014). *Ecom1* engages in prepacking when the order includes bundles of units of the same product category that have been packed in advance. For example, a bundle of shampoo and conditioner accounts for two prepacked items. *Prepack* takes one when the items in the order are prepacked, zero otherwise. In addition, we included *Wavesize*, computed as the total number of orders that were grouped in the same picking wave. A picking wave occurs when the retailer releases a batch of online orders for fulfillment (Çeven & Gue, 2017). *Ecom1* adopts wave picking for manually-operated fulfillment operations through optimization technologies. Further, we included *Experience*, computed as the ratio between the time (in days) an order was packed from the first order in the dataset was packed, and the time (in days) the order was purchased from the first order in the dataset was purchased. *Experience* accounts for the capabilities and knowledge in managing the order fulfillment process that generally retailers develop over time (Rabinovich & Bailey, 2004). Similar operationalizations have been used to capture the server's experience (Mao et al., 2019). Further, we computed three binary variables, namely *FC1*, *FC2*, and *FC3*, to control differences between fulfillment centers' performance. Each binary variable takes one if the order was processed in the relative fulfillment center, zero otherwise. In addition, we included three binary variables, namely *Year 2015*, *Year 2016*, and *Year 2017*, to control for the increase in operations volume and total revenues that *Ecom1* saw during this timeframe (Perdikaki et al. 2015). Finally, we included twelve binary variables, one for each operating month, to control the seasonal effect on the order fulfillment process, in line with prior literature studying the order fulfillment process (Lim et al., 2021; Patel et al., 2021).

Preliminary analysis

Following prior literature (Corbett et al. 2005; Hendricks and Singhal 2014), to limit the effects of outliers and nonlinearities, the original dataset was symmetrically trimmed at the 5% level in each tail for the focal predictor – *Distribution Center Operations*. Hence, the final sample size was reduced to 11,241 observations.

None of the correlations among variables are indicative of multicollinearity. In addition, all Variance Inflation Factors are in line with the literature (Lumineau and Henderson 2012; Perdikaki et al. 2015), and meet commonly acceptable thresholds (Kennedy 2008).

Prior to the final analysis, similarly to (Andritsos and Tang 2014; Chan et al. 2021), we log-transformed the variables *Transportation Time* and *Order Size* to correct for distribution skewness. All continuous variables meet acceptable standards for skewness and kurtosis (Brown 2006).

Finally, following best practices (Aiken et al. 1991) and common procedures in the operations management literature (e.g., Amengual and Apfelbaum 2021; Delfgaauw et al. 2021), in estimating the effect of interactions between continuous independent variables, prior to the empirical analysis, we mean-centered the focal predictor. This does not affect the interpretability of results since the focal predictor variable does not have meaningful zero points (Hofer 2017).

Empirical analysis and results

We tested our hypothesis with ordinary least squares (OLS) regression models using robust standard errors (same statistical inferences were obtained using classical standard errors) in STATA 17 (Wooldridge 2016). Results will be reviewed in details at the conference. Overall, we find support for our three hypotheses.

DISCUSSION AND CONCLUSION

In this study, we adopted TSEF and QT to empirically investigate the impact of DCO speed and variability on on-time orders, the key role of order focus, and transportation time as a potential solution to the bottlenecks in the order fulfillment process. We analyzed a unique dataset comprised of 11,241 actual orders from a large e-commerce retailer. Based on our findings, we offer theoretical contributions, managerial implications, and suggestions for future research.

Theoretical contributions

First, this research extends TSEF relative to the relationship between speed and productivity. TSEF generally suggests a linear relationship, whereas QT would provide a rationale for a curvilinear relationship. Our findings suggest a concave relationship indicating that decreases in process speed decrease productivity, but at a diminishing rate. This is likely because as the queue in the process increases, workers improve their service rate, resulting in improved productive (Jaeker and Tucker 2017; Shunko et al. 2018). Hence, we expand TSEF thinking (Schmenner and Swink 1998), arguing the speeding-up effect that queue visibility have on worker performance. Indeed, as the queue increases, congestion occurs due to workers' decrease in speed (or service rate) or a steep increase of orders to process. However, the congestion is not wholly harmful to the process, since it motivates workers to increase productivity and uniformity of the service rate based on the queue. This aligns, for example, with the notion that doctors speed up when they progressively fall behind schedule in visiting patients (Cayirli and Veral 2003). Relatedly, the results also expand TSEF in relation to capital investments and automation. Schmenner (2009) suggested that capital investments in automation can serve to increase process flow speed and, as such, productivity. However, we contend that with variation in the input, the human capacity to adjust the service rate could reduce the wasteful waiting time needed to adjust the automated process.

Second, this research contributes to the understanding of TSEF by investigating the joint effects of the laws of focus and speed. Indeed, prior literature addressed the importance of plant focus as means of increasing efficiency and effectiveness (Diwas Singh and Terwiesch 2011) and service focused on a limited set of tasks to improve productivity (Devaraj et al. 2013; Venkataraman et al. 2018). We investigate how process focus moderates the concave relationship between speed and productivity, finding that greater focus improves the speed of workers and, thus the productivity. Further, even if speed increases and productivity follows, if the process is not focused on a limited set of tasks, the concave relationship becomes steeper, mitigating the workers' increased effort to reduce the queue. This may have implications for work design and assignments. In DCO activities, variety in product categories increases the complexity of operations, which could be addressed by increasing the worker's focus. Thus, we contend that assigning orders based on workforce focus could improve the speed and overall productivity.

Finally, this study expands the understanding of the law of bottlenecks. Theory and literature suggest that productivity improves as bottlenecks are better managed and as process velocity aligns with the speed of the constrained resource in a process (Devaraj et al. 2013; Sartal et al. 2020; Schmenner and Swink 1998). Our results reveal that the effect of a bottleneck can be mitigated by activities that follow the bottleneck in DC operations. This suggests that improvements in the downstream process can help reduce the lateness of the upstream processes (Frohlich and Westbrook 2001). Hence, when DCO reduces productivity, transportation time can mitigate the bottleneck. This argument also suggests that DCO may have a greater impact on lateness than transportation time, but the latter can address service failures and delays occurring during the order fulfillment process (Awaysheh et al. 2021). Finally, our post hoc analysis revealed that there is a U-shaped relationship between DCO and Transportation Time, and an exponential relationship between DCO and Tardiness, supporting the notion that a retailer may in fact choose not to expedite delivery when DCO passes the tipping point. We corroborated this conclusion by interviewing a Senior Operations Managers at a large retailer operating in North America. He supported the conclusion that retailers should not hold on on-time orders to make up for late orders, arguing that: "*Don't sacrifice the mass to save the few. If an order is late by a day, does it really matter if it is two days late?"*. Finally, he also commented that shipping costs for expedite deliveries can be harmful for the retailer: "*Why pay a premium to expedite orders that are already late? You operate for the many (standard orders), not to save the exceptions*".

Managerial contributions

This study offers several managerial insights. First, despite the great importance of improving each activity of the order fulfillment, this study suggests that adopting a process flow perspective helps to visualize the strengths and weaknesses of operations (Zhang et al. 2020). Indeed, analyzing the process flow allows to reason on how the overall productivity is influenced by a sequence of activities and not a sole activity within the process. In addition, we argue that retailers need to distinguish between speed and variability of the order fulfillment process. Speed is at the core of the delivery process. While prior literature recommends that in the B2B order processing, including picking, packing, and assembly, can take up to 43% of the total lead time (Menachof et al. 2009; Stock and Lambert 2001), we found that in the online B2C, the percentage reduces to 30% before incurring in a delay. This reflects the need for greater efforts in processing orders in a timely fashion to satisfy customers while improving productivity. Alternatively, we suggest retailers investigate a dynamic lead time based on the system's workload (Shang and Liu 2011). For example, offering a 2-hour delivery can be sustainable up to the point that DCO can pace up and process orders otherwise delays occur. Hence, adjusting the lead time based on productivity can increase on-time deliveries.

Second, the complexity of DCO still impacts the overall performance. We recommend DC managers be more in tune with complex orders when monitoring DCO. Specifically, we argue that when the workforce focuses on specific types of orders, the complexity reduces, thus productivity improves. In other words, DC workers can reduce delay if they know how to process complex orders (Johnston and Jones 2004). Indeed, adding new strategies focused on individual item picking, kitting, and bundling within the warehouse can improve delivery performance (Ryder.com 2021). Ultimately, complex orders take more time, and this can create a further bottleneck in the process.

Finally, this study understands that expediting transportation time can reduce DCO delays. Last-mile delivery is a key element of the process, and its design can be the crucial factor to satisfy customers. Online retailers can address DCO issues by improving last-mile delivery systems and design, adjusting delivery operations to the urban context (Stroh et al. 2021), for example, integrating the private fleet with crowdsourced drivers, who often offer faster and more flexible deliveries (Castillo et al. 2022; Dayarian and Savelsbergh 2020), or adding to the private fleet cargo-motorcycles (Janjevic and Winkenbach 2020), as many companies are doing (e.g., UPS) (Janjevic et al. 2021). Additionally, retailers can fasten last-mile delivery by reducing the temporal and spatial distance between DCO and final customers, for example, through an omnichannel retail strategy (Glaeser et al. 2019; Harsha et al. 2019; Li 2020).

Overall, this study showcases that online retailers require a reliable, swift, and even order fulfillment process (Schmenner 2009), achieved by aligning upstream and downstream processes (Frohlich and Westbrook 2001), and reducing complexities while optimizing the logistics network performance (Apte and Mason 2006). Indeed, e-commerce fulfillment is not limited to distribution center operations but extends to the transportation management system (Ryder.com 2021).

Future research

While our study has made several important contributions to distribution center operations utilizing an e-commerce distribution channel, there are additional opportunities for future research. Future studies may expand the investigation on the relationship between speed and service productivity by focusing on how worker’s waiting time and visibility affects service rate. With regard to our examination of variation, a limitation of this study is that we analyzed variability through the standard deviation of DCO. While this is in line with prior literature (Venkataraman et al. 2018), future studies can further investigate the impact of demand and process variability on productivity.

We also provided important insights into the moderating role of focus on the relationship between DCO and on-time orders. That said, we did not investigate how the workforce's experience affects DCO speed (Batt and Gallino 2019). Future studies can address this aspect. In addition, the unique delivery system of this online retailer (i.e., using cargo-motorcycles) does not follow the same delivery schedule constraints as traditional last-mile delivery models that utilize infrequent shipping windows (i.e., at the end of a shift). The firm in our study employs hourly cutoff times that increase the flexibility of the delivery system. A limitation of this study is that we did not assess how different delivery cutoff times impact transportation time performance. Future research can investigate how tailoring the cutoff time to the urban context affects on-time performance (Stroh et al. 2021). Finally, we analyzed a dataset from only one firm. While this is a limitation of many empirical studies, and it allows to obtain cleaner results, we advise that our findings must be interpreted with caution when applied to other retailers (Lu et al. 2022).

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The Effect of Political Risk and Corporate Governance on Bank Stability in the MENA Region: Does the Arab Spring Matter?

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ABSTRACT

We examine the effect of CG on bank stability (BS) by investigating the effect of political risk on BS due to the Arab Spring that took place in 2010 - 2011. We used the 3SLS regression method to analyse data of a sample of banks in the MENA countries. We found that political stability enhances banks' financial stability. Board size, independence, managerial ownership, and audit committee meetings and size significantly and positively affect BS. However, board gender diversity, board meetings, CEO duality, and institutional ownership significantly and negatively affect BS. The Arab Spring moderates the relationship between political stability, CGM, and BS.

KEYWORDS: Bank stability, Political risk, Corporate governance, MENA, Arab Spring

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The role of coopetition in low-carbon logistics

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ABSTRACT

In logistics, measures taken by individual companies to reduce CO_2 emissions are no longer sufficient. One form of cooperation that could deliver tangible results in the field of low-carbon logistics is coopetition. This article identifies the impact of coopetition on the achieved economic and ecological performance of enterprises in the field of low-carbon logistics. Moreover, it was demonstrated that among the leaders of low-carbon logistics development, companies involved in coopetition prevailed. These are companies that achieve sufficiently high revenues, have capital ties with other entities and run manufacturing or service operations in the sectors of transportation or warehousing.

KEYWORDS: Low-carbon logistics, Coopetition, Supply Chain Coopetition, CO_2 reduction, Carbon emission reduction

INTRODUCTION

Sustainable development is becoming an increasingly important factor influencing the way in which enterprises operate. It is also one of the critical factors determining success in business. Various stakeholder groups, such as government, consumers, the media, and others, are exerting pressure on entrepreneurs to become increasingly responsible towards society and the environment.

Since the agreement regarding the Kyoto Protocol of 1997, which established targets for 37 industrialized countries and the European Community in order to reduce greenhouse gas emissions (UNFCCC, 1997), public and governmental concern for the environment has been increasing. International organizations and national governments have set targets for reducing greenhouse gas emissions for the next 10 to 50 years. One of the measures taken by the European Commission for environment protection on an international scale is the so-called European Green Deal, which aims, among others, to bring emissions of greenhouse gases to 55% below the 1990 level by 2030, and ultimately strives to achieve climate neutrality in Europe by 2050 (European Commission, 2020). Therefore, in the context of growing political and social concern regarding CO_2 emissions, environmental protection has become an important area of public policy and scientific research.

In a similar spirit, the general public has become increasingly sensitive to environmental issues. Buying low-carbon products has become an inevitable trend. More significantly, this trend is no longer just the choice of a few environmentally aware consumers but has grown on a much wider scale (Fraj & Martinez, 2007; Kanchanapibul et al., 2014; Tsen et al., 2006). As a result, consumers are willing to pay a higher price for products with a lower carbon footprint (Echeverría et al., 2014).

Environmental problems primarily stem from carbon dioxide (CO_2) emissions, the main cause underlying global warming (Akyelken, 2011). According to the European Parliament data (2019), almost 30% of the total CO_2 emissions in the European Union are generated by the transportation sector, where road freight accounts for 72%. Already 10 years ago, it was

estimated that the quantity of emissions related to logistics in the product life cycle amounts to between 5 to 15% on average (Doherty, Hoyle, 2009).
Since 1990, enterprise owners and managers have been increasingly interested in logistics processes detrimental to society and the environment, as well as the economic results of the entire economy and individual enterprises (Murphy et al., 1995; Murphy, Poist, 2003). At the same time, modern companies perceive low CO_2 emissions in production and logistics as an indispensable part of their business (Ramanathan et al., 2014). Companies increasingly require measures compliant with sustainable development with regard to supplier selection and development, carrier selection, decisions regarding warehouse location, distribution, and freight, as well as determining routes and use of vehicles (Carter, Easton, 2011). On the other hand, customers increasingly demand low-risk supply chains which, at the same time, are socially and ecologically responsible (Sundarakani, et al., 2010).
Sustainable development in corporate management is crucial for gaining a competitive advantage, meeting social requirements and maximizing the benefits of stakeholders (Beamon, 2008). The integration of social and environmental thinking with supply chain processes is becoming increasingly important in designing and operating these chains (Trapp et al., 2020; Raza, 2018; Gimenez, Sierra, Rodon, 2012). As a result, enterprises manage the environmental and social results of their logistics operations to a greater extent (Feng et al., 2021; Oyedijo et al., 2021; Kumar, Anbanandam, 2020; Mathiyazhagan et al., 2021; Yadav et al., 2020; Centobelli et al., 2017). However, the sustainability challenges which the world is facing today are too great for any company to face on its own. Consequently, many companies began to realize that individual efforts would no longer be sufficient in order to achieve the goals of a sustainable supply chain (Vachon, Klassen, 2006, 2008). On the other hand, sharing resources, intelligence, leadership, and common sustainable development goals with other companies, even competitive ones, may translate into better outcomes.
Cooperation between rival companies in the field of low-carbon production and logistics is closely related to the concept of coopetition, which refers to the interdependence of competitive and cooperative relations between competitors, as well as to cooperation mechanisms aimed at maximizing individual profits (Brandenburger, Nalebuff, 1996). Coopetition may also play an important role in achieving the goals of a low-carbon economy. Coopetition can improve both the environmental and economic performance of enterprises (Lou et al., 2016).
The literature contains the results of research on the impact of inter-organizational cooperation on improving the achieved results of sustainable development in the field of logistics and transportation. Examples of such cooperation initiatives include: reducing emissions through joint transportation (Cruijssen et al., 2007), consolidation of transportation (Ergun et al., 2007), and cooperation between purchasers and suppliers leading to an improvement of environmental or social practices (Saghiri, Mirzabeiki, 2021). In other words, research on cooperation for sustainable development demonstrates that coopetition facilitates the use of limited technological, financial, and human resources in a more efficient way including from the perspective of sustainable development. In this context, the aim of the article is to identify the impact of coopetition on the economic and ecological results of enterprises in the field of low-carbon logistics. Additionally, the authors intend to identify key characteristics of those enterprises that are involved in coopetition and, at the same time, are leaders in the implementation of low-carbon logistics.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

The essence of low-carbon logistics

Since 1970, global emissions of CO_2 from fossil fuels have increased by about 90%, with fossil fuel combustion and industrial processes accounting for about 78% of total CO_2 emissions (IPCC, 2014). The International Energy Agency (IEA) identified three main contributors to CO_2 emissions: electricity, industry and transportation (IEA, 2015). Nevertheless, despite the fact that transportation can be undoubtedly considered an important contributor to global warming, insufficient attention is still being paid to specific low-carbon management practices in the logistics and transportation sectors (IEA, 2015). Logistics processes in enterprises result in polluting the natural environment to a considerable degree. However, it is tricky to easily reduce the scale of logistics processes since it is difficult to imagine the functioning of modern supply chains without significant support from logistics. Therefore, the problem is not to reduce the number of logistics processes, but to transform them so as to curb their harm to the environment.

The source literature mentions the concept of *low-carbon logistics* (Böttcher, Müller, 2015) or *low-emission logistics* (Osieczko et al., 2021) specifying measures limiting greenhouse gas carbons (mainly CO_2) undertaken in implemented logistics processes. Low-carbon logistics is defined as a set of optimization logistics processes that use new technologies or innovative management methods in order to reduce resource consumption and CO_2 emissions (Li et al., 2020). Frequently, the energy efficiency of logistics processes is also considered as part of low-carbon logistics (Tozanli et al., 2017). Low-carbon logistics means that logistics processes are focused on achieving goals in terms of reducing energy consumption, pollution and emissions, owing to the use of renewable energy and technologies enabling the attainment of energy efficiency (Xu, 2011). The authors understand low-carbon logistics as a concept of managing material flows and accompanying information flows, starting from the design stage, in such a way that, together with the expected economic objectives, it is possible to achieve a set environmental goals related to the reduction of greenhouse gas emissions and improvement of energy efficiency in the field of logistics processes.

Considering the above, low-carbon logistics can be considered as an integral part of the concept of *green logistics* that aims to create logistics systems responsible for the natural environment which are, at the same time, economically efficient. The concept of low-carbon logistics has been highlighted in the literature with a view to emphasizing the gravity of the detrimental effect of greenhouse gas emissions, which constitutes a global problem for natural environment protection.

According to WWF (2012) and Javid et al. (2014), CO_2 reduction initiatives can be categorized as follows: avoidance of carbon dioxide emissions (e.g., using alternative means of transportation), CO_2 reduction (e.g., fuel efficiency) and CO_2 substitution (e.g., electric cars). By adopting such an approach, the following initiatives in low-carbon logistics may be distinguished: daily transportation management, advanced logistics systems and intermodal transport, as well as advanced vehicle technology and alternative fuels. While transportation management, logistics systems design and intermodal transport can be labelled as “avoidance” initiatives, improvements in vehicle technology can be seen as “reduction”, whereas alternative fuels utilization can be treated as “substitution”.

Economic effects of low-carbon logistics

Action taken by stakeholders to develop and enhance the solutions for low-carbon logistics are based on their ongoing or planned economic and environmental results. From the perspective of individual companies, the set of economic effects most often focuses on reducing the costs of process implementation, improving competitiveness and building the company's image as environmentally responsible. (Rao, Holt, 2005; Lai, Wong, 2012; Pazirandeh, Jafari, 2013; Furlan Matos Alves et al., 2017). When assessing the impact of low-carbon logistics on corporate performance, the economic effects of such an approach need to be carefully analyzed. Reducing costs by improving energy efficiency is the most obvious source of business value associated with emissions reduction. Therefore, it does not come as a surprise that cost reduction is the reason why many of the 57 international corporations (as diverse as Dell, Ford, EADS and Vivendi) participating in the Carbon Disclosure Project (CDP) supply chain program (Carbon Disclosure Project, 2011) are

striving to measure and reduce emissions in the supply chain. In addition, companies which undertake proactive action in the face of climate changes might be supported with investment and financial subsidies (Furlan Matos Alves et al., 2017).
Improving public relations through low-carbon operational initiatives may help companies reach places and attract communities where, under normal conditions, they would encounter greater resistance. At the same time, it can help companies attract more customers to their existing locations (Plambeck, 2012). Thanks to the visibility of their efforts to reduce greenhouse gas emissions, companies enhance their image (Plambeck, 2012). A positive public image and the opportunity to be part of environmental initiatives help companies motivate employees and attract new talent. Out of the 57 well-known companies participating in the CDP supply chain program, 47% reported that the reduction of emissions in the company helped increase employee motivation (Carbon Disclosure Project, 2011). In turn, the emissions/sustainability indicators presented on the stock exchange attract investors' attention. Improving the company's reputation is beneficial as it quells stakeholders' criticism and boosts the company's market position (Furlan Matos Alves et al., 2017).

Environmental effects of low-carbon logistics

In the area of ecological effects, in addition to using fewer resources in a more rational way and improving energy efficiency, the highest priority is attached to reducing greenhouse gas emissions, in particular CO_2.
Operational streamlining also a key environmental benefit in terms of increasing efficiency, reducing the amount of waste throughout the production process as well as optimizing the fleets used in transportation (Furlan Matos Alves et al., 2017). In the well-known just-in-time production system, suppliers are located close to the production site, which facilitates operational management. Employees seek to immediately identify quality issues and eliminate waste, which is synergistic with just-in-time operations and proximity to suppliers. Eliminating waste and designing products which require fewer materials can reduce emissions from the production and transportation of materials (Lapre et al., 2000; Lee, 1997). However, one objection may arise from the fact that when a company converts waste into a product, it has an incentive to increase production, which tends to increase emissions (Lee, 1997).
An essential element highlighted in the literature on low-carbon logistics is the need for close cooperation not only with partners, but also with competitors in the supply chain and beyond. This cooperation aims at achieving sustainable development by redesigning interorganizational activities, production and distribution processes and giving priority to social and environmental responsibility (Murphy, Poist, 1992; Bowen et al., 2001; Carter, Dresner, 2001; Carter, Jennings, 2002). Consequently, it is also worth looking at other forms of business cooperation, for example coopetition and its possible connections with the measures undertaken in the scope of low-carbon logistics.

Coopetition as a tool of low-carbon logistics

Coopetition as a business strategy means that an organization should cooperate and compete simultaneously with its competitors in order to achieve common goals and objectives through joint operations (Brandenburger, Nalebuff, 1998; Bengtsson, Kock, 2000; Chin et al., 2008; Ritala, 2012; Cruijssen et al., 2007; Osarenkhoe 2010). Verstrepen et al. (2009) identify strategic, tactical and operational cooperation as three levels of cooperation with a competitor. By narrowing the definition of coopetition to logistics, cooperation with competitors is identified as a partnership between two or more transport carriers, distribution companies (for example, wholesalers) or retailers (Gonzalez-Feliu et al., 2013).
Much has been written on the issue of coopetition in management, in areas such as product development, production, marketing, knowledge acquisition, interorganizational learning,

knowledge sharing, innovation and project management. Coopetition relationships are widely considered to be complex and operationally challenging (Gnyawali, Park, 2011; Ho, Ganesan, 2013; Ritala, Sainio, 2014; Osarenkhoe, 2010; Yilmaz et al., 2015; Bengtsson, Raza-Ullah, 2016; Bouncken, Fredrich 2016; Peng et al., 2018; Gnyawali et al., 2016; Gast et al., 2019; Botelho, 2018; Li et al., 2011; Park et al., 2014; Le Roy, Fernandez, 2015).
Some interesting solutions stand out among the examples of the application of coopetition relations in enterprises. One of them is the Australian wine industry, which reduced the use of fossil fuels and refrigeration through joint outsourcing of bottling and packaging (Christ et al., 2017). In another example, Planko et al. (2019) identify key factors enabling coopetition in the Dutch smart grid sector, in which competitors collaborate to develop innovative technologies supporting sustainable development. By narrowing the application of coopetition to the field of logistics, behaviors such as sharing logistics and transport capabilities (Ferrell et al., 2020), intelligent freight combinations, incremental delivery frequencies (Saenz et al., 2014), as well as sharing entire transport networks and joint deliveries to warehouses, as well as sharing them, can be observed (Sheffi et al., 2019).
Many advantages of coopetition can be identified in the literature. Outstanding examples include the development of new products (Bouncken et al., 2017), improved market position (Gnyawali, Park, 2011), improved procurement and supplier relationship management (Wilhelm, 2011; Wilhelm, Sydow, 2018), increased supply chain resilience (Shin, Park, 2021), higher production efficiency (Luo, 2007), price competition through logistics costs reduction (e.g. by using standard unit packaging) (Kotzab, Teller, 2003), coping with changes in the logistics market (Song et al., 2015) and increased innovation of the business model (Ritala et al., 2014). Moreover, the results of coopetition in supply chains include reduction of collective operating costs (Zhang, Frazier, 2011), lower inventory storage costs and shorter lead times (Shockley, Fetter, 2015), expansion of logistics networks (Song et al., 2015), improvement of the company's image (Mirzabeiki et al., 2022) and a higher level of logistical customer service (Song, Lee, 2012).
The above literature analysis proves that the effects achieved through coopetition are in many cases consistent with the assumed effects of low-carbon logistics. Coopetition can therefore be considered as a tool for achieving the goals of low-carbon logistics. Table 1 compares the most popular economic effects of low-carbon logistics and the effects of cooperation with competitors.

Table 1: Comparison of the economic effects of applying low-carbon logistics vs. undertaking a coopetition relationship

Effects of application	Low-carbon logistics	Coopetition
Reduction of the costs of implemented logistics processes	**YES**	**YES**
Improving the company's competitive position	**YES**	**YES**
Improving the company's image	**YES**	**YES**
Increase in the efficiency of the implemented processes	**YES**	**YES**
Development of new products	NO	**YES**
Higher level of customer and logistics service	**YES**	**YES**
Enhanced coping with changes	NO	**YES**
Reduced market uncertainty	NO	**YES**
Access to foreign know-how	NO	**YES**

Source: The authors' own elaboration

As a consequence of the above analysis, a question arises: to what extent are the economic effects in the field of low-carbon logistics achieved by using coopetition?
In order to answer such a research question, the authors formulated hypothesis:
H.1. Enterprises undertaking coopetition achieve better economic effects in the area of low-carbon logistics than the ones that do not engage in coopetition.

Researchers also suggest that the cooperation of competitors may be a means of achieving positive results in terms of sustainable development (Limoubpratum et al., 2015; Stadtler, 2017). For example, according to the research conducted by Gimenez and Sierra (2013), cooperation between buyers and suppliers in the form of training and joint programs reduces the quantity of waste and improves recycling. Environmental advantages of coopetition also include improved efficiency in the use of organizational resources and potential environmental improvements (Manzhynski, Figge, 2020); joint initiatives for the recycling of used packaging (Volschenk et al., 2016) and improving environmental efficiency in transport and logistics operations through cooperation-based logistics (Trapp et al., 2020; Christ et al., 2017; Limoubpratum et al., 2015). Table 2 compares the most common ecological effects of low-carbon logistics and the effects of working with competitors.

Table 2: Comparison of the ecological effects of applying low-carbon logistics vs. undertaking a coopetition relationship

Effects of application	Low-carbon logistics	Coopetition
Improved use of resources	**YES**	**YES**
Improvement of energy efficiency	**YES**	**YES**
Reduction of greenhouse gas emissions	**YES**	**YES**
Reduced quantity of pollutants	**YES**	**YES**

Source: The authors' own elaboration

When considering the coopetition effect in the field of low-carbon logistics, a question emerges: to what extent has coopetition achieved ecological effects in the field?
In order to answer such a research question, the authors formulated hypothesis:
H.2. Enterprises undertaking coopetition achieve higher ecological effects in the area of low-carbon logistics than the ones which do not engage in coopetition.

METHODOLOGY

In order to achieve the intended research goal, empirical research was conducted in the second quarter of 2021 by means of an electronic survey questionnaire. The group of enterprises surveyed included 250 entities: 200 small and medium-sized enterprises (subgroup 1) and 50 large enterprises (subgroup 2). For financial and organizational reasons, within each particular subgroup, the sample selection was quota-based taking into account the core business type (according to Statistics Poland). This means that the surveyed sample (within subgroups 1 and 2) reflects the population structure of small and medium-sized enterprises and large enterprises operating in Poland, taking this feature into account. The structure of the surveyed enterprises is presented in Table 3.

Table 3: Quantitative structure of the surveyed sample

Business type	Enterprise type by employment volume		
	Subgroup 1 = 200 enterprises		Subgroup 2 = 50 enterprises
	Small (number of employees <50)	Medium (number of employees <250)	Large (number of employees equaling 250 and more)
Industry	41	20	26
Construction	20	4	2
Commerce	42	9	7

Services	51	13	15
Total	154	46	50

Source: The authors' own elaboration

In order to identify the impact of coopetition on the outcomes achieved (economic and ecological) by the surveyed enterprises in low-carbon logistics, a comparative analysis was performed, using descriptive statistics methods and non-parametric tests for independent samples (the Mann–Whitney U test). In order to ensure the meritorical value of the obtained results, a reliability analysis was conducted using Cronbach's alpha coefficient (0.942). It demonstrated great consistency in the replies from the respondents regarding the results achieved by implementing low-carbon logistics.
In order to identify the features of the enterprises, which at the same time undertake coopetition and are leaders in the field of low-carbon logistics implementation, the method of classification trees was employed. This method was first described by Breiman et al. (1984) and consists in dividing the set of studied objects into homogeneous classes. As a result, a set of classification rules is obtained, allowing one to assign the examined objects to a specific class.
Finally, it is worth emphasizing that the period in which the research was conducted was extremely difficult for the functioning of enterprises due to the COVID-19 pandemic, which may constitute a research limitation. The perception of certain phenomena by the representatives of the surveyed enterprises in the face of the ongoing pandemic may have changed over time. According to the authors, the conducted research is therefore worth repeating in the post-pandemic period in order to perform a comparative analysis, which may stimulate an interesting discussion on the impact exerted by the COVID-19 pandemic on the implication of the low-carbon logistics concept.

RESULTS AND DISCUSSION

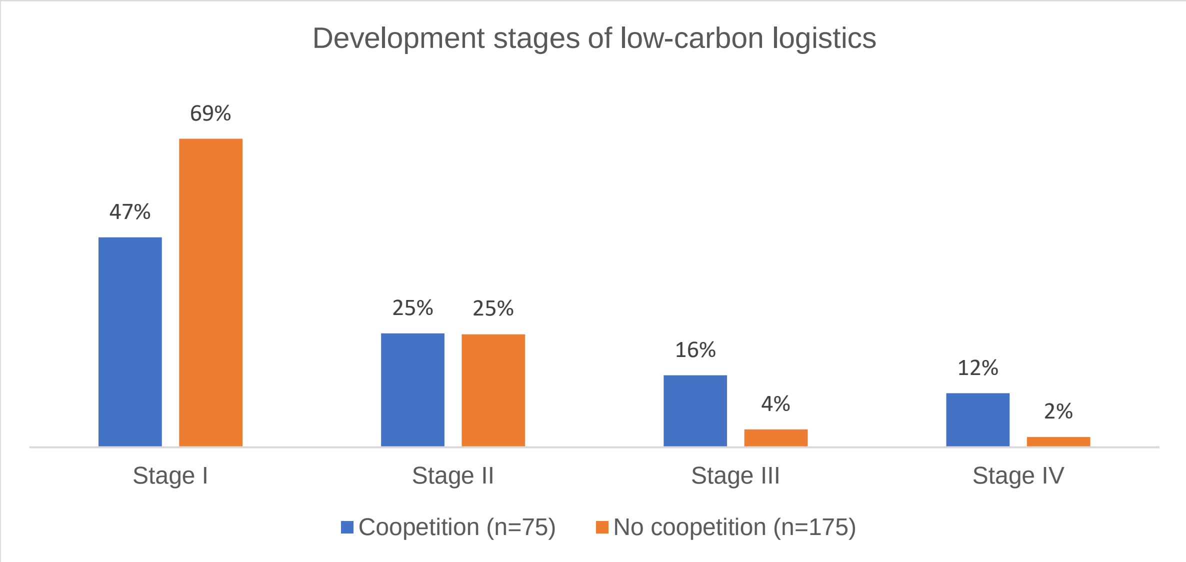
In the first part of the analysis, the surveyed enterprises were divided into two groups. In group 1, there were 75 enterprises (30% of all surveyed enterprises) involved in coopetition (the group was designated as: Coopetition). In group 2, there were 175 enterprises not involved in coopetition (the group was designated as No Coopetition). Subsequently, the development level of low-carbon logistics in each group was determined (Figure 1), taking into account 4 stages of the low-carbon logistics development (Table 4).

Table 4: Development stages of low-carbon logistics

Development stages of low-carbon logistics	Description
Stage I	an enterprise complies with legal regulations regarding environmental protection in terms of emitting harmful substances into the atmosphere,
Stage II	an enterprise, in addition to observing legal regulations, implements emerging technologies to reduce the emissions of harmful substances into the atmosphere
Stage III	an enterprise, in addition to the activities specific to stage 2, integrates with its business partners in order to achieve the assumed effects of “low-carbon” logistics
Stage IV	an enterprise is at the highest stage of implementing “low-carbon” logistics, which, in addition to the activities specific to stage III, includes effective management and organization policy based on the principles of “low-carbon” logistics.

Source: The authors' own elaboration

Figure 1: Low carbon logistics development level in the surveyed enterprises

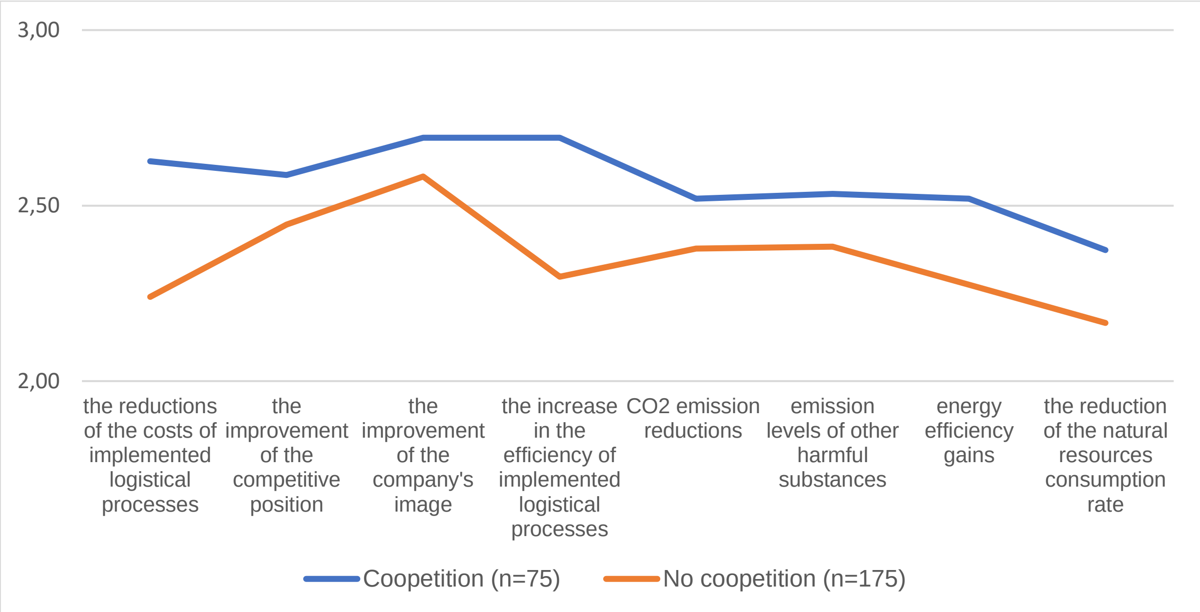


Source: The authors' own elaboration

The conducted research revealed that the vast majority of the surveyed enterprises are at the first stage of low-carbon logistics development, and so they only comply with legal regulations regarding environmental protection in terms of emitting harmful substances into the atmosphere. As the research showed, 25% of the surveyed companies, in addition to complying with legal regulations, are also implementing emerging technologies to reduce the emissions of harmful substances into the atmosphere. A small group of companies are at the two successive stages. Such a situation is undoubtedly a consequence of the relatively recent process of transforming the European Union's economy into a low-carbon one, as a result of which some relevant legislative processes were initiated in the recent past. Examples of applicable legal acts may be furnished by the directives on emission limits, successively implemented by the European Union, which aim to eliminate vehicles emitting excessive amounts of harmful substances into the atmosphere. It is worth emphasizing that the current legal regulations regarding low-carbon solutions in the area of logistics processes are perceived by most enterprises more as incentives rather than as penalties. The regulations linking traffic tolls to the vehicle's compliance with an emission standard may be an example. Secondly, ecological effects are more difficult to identify and are less measurable, which may be related to the different methodology of calculating the so-called carbon footprint, for example. Furthermore, results in low-carbon logistics are not directly noticeable by managers and owners from the perspective of their enterprises (from the micro perspective) but are visible from the perspective of the entire economy (the macro scale). On the other hand, the lack of visible effects at the micro level does not motivate owners or managers to take further steps towards the low-carbon logistics development of their business.
From the point of view of the objective set for this article, the structure of the analyzed enterprises (Figure 1) plays a significant role in their attitude towards coopetition. The companies that do not engage in coopetition are predominantly at the first or second stage of low-carbon logistics development (94% of the surveyed companies). On the other hand, the enterprises that choose coopetition are also at the third and fourth stage (16% and 12% of the surveyed enterprises, respectively). Such a situation may stem from the fact that the enterprises engaging in coopetition are capable of implementing such measures in the area of low-carbon logistics which require external cooperation. For instance, this might be an optimization of a distribution network shared with a competitor. This helps, on the one hand,

minimize unit delivery costs and, on the other hand, reduce distances travelled separately, thereby achieving the CO_2 reduction targets. The range of goals the surveyed companies managed to achieve in the field of low-carbon logistics is presented in Figure 2, showing the average values. Respondents rated the achieved goals on a scale from 1 to 5, where: 1 – it has not been achieved, 5 – it has been achieved on a considerably large scale (Appendix I).

Figure 2: Effects of low-carbon logistics in the surveyed enterprises (average values)



Source: The authors' own elaboration

The analysis of the data presented in Figure 2 demonstrated that the average outcomes achieved through implementing low-carbon logistics in the surveyed companies is relatively low. This is most likely due to a lack of experience in the implementation of low-carbon logistics solutions among Polish companies. Secondly, a slight advantage for all the obtained effects was observed in the group of coopeting companies. The greatest differences are visible when it comes to economic effects in terms of *reducing the costs of logistics processes* and *increasing the efficiency of logistics processes*. Statistically significant differences in the distribution of the mentioned effects in the group of coopeting and non-coopeting enterprises were also demonstrated using the Mann–Whitney U test (Table 5).

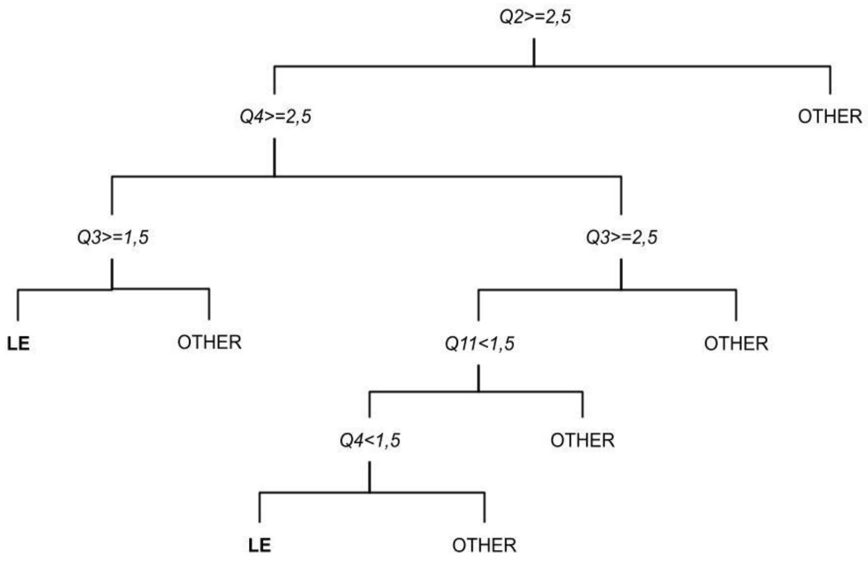
Table 5: The results of the Mann–Whitney U test		
Distribution of the achieved effects regarding:	P value	Decision
the reductions of the costs of implemented logistical processes is equal for both coopeting and non-coopeting companies	0.005	No
the improvement of the competitive position is equal for both coopeting and non-coopeting companies	0.274	Yes
the improvement of the company's image is equal for both coopeting and non-coopeting companies	0.511	Yes

the increase in the efficiency of implemented logistical processes is equal for both coopeting and non-coopeting companies	0.010	No
CO_2 emission reductions are equal for both coopeting and non-coopeting companies	0.375	Yes
emission levels of other harmful substances are the same for both coopeting and non-coopeting companies	0.231	Yes
energy efficiency gains are the same for both coopeting and non-coopeting companies	0.091	Yes
the reduction of the natural resources consumption rate is the same for both coopeting and non-coopeting companies	0.127	Yes

($p<0.01$)
Source: The authors' own elaboration

The results of the conducted test confirmed statistically significant differences in the distribution of effects achieved by coopeting and non-coopeting enterprises in terms of: *logistics processes cost reduction* and *logistics processes efficiency increase*. As for other effects, no statistically significant differences were observed. There are therefore no grounds for rejecting hypothesis H1 for the two aforementioned economic objectives, whereas hypothesis H2 should be rejected for all environmental objectives.
As for *logistics processes cost reduction* and *logistics processes efficiency increase*, these are typical benefits resulting from engagement in coopetition. It can therefore be concluded that coopetition can also be a useful tool for achieving economical goals of low-carbon logistics. In the case of ecological objectives, no statistically significant differences were identified. However, a slight advantage in terms of achieved ecological goals in the group of coopeting companies is worth noticing. Additionally, the research conducted by the authors demonstrated that the group of coopeting companies also included enterprises which had achieved the highest, IV stage of low-carbon logistics development. As such, it would be an interesting study to identify the characteristics of leading enterprises in low-carbon logistics. In order to distinguish the leaders of low-carbon logistics from other coopeting enterprises, the authors employed the method of classification tree, thereby dividing the set of examined objects into homogeneous classes. As a result, a set of classification rules was obtained, which allowed the authors to assign the enterprises under study to specific classes. In this specific research, the surveyed enterprises were divided into two classes (LE and Other). The leaders of low-carbon logistics (LE) included 9 companies. The remaining 66 companies were labelled as Other. When building the classification tree, the following features of the surveyed enterprises, identified in the literature as important for introducing ecological solutions, were taken into consideration: employment level, annual net revenue, capital links, industry sector, etc. (Wu, Dunn, 1995; Murphy et al., 1995; Zhu, Sarkis, 2007; Lin, Ho, 2011; Tacken, 2014; Böttcher, Müller, 2015) (Table 7 - Appendix II).
The classification tree created on the basis of the conducted modelling is presented in Figure 3. The model of the classification tree exhibits highly satisfactory alignment with the data. Its classification error was only 2.67%, which means that the classification rules correctly assign examined companies to the correct classes in 97.33% of cases (other classification quality measures: sensitivity = 89%; precision = 89%; F1 = 89%; AUC = 93.7%). A more in-depth analysis showed that 8 LE companies and 65 Other companies were correctly classified (this means that 1 LE company and 1 Other company were misclassified).

Figure 3: Classification Tree Model



Source: The authors' own elaboration

The graphic form of the tree model (following the edges of the tree from top to bottom) helps identify 2 rules determining membership in the class *LE* (Table 6) and 5 rules that determine membership in the class *Other*.

Table 6: Rules of membership in the LE class

Rule Number	Enterprise number	Company profile
1	4	▪ an enterprise with an annual net revenue of at least 10 million Euro, ▪ a service enterprise, ▪ an enterprise with capital links to other entities
2	4	▪ an enterprise with an annual net revenue of at least 10 million Euro, ▪ a manufacturing enterprise, ▪ an enterprise with capital links to other entities in min. 25%, ▪ an enterprise with ISO 26000 standard implemented.

Source: The authors' own elaboration

The ratio of the number of classification rules (2 rules) to the number of LEs distinguished by means of the classification tree (8 enterprises) makes it possible to create a narrow list of typical features, specific only to the leaders of low-carbon logistics undertaking coopetition. Firstly, appropriately high annual net revenue (at least 10 million Euro) is a highly important feature. Undoubtedly, the implementation of pro-ecological (low-carbon) solutions is costly and requires appropriate financial support. In this respect, the authors' results are consistent with the reports (Murphy et al., 1995; Seuring, Mūller, 2008; Tacken, 2014; Govindan et al., 2014; Mala, Musova, 2015). This means that financial barriers are often the main obstacle to the implementation of low-carbon solutions. The second important feature is capital reliance on other entities. In the case of the surveyed companies operating in Poland, most likely this means that they are subsidiaries of the parent company located abroad. Therefore, we deal with the transmission of good practices and know-how in the field of low-carbon solutions here.

In addition to the two features mentioned, membership rules also indicate the type of enterprise (manufacturing or service). As for manufacturing companies, they have long been among the entities monitored in terms of emissions of harmful substances into the atmosphere due to the scope of their activities. When it comes to service enterprises – in the examined sample they represented mainly section H (according to PKD - Polish Classification of Activity) – Transport and warehouse management, thus most probably they were enterprises providing logistics services. In this case, as the research demonstrates (Tian, Yang, 2013; Herold, Lee, 2017; Zhang et al., 2021; Lin, Wang, 2022), the enterprises are interested in implementing pro-ecological solutions (including low-carbon ones), as such attitude increasingly determines the competitive position and brand image of a given logistics provider.

CONCLUSION

Low-carbon logistics has recently become a very important tool in the area of environmental protection, mainly in reducing excessive CO_2 emissions. However, the measures taken by individual enterprises are no longer sufficient. Increasingly often, initiatives undertaken as part of low-carbon logistics are implemented within the framework of cooperation between several entities. One form of collaboration that can bring tangible effects in terms of reducing CO_2 emissions is coopetition. For example, it may consist in the optimization of a distribution network shared with the competitor. On one hand, this allows for minimizing cost per delivery and, on the other hand, for reducing the distances travelled separately, thereby achieving the CO_2 reduction targets. In this context, it can be said that coopetition is a tool used to achieve the assumed economic and ecological goals in terms of low-carbon logistics. Empirical research confirmed that the enterprises undertaking coopetition achieve higher results, such as reduction in cost and increase in the efficiency of logistics processes, than the enterprises not undertaking coopetition. On the other hand, the obtained research results led to rejecting H2 hypothesis according to which enterprises undertaking coopetition achieve higher ecological effects in the field of low-carbon logistics than those that do not undertake coopetition. However, a slight advantage in terms of achieved ecological goals in the group of enterprises undertaking coopetition should be stressed. Perhaps in the longer term, this prevalence will grow as a result of increased managerial awareness of the opportunities offered by coopetition, not only in the area of economic effects, but also in ecological benefits of low-carbon logistics. What is important, the same research demonstrated that the enterprises engaging in coopetition prevailed among the leaders in the development of low-carbon logistics. These are enterprises generating sufficiently high revenues, with capital ties to other entities, undertaking manufacturing or service activities in the area of transportation or warehousing.
The authors believe that research on the impact of coopetition on low-carbon logistics outcomes should be continued. In the future, it will be necessary to recognize the mechanism for the development of low-carbon logistics in the area of coopetition not only between individual enterprises, but also in entire supply chains.

APPENDIX I

Table 7: The features of the surveyed enterprises used in the development of the classification tree

Question number, criterion			
Q1. Employment level			
1.1	10-49 persons		
1.2	50-249 persons		
1.3	250 and more persons		
Q2. Annual net turnover [EURO]			

2.1	<0-2 million>		
2.2	(2-10 million>		
2.3	(10-50 million>		
2.4	(50 and more)		
Q3. Capital ties			
3.1	Our enterprise is independent from other entities in terms of capital (ownership)		
3.2	Our enterprise has capital (ownership) ties with other entities in less than 25%		
3.3	Our enterprise has capital (ownership) ties with other entities ranging from 25% to 50%		
3.4	The capital (ownership) ties of our company with other entities amount to more than 50%		
Q4. Type of enterprise			
4.1	Manufacturing		
4.2	Commerce		
4.3	Service		
Q5. Please indicate the dominant area of activity according to PKD (Polish Classification of Activity)		Yes	No
5.1	Heavy industry (section: B, C, D, E)	1	2
5.2	Construction (section: F)	1	2
5.3	Commerce (Section: G)	1	2
5.4	Services (Section: H, I, J, L, M, N, P, Q, R, S)	1	2
Q6. Operating range			
6.1	Local		
6.2	Regional		
6.3	Domestic		
6.4	International		
6.5	Global		
Q7. Position in the supply chain			
7.1	indirect supplier to the supply chain leader		
7.2	direct supplier to the supply chain leader		
7.3	supply chain leader		
7.4	direct recipient from the supply chain leader		
7.5	indirect recipient from the supply chain leader		
Q8. Form of products that leave your company			
8.1	raw materials that will be further processed		
8.2	semi-finished products that will become part of another product		
8.3	finished products that will not become part of another product		
8.4	we are a service company		
Q9. ISO 14001 implemented		Yes	No
9	ISO 14001	1	2
Q10. CSR implemented		Yes	No
10	CSR	1	2
Q11. ISO 26000 implemented		Yes	No
11	ISO 26000	1	2

Source: The authors' own elaboration

APPENDIX II

Table 8: The range of goals the surveyed companies managed to achieve in the field of low-carbon logistics (Coopetition n=75)

Effects of low-carbon logistics	Scale (1-5), where: 1 means that the effect has not been achieved; 5 means that the effect has been achieved on a considerably large scale					Average	Standard Deviation
	1	2	3	4	5		
	Number of responses provided						
the reductions of the costs of implemented logistical processes	14	18	27	14	2	2,63	1,08
the improvement of the competitive position	15	16	31	11	2	2,59	1,05
the improvement of the company's image	16	18	18	19	4	2,69	1,22
the increase in the efficiency of implemented logistical processes	15	17	21	20	2	2,69	1,15
CO2 emission reductions	14	23	26	9	3	2,52	1,06
emission levels of other harmful substances	16	19	25	14	1	2,53	1,07
energy efficiency gains	16	20	24	14	1	2,52	1,07
the reduction of the natural resources consumption rate	22	15	26	12	0	2,37	1,08

Source: The authors' own elaboration

Table 9: The range of goals the surveyed companies managed to achieve in the field of low carbon logistics (No coopetition n=175)

Effects of low-carbon logistics	Scale (1-5), where: 1 means that the effect has not been achieved; 5 means that the effect has been achieved on a considerably large scale					Average	Standard Deviation
	1	2	3	4	5		
	Number of responses provided						
the reductions of the costs of implemented logistical processes	39	67	59	8	2	2,24	0,89
the improvement of the competitive position	39	46	69	15	6	2,45	1,04
the improvement of the company's image	34	44	63	29	5	2,58	1,07
the increase in the efficiency of implemented logistical processes	44	56	55	19	1	2,30	0,98
CO2 emission reductions	44	45	67	14	5	2,38	1,04

emission levels of other harmful substances	42	52	61	12	8	2,38	1,06
energy efficiency gains	50	47	61	14	3	2,27	1,02
the reduction of the natural resources consumption rate	62	43	53	13	4	2,17	1,07

Source: The authors' own elaboration

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DECISION SCIENCES INSTITUTE
The role of hospital crisis leadership and resilience during crisis

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ABSTRACT
Delivering high patient care quality (PCQ) is one of the avowed aims of a U.S. hospital. The role of organizational leaders is magnified during times of a crisis, such as the current COVID-19 pandemic. Drawing from four theories—situational leadership, a contingent resource-based view, information processing and quality management we offer an over-arching conceptual framework suggesting the crucial role of crisis leadership and hospital resilience in ensuring high PCQ even during a crisis. We further suggest that the extent of EMR adoption in the hospital positively moderates these relationships. Implications for healthcare theory and medical practice are discussed.

KEYWORDS: COVID-19 pandemic; crisis leadership; hospital resilience, extent of EMR adoption; patient care quality (PCQ).

INTRODUCTION

The COVID-19 pandemic wreaked havoc on care delivery organization (CDO)s in the U.S. such as hospitals with unusually large numbers of patients simultaneously needing admission to the intensive care units (ICUs) because of the severity of their symptoms and sufferings (Barbash & Kahn, 2021). According to recently released data from the Centers for Disease Control and Prevention (CDC) (CDC, 2020), almost half of hospitals in the U.S. (2199 of 4587) operated at more than 85% capacity sometime during the pandemic (Barbash & Kahn, 2021). Most U.S. hospitals struggled to maintain their standards of care, with some critically ill patients treated outside of ICUs, and clinicians unable to keep pace with delivering the much needed care quality because of increased patient-to-staff ratios (Scales, 2020). Yet these problems were not universally experienced at all U.S. hospitals. Some hospitals, such as the New York-Presbyterian, Columbia University Vagelos College of Physicians and Surgeons, and Weill Cornell Medicine could accommodate the sudden increase in demand, maintain their care standards, and still manage to deliver high patient care quality (PCQ) even during times of rapidly surging COVID-19 cases (Kumaraiah et al., 2020). As another example, the state of Arizona had implemented a “surge line” during the pandemic to coordinate patient care across more than 100 hospitals and multiple health systems (Villarroel et al., 2021). These facts suggest that it must be internal factors in those hospitals including their leadership that could help explain how and why their care delivery well even during a full-blown health crisis.

It has been almost two and half years now since the beginning of the COVID-19 pandemic in China in December 2019. Most organizations have adapted their operations and transitioned to the “new normal” by now, and leadership decisions have become a lot easier as the nature of the pandemic became clearer. The pandemic, which began as a physical health crisis, had quickly turned into an economic crisis, with the virus affecting all major countries in the world (World Health Organization, 2020). Leaders were faced with many new challenges and were posed several questions for which they did not have answers, even as their own teams looked to them for direction because the crisis was unprecedented in nature. The COVID-19 pandemic has presented an ultimate test for organizational leaders across the world (Dirani et al., 2020).

The role of organizational leaders and the impact of their decisions and actions are magnified during times of a crisis, especially during its initial phases, wherein the organization experiences acute shock, and the crisis could threaten their very existence (Fink et al., 1971). Leaders are also vulnerable to crisis shock themselves which could paralyze them into inaction (Fink et al., 1971). The COVID-19 pandemic is a rare, long-drawn global health and economic crisis, and no training or experience in handling previous crises could have prepared leaders for it. Most organizations (and even countries) though have relied on their leaders to lead them out of the COVID-19 crisis despite new uncertainties coming with every mutation of the virus. While many firm leaders successfully managed the crisis, others were not so successful, and have failed under pressure, resulting in their temporary or permanent business closures. The varying degree of success of firms during the COVID-19 has reemphasized the importance of having a strong leadership during a crisis, which enabled those organizations to seize the opportunities shown by the crisis and stay ahead of the competition (McKinsey & Company, 2020).

Extant research has offered some guidance on leadership for crisis situations (Kurz & Haddock, 1989; Sriharan et al., 2021). A few specific crisis and emergency management competencies have been identified (Boin et al., 2013). The crisis and emergency management literature is too focused on planning and executing predefined tasks and processes in response to crises (Klann, 2003; Mitroff et al., 1987), which has led to a narrow emphasis on oversight functions (Sriharan et al., 2021). Crisis leadership, as defined by Klann (2003), involves considering human aspects of crisis and planning for the dynamic nature of the crisis and its context—the needs, emotions, and behaviors of people implementing strategies to address, prevent, mitigate, and recover from crises. The COVID-19 pandemic crisis has raised the important question of which crisis leadership competencies are needed by healthcare CDOs such as hospitals and their leaders to implement health and safety measures that would mitigate the spread of the pandemic, and also address the pandemic's health and economic consequences (Armstrong et al., 2021; Sriharan et al., 2021). There is scant research on the role of crisis leadership and hospital outcomes such as PCQ.

In the U.S. healthcare system, resilience is defined as the system's emergent ability to provide a robust response to unforeseen, unpredicted, and unexpected demands and to resume normal operations after the event (Nemeth et al., 2008). The ultimate goal of healthcare should be to provide a seamless continuum for the patient as they transition among care providers from initial presentation to diagnosis to treatment and to follow up post procedures. Gaps in the continuity of care that threaten a patient's wellbeing and introduce the potential for adverse events (Cook et al., 2000) are the evidence that the U.S. healthcare system (as a whole) is unable to respond to meet the demand for high PCQ. Whether, or how, the U.S. healthcare system responds to fill such gaps in care continuity would indicate its overall resilience (Nemeth et al., 2008). From the way the COVID-19 pandemic was managed, it is clear that most U.S. hospitals would score exceptionally low on firm or hospital resilience.

Next, considering a major enabler in U.S. hospitals, the role of information technology (IT) systems and their seamless integration in hospitals have been found to indirectly impact PCQ (Bayramzadeh & Aghaei, 2021; Chakraborty et al., 2021; Dobrzykowski & Tarafdar, 2015). The electronic medical records (EMR), an end-to-end digital version of a patient's healthcare record (Miller, 1993) is widely accepted as the technology backbone for modern hospitals because it serves to provide patient information readily to all healthcare team members who require it (Pai et al., 2022), as well as to the hospital leaders in their dissemination of goals to all healthcare team members.

In sum, while several decades of research have gone into identifying antecedents to PCQ in hospital settings, to the best of our knowledge, no study has investigated the role of crisis leadership, hospital resilience and extent of EMR adoption on patient care quality delivered in hospitals during a crisis. We therefore investigate the following research question to address this omission: *What is the role of hospital crisis leadership, hospital resilience and the extent of EMR adoption on the patient care quality delivered in hospitals during a crisis?*

The remainder of our paper is organized as follows. First, we briefly discuss the extant literature on PCQ, also highlighting the scant literature on the role of crisis leadership in healthcare and hospital resilience on PCQ in U.S. hospitals during crises. We examine the role of the extent of EMR adoption and explicate why it moderates the relationships among each of the two constructs and PCQ. Second, drawing support from four theories—situational leadership, a contingent resource-based view, information processing and quality management, we offer an over-arching conceptual framework and then offer specific propositions detailing the relationships. Finally, we conclude with a discussion on practice implications and future measurement of the framework.

LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

Pearson and Clair (1998) defined a crisis as “a low-probability, high-impact event that threatens the viability of the organization and is characterized by ambiguity of case, effect, and means of resolution, as well as by a belief that decisions must be made swiftly” (p. 60). Put differently, any event that disrupts normal business practice can be considered as a crisis. A crisis has multiple stages with the main event being only the first stage, but most people identify only with the highly visible crisis event often ignoring the other stages of crisis management. Wooten and James (2008) developed a conceptual model of competencies needed by leadership in order to lead well through the five stages of crisis management: signal detection; preparation and prevention; damage control and containment; business recovery; and learning and reflection (Mitroff, 2004).

In healthcare, despite past successful experiences of handling health crises such as the SARS, Ebola, bird flu, H1N1, and MERS epidemics, there is no established framework available to guide hospital leaders on how to manage crises such that the PCQ delivered to patients in CDOs such as hospitals remains unaffected. Next, we elaborate on these aspects in detail with the aim of offering such a guiding framework for hospitals.

Patient Care Quality

Patient care quality (PCQ) is defined by the Institute of Medicine (IOM) as “the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge" (IOM, 2001). In the last five decades many interdisciplinary studies have investigated PCQ and its antecedents (Marjoua & Bozic, 2012). Based on an extensive study of the literature, we suggest that a comprehensive conceptualization of *patient care quality (PCQ)* comprises four facets—interpersonal, technical, environmental and administrative quality (Chakraborty et al., 2021; Dagger et al., 2007; Gill & White, 2009).

Interpersonal quality includes the dyadic interplay occurring between the healthcare team and patient. It takes into account whether: (a) healthcare teams treat their patients with respect; (b) healthcare team members listen to what patients have to say; (c) members give personalized attention to patients, and (d) team members are willing to answer questions that the patient or their kin may have (Dagger et al., 2007). Technical quality implies the medical expertise, professionalism, and competency of the healthcare team in delivering the cure. It includes whether: (a) patients are administered the correct medical treatment that is needed to cure their ailment; (b) tests (e.g., X-rays and lab tests) are ordered on patients only when they are necessary; (c) healthcare team members are medically qualified; and (d) if team members conduct their tasks competently (Dagger et al., 2007). Environmental quality refers to the quality of the hospital atmosphere related to cleanliness and tangibles, such as hospital bed and necessary equipment like drip stands and other required equipment for patient health needs. It includes whether: (a) the hospital has been designed in a patient friendly manner; (b) the lighting at the hospital is adequate; (c) the temperature at the hospital is pleasant; and (d) the furniture at the hospital is comfortable for patient stay and recovery (Dagger et al., 2007). Administrative quality refers to those aspects which help the delivery of the medical cure while adding value to the patient such as whether: (a) the internal hospital services (e.g., pathology) work well; (b) waiting time at the hospital is minimal for the patient; (c) the hospital provides patients with a range of patient support services, e.g., post-operative care and trauma counseling; and (d) the hospital records and documentation (e.g., billing) are error free (Dagger et al., 2007).

Crisis Leadership

During a crisis, the crucial task of an organizational leader is to own up the responsibility for communication (Urick et al., 2021) to all employees and other staff in the organization and to others in the community. A leader is the person responsible for communication at critical moments, particularly early in the crisis, during the crisis, and while transitioning out of the crisis (Ulmer, 2001; Urick et al., 2021). During extreme crises such as the COVID-19 pandemic, leaders need to communicate with the community and stakeholders proactively and prepare to engage with media (Lerbinger, 1997; Urick et al., 2021). A leader should disseminate a simple, cohesive message to prevent confusion, demonstrate involvement, and openly invite constant feedback from all stakeholders (Boin et al., 2010; Lucero et al., 2009).

During a crisis, communication is one of the main tasks of an organizational leader but not their only responsibility as leaders need to implement an action plan for the organization and its employees to recover from the crisis. Muffet-Willett and Kruse (2009) suggest that crises may need different leadership styles and a transactional leader who is effective in routine, day-to-day situations may not turn out to be successful in a crisis. Crisis leaders must make decisions in an unknown and complex environment containing possible severe threats while under increased stress and scrutiny (Muffet-Willett, 2009). Boin et al. (2005) identified five critical tasks of crisis leadership—sensemaking to diagnose the situation, decision making to formulate a strategy, coordination of the implementation efforts for recovery, meaning making to motivate others to move beyond the situation towards recovery, accounting to achieve closure by taking responsibility, and learning from response efforts for managing future crisis (Urick et al., 2021). Further, a few studies have underscored the importance of values and ethics as the foundation for how leaders should engage others during a crisis (Bauman, 2011; Seeger & Ulmer, 2003; Ulmer, 2012). Crisis leaders are those who can successfully address safety, handle the psychological stress, share a plan for stability, and work with the community and other organizations to aid the restoration and recovery after the crisis (Dückers et al., 2017; Marcus et al., 2006; Urick et al., 2021).

In the context of the recent COVID-19 pandemic which was a major unprecedented crisis, we align with Balasubramanian and Fernandes' (2022) conceptualization and define *crisis leadership* as emergent and transitory leadership comprising the following seven facets: compassion and care; openness and communication; adaptiveness; resilience and courage; decisiveness; consultation and collaboration; and empowerment. We believe that this comprehensive construct captures all aspects required of an organizational crisis leader.

Hospital Resilience

In the business press, firm resilience is defined as firms' ability to quickly adapt to disruptions while maintaining continuous business operations and safeguarding people, assets and overall brand equity (Kirvan, 2022). In extant literature, Kantur and Iseri-Say (2012) defined organizational resilience to comprise four dimensions— robustness, redundancy, resourcefulness and rapidity of an organizational response to the crisis.

Most service organizations, including hospitals cannot function today in isolation, but work in conjunction with their supply chains. In this context of the broader supply chain, Azadegan and Jayaram (2018) suggest that supply chain resilience has three broad parts—inherent, anticipative and adaptive resilience. Firms obtain inherent resilience is from the strength of resources that they already possess, and these are permanent and inseparable from the supply chain itself. On the other hand, anticipative resilience are those preparatory resources that firms develop purposefully to face crises and disruptions such as business continuity plans, or insurance policies. Finally, adaptive resilience refers to the collaborative capabilities, collective decision-making, and leadership that combines care and concern with the ability to make on the spot decisions. Organizations within their respective supply chains need to leverage these three capabilities together to face disruptions (Azadegan & Jayaram, 2018).

We define *hospital resilience* as a hospital's ability to recover from healthcare supply chain disruptions quickly (Blackhurst et al., 2011). Drawing from Ambulkar and colleagues' (2015) work on firm resilience in the context of supply chain, we suggest that resilient firms are able to reconfigure resources, which in turn help firms face supply chain disruptions and still deliver high service quality.

We suggest that hospital resilience differs from disaster preparedness, wherein hospitals would plan for a relatively narrow operational challenges, such as flooding, structural damage, communication system failure, and disruption of the power grid and the responses are often algorithmic (Nemeth et al., 2008). For example, a hospital that was well prepared only for the Ebola virus outbreak would not have been prepared for COVID-19. Ebola preparations had focused on having hospitals set up relatively small, high-level containment units for treating patients with a disease that was transmitted primarily by direct contact (Herstein et al., 2020),whereas COVID-19 cased several hundred critically ill patients to have respiratory failure from an airborne virus. Similarly, focusing on mere task-level preparedness for COVID-19, such as building a large stockpile of ventilators and N95 masks is unlikely to translate into an effective hospital response to the next emergent pathogen (Nemeth et al., 2008). In other words, hospitals cannot fully prepare for a crisis because of its unprecedented nature.

Organizational resilience refers to the flexibility to pivot as new and unexpected challenges arise, and to absorb unexpected shocks that cannot be avoided with proper planning (Nemeth et al., 2008). Resilient hospitals would have more freedom, allowing them to consider a range of solutions to each problem and quickly change when a pre-planned strategy is not working to rapidly implement novel solutions. Like other service firms, hospitals too could be resilient but unprepared (for specific disasters), and on the other extreme, they could similarly be prepared but not resilient. Unlike preparedness, which is useful only in the event of disasters and known pandemics, the intrinsic capability of resilience is likely to support high-quality care during routine day-to-day operations as well (Nemeth et al., 2008).

Based on the guidance provided in a recent study (Rieckert et al., 2021), we reiterate that irrespective of the challenges they may encounter, hospitals should implement valuable and necessary changes to gain resilience capabilities. Making their own supply chains more robust, instilling cultures of excellence and collaboration, and building and operating seamless systems for coordinating operations within and across multiple nearby hospitals (Nemeth et al., 2008) are some examples of changes that hospitals could make to gain resilience capabilities. Such capabilities would be useful even during normal non-crisis times.

Extent of EMR Adoption

Miller (1993) defined an *electronic medical record (EMR)* as a comprehensive record of a patient information that includes their health history such as diagnoses, medicines, tests, allergies, immunizations, and treatment plans and is stored in an electronic format accessible from both inpatient and outpatient environments. It is used by medical practitioners within and across CDOs such as a hospital, a private clinic or a nursing home to document, monitor, and manage healthcare delivery. The EMR is a legal record of what happened to the patient during their encounter at the CDO and is owned by the CDO (Garets & Davis, 2006). A patient's EMR can be viewed by all healthcare team members in the CDO who take care of a patient and need to access patient records to make appropriate decisions about the patient's care.

An EMR created in a hospital provides source data for electronic health records (EHR), a software system that most hospitals have implemented and is optimized to improve the quality and efficiency of patient care (Garets & Davis, 2006; Gopalakrishna-Remani et al., 2019). Higher levels of EMR adoption help to transmit patient-specific recommendations and medical tasks efficiently and help physicians determining optimal treatment options. In sum, EMR adoption helps to establish a knowledge-based decision support system in the hospital that serves to improve the technical quality associated with patient care (Yang et al., 2012).

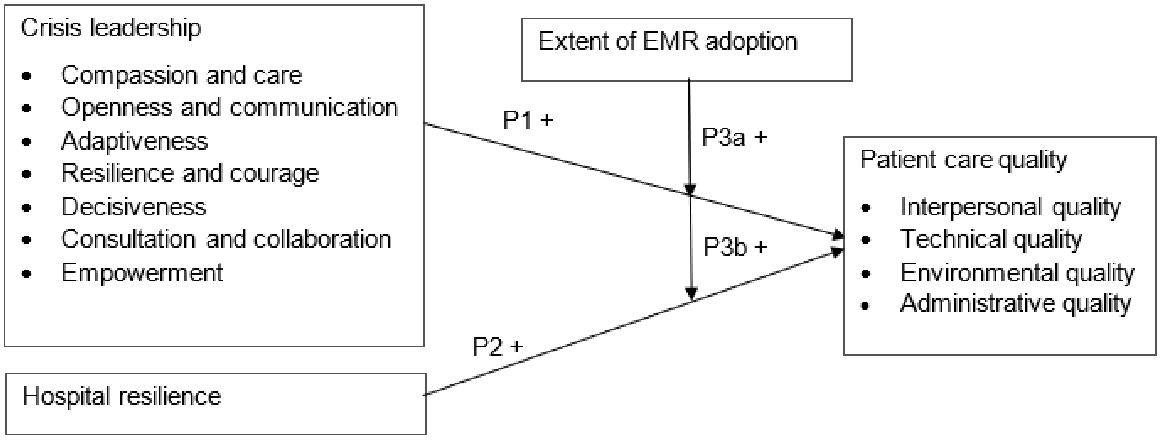
Conceptual Framework Development

An extensive review of the extant literature related to exemplary leadership during crises, organizational resilience and quality of services offered by firms, in general, and PCQ delivered in a hospital, in particular yielded the following four theories—situational leadership theory (Hersey et al., 1979; Hersey & Blanchard, 1977), a contingent resource based view (Aragón-Correa & Sharma, 2003; Brandon-Jones et al., 2014; Gupta et al., 2018), information processing theory (Galbraith, 1973; Galbraith et al., 1972; Tushman & Nadler, 1978), and quality management (Deming, 1986; Feigenbaum, 1961)—that support our constructs and relationships among them. Table 1 presents the main tenets of each theory and their applications in recent healthcare studies. Figure 1 depicts our conceptual research framework.

TABLE 1: Theories Supporting Research Framework

Theory	Main tenets	Healthcare studies
Situational leadership theory (Hersey et al., 1979; Hersey & Blanchard, 1977)	There is no one 'best' leadership style. Effective leadership is relevant to the tasks that need to be performed, and successful leaders are those who adapt their leadership style to the ability and willingness of the individual or group that they are leading. Effective leadership varies with the person or group that is being influenced, but it also depends on the task, job, or function that needs to be accomplished.	Belrihiti et al. (2018); Gulati et al. (2020); Rabarison et al. (2013)
Contingent Resource-based View (Aragón-Correa & Sharma, 2003; Brandon-Jones et al., 2014; Gupta et al., 2018)	Contingent resource-based view suggests that contingencies in the business environment may affect the usefulness of different resources and capabilities for enhancing resilience (Aragon-Correa & Sharma, 2003). Different contingent factors such as the geographical context (the national culture or the country's economic development status), company size, organizational structure have been suggested (Iftikhar et al., 2021; Mackelprang & Nair, 2010).	Burton and Rycroft-Malone (2014); Burton et al. (2014); Minbashrazgah and Atefeh (2019)
Information processing theory (Galbraith, 1973; Galbraith et al., 1972; Tushman & Nadler, 1978)	Task uncertainty determines an organization's structure. Investment in information systems is a strategy followed by organizations to reduce the uncertainty by increasing the capability of information processing and sharing. By sharing relevant information among all those organizational team members as and when needed, information technology systems (e.g., electronic medical record (EMR) (Miller, 1993) in hospitals) are the necessary infrastructure that helps reduce organizational uncertainty among all the parts of an organization.	Bag et al. (2021); Gopalakrishna-Remani et al.(2019); Offredy and Meerabeau (2005)
Quality management (Deming, 1986; Feigenbaum, 1961)	Quality of the services generated by any organization is the responsibility of all its members, including employees. Quality of the service delivered in hospitals is the most important outcomes that matter to all stakeholders, including patients and hospital leaders because most hospitals claim delivering patient-centric care as their avowed aim.	Chakraborty et al. (2021); Erthal et al. (2021); Mosadeghrad (2015)

FIGURE 1: Research Model



Next, we elucidate how and why crisis leadership and hospital resilience influence the four different dimensions of the PCQ delivered in hospitals. We elaborate on the role of extent of EMR adoption on PCQ in U.S. hospitals. Drawing from the above four theories, we then offer specific propositions that delineate our expected relationships.

During a crisis, such as the COVID-19 pandemic hospitals needed to set their priorities on providing immediate care to the patients who kept flocking into the hospital, many of whom needed to be moved into intensive care units (ICU)s right away because of their severe respiratory problems and other complications. During such a crisis, which tested the ability and skills of all hospital team members to the fullest, several aspects of PCQ (e.g., interpersonal quality, in and some cases environmental and administrative quality) took a backseat (Barbash & Kahn, 2021). The most attention was given to providing the required medical care or the technical quality facet of PCQ to COVID patients to ensure that the patients did not die. Under such strenuous and trying times, it is a special type of leadership, labeled as crisis leadership, which helped some hospitals manage better and tide over the surging demand for hospital beds and other resources much better than others. Per extant literature (Boin et al., 2005), crisis leaders use their sensemaking abilities to diagnose the situation, their decision making capabilities to formulate their strategy, coordinate all the implementation efforts, use meaning making skills to motivate others to move beyond the situation, accounting sense to achieve closure by taking responsibility, and learn lessons from the response efforts.

Situational leadership theory (Hersey et al., 1979; Hersey & Blanchard, 1977) suggests that there is no one “best” leadership style suitable for all occasions. Successful leaders are those who adapt their leadership style to the current situation, taking into account the ability and willingness of the individual or group that they are leading. Quality management theory (Deming, 1986; Feigenbaum, 1961) suggests that ensuring high quality of the service delivered (PCQ, in the context of hospitals) is the responsibility of all firm employees, including its leaders.

Based on the above discussions and drawing support from the tenets of situational leadership theory and quality management, we suggest that a crisis leader would have their priorities fixed on delivering high PCQ in the hospital and could positively influence all four facets of PCQ—interpersonal, technical, environmental and administrative quality. We therefore propose:

P1: *Crisis leadership is positively related to patient care quality.*

Next, any crisis affects organizations differently in terms of their ability to cope with it and fully recover later. Like any other service organization, hospitals that are resilient, are likely to come back better and financially stronger than before once the current COVID-19 crisis is fully over.

Resilient hospitals are likely to respond to COVID-19 in ways that would preserve the quality of care, especially the technical quality or the medical cure for all patients, those with COVID-19 or those without COVID-19, such as those needing cancer care, emergency cardiac care, or trauma surgery or suffering from other sickness or ailment (Barbash & Kahn, 2021). First, resilient hospitals would acknowledge that accommodating urgent needs of non–COVID-19 patients is equally important as addressing the needs of patients with COVID-19. Second, resilient hospitals would preserve access to care for the entire community of patients they serve, continuing with patient elective surgeries on time, as scheduled and mitigating all health disparities during the pandemic. These hospitals would better anticipate the patient demand and mitigate ways in which changes to care delivery (such as rapid change to telemedicine that was implemented in many hospitals by several physicians) might differently affect vulnerable individuals in the surrounding communities, especially those who cannot afford high quality internet or phone network at home (Roberts & Mehrotra, 2020). Third, resilient hospitals would protect the well-being of their frontline healthcare staff, not just by ensuring adequate personal protective equipment (PPE) but also by having clear communication from leaders that make healthcare team members feel valued and connected to the organizational mission (Barbash & Kahn, 2021). Resilient hospitals would use all resources at their disposal optimally to preserve the high care quality standards for all four PCQ facets—interpersonal, technical, environmental and administrative quality.

A contingent resource-based view (Aragón-Correa & Sharma, 2003; Brandon-Jones et al., 2014; Gupta et al., 2018) suggests that contingencies in the business environment may affect the usefulness of different resources and capabilities for enhancing resilience. These contingencies could be the geographical context (the national culture or the country's economic development status), company size or the organizational structure (Iftikhar et al., 2021; Mackelprang & Nair, 2010). Quality management (Deming, 1986; Feigenbaum, 1961) emphasizes the shared responsibility for quality of the service delivered between employees and the firm's leaders.

Based on above discussions and drawing support from the tenets of a contingent resource-based view and quality management, we suggest that resilient hospitals are likely to better deliver all four facets of PCQ—interpersonal, technical, environmental and administrative quality even during, and after an unprecedented crisis like the current COVID-19 pandemic is over. Therefore, we posit:

P2: *Hospital resilience is positively related to patient care quality.*

Finally, all the different components and sub-systems of a hospital's technology, including both hardware and relevant software systems that allow frequent and up-to-date information (e.g., hospital patient's medical information, inventory data about medicine/other supplies and personnel information) exchange in digital format need to be interconnected. In most U.S. hospitals today, EHR is typically the integrated system that they have implemented which allows seamless flow of information between different entities within the hospital and the healthcare team and hospital management (Leidner et al., 2010; Li & Lin, 2006). Improving the smooth flow of information in the hospital will aid in improving technical, as well as administrative quality facets of PCQ.

If the extent of EMR adoption in a hospital is high, it would help the hospital leaders propagate their overall will and direction to their hospital team members quickly. A high degree of EMR adoption will ensure that the hospital leaders' collective and final decision on the hospital goals can be quickly broken down into the specific strategic as well as tactical steps that need to be implemented by the healthcare team and accordingly, acted upon by the healthcare team members in their interaction with patients even during crises. Such an initiative will serve to improve PCQ interpersonal and environmental quality as well. Technology, in the form of a hospital EMR is the all-pervasive platform that connects all health records and other patient-related records, including the billing and other administrative quality in an electronic format. Integrated technology systems, that gets enhanced with high EMR adoption is beneficial for all four aspects of PCQ—interpersonal, technical, environmental and administrative quality because complete and accurate digital information about the patient available on fingertips of the physician, nurses and other staff in the hospital which will ensure that healthcare team members deliver the best possible quality care (Chakraborty et al., 2021; Pai et al., 2022). Accordingly, we suggest that if the EMR adoption is high in the hospital, especially during a crisis all required patient information is readily available to the healthcare team members as well as the hospital crisis leaders. Hence, the positive effect of crisis leadership will be enhanced. Therefore, drawing support from the tenets of information processing theory, our final proposition posits the enhancing effects of the extent of EMR adoption on the two relationships between crisis leadership and PCQ, and between hospital resilience and PCQ, in two parts:

> *Extent of EMR adoption positively moderates the relationship between—(a) crisis leadership (**P3a**); and (b) hospital resilience (**P3b**)—and patient care quality such that crisis leadership (or hospital resilience) is more strongly related to patient care quality in hospitals that have adopted EMR to a high degree than those hospitals which have either not adopted EMR or have adopted EMR to an extremely low extent.*

DISCUSSION AND CONCLUSION

In this conceptual paper, we suggested that a hospital's crisis leadership and its resilience help a hospital deliver high PCQ thereby helping the hospital survive an unprecedented crisis such as the COVID-19 pandemic. We also posited that the effectiveness of the hospital crisis management to improve PCQ is positively moderated by the extent of EMR adoption in the hospital. Our research has several implications for both healthcare theory and medical practice, in general, and hospital operations, in particular.

From a theoretical standpoint, first, our framework will turn the spotlight on understanding the crisis leadership construct and its application, especially in healthcare research. In extant literature, because a crisis such as COVID-19 pandemic is not clearly delineated and is often mixed up with disasters such as a hurricane or earthquake that can be predicted to some degree, it is not adequately acknowledged that crisis leaders are a different breed, and crisis leadership is not for everyone. Crisis leadership is a unique emergent and transitory style that is different from any of the traditional styles of leadership that have been explored in depth in extant literature such as transactional, transformational, charismatic, servant leadership, or leader-member exchange (LMX) which takes into account how the leader and the followers interact. In this context, the situational leadership theory fits well to explain in depth why and how a crisis leader is different from all other leaders. It is quite possible that crisis leaders may not be able to lead an organization effectively during normal non-crisis periods because crisis is a different contextual setting than normal times. Our conceptual framework and future empirical work will push the delineation and the application of crisis leadership in the field of healthcare, especially as we strive to understand in depth why and how a crisis leader is successful in motivating hospital healthcare teams to not lose sight of the ultimate outcome, i.e., PCQ as they all go through a full-blown crisis such as the current COVID-19 pandemic and come out successfully.

Second, our study will give a fillip to the application of a contingent resource-based view (Aragón-Correa & Sharma, 2003), especially in hospital settings. The resource-based view

(RBV) (Barney, 1991; Wernerfelt, 1984) originally suggested that an organization merely possessing valuable, rare, inimitable and non-substitutable resources is likely to enjoy a sustained competitive advantage. However, the contingent RBV suggests that firms (hospitals) will not directly enjoy competitive advantages merely due to possessing above types of resources but there are situations that will arise which the firm (hospital) needs to manage well. Crisis is a perfect example of such a contingency/situation when leadership and their skills related to organizational management of resources are evaluated. It then follows those hospitals that have such resources and are able to manage themselves during a crisis such as the current pandemic will enjoy a sustained competitive advantage to thrive much better than others. Contingent RBV has not been applied to healthcare in hospitals settings extensively yet. We are confident that our conceptual framework offered herein, and our planned empirical test will push such efforts.

Third, our framework will refocus the attention on the role of the ubiquitous medium or platform in hospitals—the EHR system used, and by extension, on the extent of EMR adoption, turning the lens on the role of IT infrastructure in hospitals. It will highlight how IT helps leadership efforts during normal times and more so, during a crisis when many of the routine hospitals teams and their functioning may be affected by the surge in patient demand. During and post-crisis, when most hospital beds, especially in the ICUs were getting filled up fast due to the surge in incoming sick patients, smooth day-to-day operations of the hospital became key. It is in this context that technology helps rapid and accurate information sharing and makes the day-to-day job of the healthcare teams easier and better. Our framework suggests a positive moderating role of the extent of EMR adoption on the relationships thereby highlighting the importance of technology integration in hospitals.

Our research has several implications for the medical practice in U.S. hospitals. First, in line with our first proposition, we believe that hospitals need to consider crisis leadership as a capability worth developing and sustaining, in order to manage the hospital well during the next crisis, which could be a health or an economic crisis or both like the current pandemic. The COVID-19 pandemic was not the first one and is unlikely to be the last one ever. Like other service organizations, U.S. hospitals will need to develop and nurture such crisis leaders who can manage and successfully lead their organizations through crisis.

Second, hospitals should do more to develop resilience. In this context, hospital leaders need to understand that preparedness and resilience are not the same, and preparedness does not necessarily lead to resilience. Hospitals, like all other service organizations need to be prepared to effectively oversee events such as an earthquake or a hurricane (if the hospital is located in any of those special zones). In other words, all hospitals need to be prepared to handle known and predictable disasters, both natural and human-made (like shooting or arson) but such disaster-handling capabilities do not guarantee effective crisis management or resilience to tackle a crisis (Barbash & Kahn, 2021). Organizational resilience needs much more than mere disaster planning skills, which are much more short-term in nature because it involves capability of not only the leaders but also every member of the healthcare team to be flexible and quickly adopt to the fast-changing scenario during a crisis and follow all directions given by leaders during such unprecedented times. Our research highlights that resilience is a much more long-term objective that hospitals need to build in order to better manage another unprecedented crisis in the future, in addition to being able to successfully manage all planned and unplanned disasters.

Third, for those hospitals that have not yet fully adopted EMR, we provide a pointer to their leaders to speed up integrating all technology systems in their hospital. As our framework suggests, EMR adoption (or the EHR system that they use) is the basic technology enabler in U.S. hospitals. During normal times, and more so during a crisis when many functional parts of a hospital could be broken or non-functional, leaders cannot expect their will and directions to reach all employees and be implemented effectively unless the technology enabler is fully active and all discrete technology platforms in the hospital are integrated to help with the information exchange and can “talk to each other”.

Finally, our conceptual framework offered in this research is a first step. A planned empirical measurement of the framework in the next step should reveal interesting insights. All variables could be measured using perceptual measures. Secondary data on hospital leaders could be used too to supplement the primary data. An extensive online survey campaign using Qualtrics is planned to randomly collect data from a select few members of hospitals leaders, followed by semi-structured interviews with them. Available measures from literature, modified to the context of an unprecedented crisis such as the COVID-19 pandemic in US hospitals and pilot-tested before the main study could be used. The second-order construct, hospital crisis leadership characteristics can be measured by a scale developed by Balasubramanian and Fernandes (2022) comprising 24 items. Hospital resilience could be measured with four items from a scale developed by Ambulkar and colleagues (2015). The extent of EMR adoption could be measured using three items from a modified scale developed by Gopalakrishna-Remani et al.(2019). PCQ delivered in the hospital may be measured using 14 items from a modified scale (Chakraborty et al., 2021) based on literature (Dagger et al., 2007). Further, based on recent healthcare operations management studies (Sharma et al., 2016; Wani & Malhotra, 2018), a few hospital-level controls such as the size (indicated by number of beds in the hospital), its teaching status, its ownership (private vs. public) and its location (urban or rural) could be gathered from secondary sources and used as controls. Because of the moderator relationships being proposed, the PROCESS macro in SPSS (Hayes & Cai, 2007) could be used to evaluate these relationships. Structural equations modeling software package such as AMOS could be used to assess all relationships simultaneously. The semi-structured interviews could be used to corroborate the findings from the empirical study.

In closing, we want to note that COVID-19 is unlikely to be the last large-scale public health crisis for U.S. hospitals. In addition to infectious diseases, hospitals will likely confront a few other crises such as the climate-mediated extreme weather events, cyber-terrorism disruptions, and other threats that cannot be even imagined today in the decades to come. Hospitals can never be truly prepared for these events (Nemeth et al., 2008) but if the leadership understands and build sustainable resilience, along with identifying and developing crisis leaders they should be ready to better handle the next crisis than they could during the current COVID-19 pandemic.

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ABSTRACT

We present a new and practice-oriented approach to combatting high medical supply costs by exploiting cost-saving opportunities hidden in complex hospital procurement contracts. A MILP model is formulated to optimize hospital procurement decisions while considering real-world complexities, including complicated tier-pricing schemes, physician preference items (PPIs), and asymmetric product substitutability. The application of our approach to regional and nationwide health systems shows up to 35% cost reduction. We demonstrate that not all PPIs inflate costs and the financial impact of PPIs can be quantified. Furthermore, the current contracting structure may not encourage product standardization for which hospitals have long been striving.

KEYWORDS: hospital procurement; quantity discount; tier contract; physician preference items; contract management

1. INTRODUCTION

1.1 Background and Challenges

Spending on medical supplies has historically been the largest non-labor cost category, representing up to 40% of a hospital's operating budget, and this continues to grow faster than labor costs (Y. Abdulsalam et al., 2015; Cooper et al., 2019). The U.S. Congressional Budget Office projected (prior to the pandemic) that 60% of hospitals could have negative profit margins by 2025, in spite of the escalating hospital prices charged to Americans. Large hospital systems such as Cleveland Clinic saw a 47% increase in operating revenue from 2015 to 2019, but a 19% drop in operating income as expenses continued to outpace revenue growth. The outbreak of COVID-19 has only further intensified the financial challenges facing hospitals. Reducing costs, especially medical supply acquisition costs, has become more important than ever for hospital executives (Thiel & Horwitz, 2019; Volland et al., 2017; Young et al., 2015).

Hospital procurement, however, is known for its exceptional complexity compared to other industries, such as retail and manufacturing. We refer the reader to Chen et al. (2013) and Abdulsalam et al. (2015) for a detailed discussion of the unique characteristics of hospital supply chains. We focus on four distinctive factors that shape hospital procurement. First, medical supply tier contracts are exceptionally complex and not standardized. A health system (also known as an Integrated Delivery Network, or IDN, that owns one or more hospitals) establishes contracts with a set group of clinical products suppliers, either directly or through group purchasing organizations (GPOs). These contracts contain complicated pricing schemes with several unique aspects: (a) tier requirements are built upon multiple criteria involving consumption level, market share, the number of suppliers, a healthcare provider's organizational hierarchy, and in some cases, the type of a hospital. The combination of these criteria results in a few to more than a dozen tier prices in a contract; (b) a tier contract is often specific to a clinical category; for example, there may be a three-tier contract in total joint implants, but a completely different seven-tier contract in electrophysiology products from the same supplier, with each using different criteria; (c) a category-based contract may cover dozens to over a hundred items with varying discount rates for the same tier, in contrast to the manufacturing industry where suppliers in general apply the same discount rate across all products; (d) spend and quantity-based market share contracts may coexist, as some suppliers prefer to measure market share based on dollar amount while others use quantity; (e) market share requirements concern not only the supplier's own market share, but also the combined market share over multiple suppliers. and (f) there is no standardized tier contract structure across suppliers, even for the same product category. As such, optimizing procurement decisions in a health system is uniquely more complex than in a traditional industry.

Second, physicians have preferred products. Purchasing decisions in most industries are driven by product quality, cost, and supplier service commitment. Hospital procurement is different and strongly influenced by physician preferences (Moons et al., 2019). Physicians, in general, possess limited knowledge of product costs and often underestimate the prices of high-cost items (Lake et al., 2003; Pennington & DeRienzo, 2013; Tyson, 2010). Physician preference is widely criticized for inflating supply costs, which has motivated research in hospital-physician conflicts and organizational alignments (e.g., Y. J. Abdulsalam & Schneller, 2021; Greg Carlson & Hugh Greeley, 2010; Lake et al., 2003; Montgomery & Schneller, 2007; Young et al., 2015). Some core questions that have yet to be answered are: (i) to what extent do physician preferences impact a hospital's bottom line; (ii) which physical preference items (PPIs) shall be standardized; and (iii) which suppliers' products are economical and reliable substitutes? Montgomery and Schneller [30] document physicians' avoidance of participating in value analysis committees and heavy resistance to product standardization, but they also noted that "physicians like numbers." A study by Guzman et al. [18] shows that physicians are more willing to work with hospitals on product standardization when they are informed of the cost implications of alternative products.

Third, substitutability is asymmetric. Medical supplies, such as surgical products, have stringent quality requirements, require special handling, and are modified frequently (Chen et al., 2013). Since no two products are identical and a small variation may compromise the safety and outcome of patients, products from different suppliers cannot be assumed interchangeable in hospital procurement.

And finally, there is no standardization across supply items. An average hospital in the U.S. maintains nearly 35,000 stock keeping units (SKUs), from inexpensive commodities (e.g., bandages) to critical, high-value, and life-saving surgical products (e.g., mitral stented valves) (Abdulsalam & Schneller, 2019; Darling & Wise, 2010). Bon Secours Mercy Health, for example, used to have more than 150 different types of lotion throughout the system and still maintains nine different types today after standardization (Renfrow 2019). The more complex products that require training and special knowledge face more obstacles to standardize. Thus, the ability to make optimal procurement decisions is essential for a health system to improve its cost structure.

From our work with GPOs and healthcare organizations headquartered in the Midwest and southern U.S., we find that the intricate entwinement of tier pricing, asymmetric substitutability, and physician preferences prohibits hospitals from optimizing procurement decisions and capturing the important cost-saving opportunities in existing tier contracts. A medium-sized GPO that we have worked with estimates that validating or auditing tier prices alone (not even optimizing) for all its member healthcare systems, will require a minimum of ten analysts and may still not "catch" all tier assignment and pricing errors from suppliers. Optimizing product and supplier selection decisions requires a mathematical modeling approach due to the combinatorial nature of the tier pricing problem.

1.2 Research Gaps

The existing literature on hospital supply management focuses primarily on three areas: hospital-supplier relationships (e.g., Abdulsalam & Schneller, 2021; Chen et al., 2013), hospital-physician dynamics given the substantial influence of physicians on medical supplies (e.g., Montgomery & Schneller, 2007; Young et al., 2015), and the impact on healthcare product supply chains of GPOs who manage supply chains for healthcare providers (e.g., (Ahmadi et al., 2019; In et al., 2019). The literature on using mathematical programming to optimize hospital procurement is scarce. Wetzstein et al. (2016) review 221 papers published in the last two decades that investigate supplier selection problems and cannot find much (if any) research in healthcare. To the best of our knowledge, no work has been done on reducing hospital procurement costs by exploiting cost-saving opportunities under complex real-world tier pricing schemes through mathematical programming, and no work has been done on quantifying the financial impact of PPIs. To this end, this research addresses the following questions:

- To what extent can a health system lower its procurement cost by optimizing its procurement decisions under the current tier contracts?
- To what extent can product substitution and PPIs impact procurement costs, and how can a health system quantify the financial impact of a PPI?

1.3 Contributions

Our research makes several contributions to health system procurement. First, we introduces a novel four-dimensional structure to capture the complex and diverse tier requirements in tier contracts, which lays a foundation for systematic management of hospital procurement contracts. Second, we develop a decision-support framework to validate and optimize tier spending for healthcare organizations and GPOs, with the consideration of one-way product substitution and PPIs. While the problem is complex and inherently nonlinear (Stadtler, 2007), we formulate a novel linear optimization model that allows real-world cases to be solved in reasonable time with an open-source or commercially available off-the-shelf solver. We apply the model to four real-world cases and demonstrate that if spending against tier contracts is optimized, hospitals could realize up to 35% savings on medical supply costs. Furthermore, our work brings a new perspective to the hospital-physician dynamics literature by offering a model and a process to quantify the financial impact of PPIs. We show that hospitals could significantly improve their cost structure by focusing on standardizing a few impactful PPIs.

The remainder of the paper is organized as follows. Section 2 provides a review of procurement literature concerning quantity discounts. Section 3 presents the modeling framework and formulation for supplier selection and procurement cost minimization problems in the presence of quantity discounts, one-way product substitution, and physician preferences. In Section 4, we apply the model using data from regional and nationwide healthcare organizations and discuss the results and managerial insights. Section 5 provides a summary of findings and opportunities for future research.

2. LITERATURE REVIEW

Hospital tier contract is a form of quantity discount. We address a multi-product all-unit total quantity discount (TQD) problem observed in hospital purchasing. We organize this section by first reviewing quantity discount problems, and then discussing research on general and industry-specific TQD problems, followed by the discussion on studies that use mathematical programming to optimize hospital procurement decisions. The novelty contribution of this research compared with some of the relevant papers is summarized in Table 1.

2.1 Quantity Discounts

Quantity discounts offered by suppliers have two forms: all-unit discount, where the discount applies to all the units purchased; and incremental discount, where the discounted price applies only to the units above the lower threshold of a volume interval (Munson & Rosenblatt, 1998). In the case of multiple products, a volume discount could be based on quantities of individual products, or the total amount across all the products. The former suggests that the discounts for different items are independent, while the latter, known as total quantity discount (TQD), states that the discount of an item depends on the total amount of other products purchased. The vast majority of the supplier selection literature focuses on either a single product with multiple suppliers (e.g., Burke et al., 2008; Chaudhry et al., 1993; Zhang & Zhang, 2011; Choudhary & Shankar, 2014) or multiple products with independent discount schedules (e.g., Benton, 1991; Jackson & Munson, 2016; Rubin & Benton, 2003). The TQD problem is strongly NP-hard (Goossens et al., 2007). Research on the TQD problem is limited and mainly focuses on developing heuristics to efficiently solve extended general TQD problems.

2.2 General TQD Problems

Goossens et al. (2007) is one of the first studies that formally introduced the TQD problem. The authors present a mixed-integer linear programming (MILP) model and investigate four variants of the TQD problem including adding lower/upper bounds on the quantity purchased from a supplier, allowing the purchase of more than needed, limiting the number of winning suppliers, and introducing multi-period procurement. Mansini et al. (2012) extend the research by considering both procurement and truckload shipping costs. They develop a MILP formulation and solve it using an iterative rounding heuristic. The efficacy of the heuristic is evaluated on randomly generated instances consisting of 49 suppliers and 50 products. Manerba and Mansini (2012) assume that suppliers have capacity constraints and propose a branch-and-cut approach with different families of valid inequalities to solve the MILP model. Manerba and Perboli (2019) include fixed contract activation costs in addition to the capacity constraints and study the cases in which product price or demand is stochastic. The authors propose a two-stage stochastic programming model solved with a progressive-hedging-based heuristic approach and Benders decomposition.

2.3 Industry-Specific TQD Problems

The TQD problem in the real world can be much more complex and varies greatly by industry, which has motivated a number of industry-specific studies (e.g., Crama et al., 2004; Degraeve et al., 2004; van de Klundert et al., 2005). These studies focus on formulating mathematical programming models and solve complex real-world cases with open-source or commercially available off-the-shelf solvers. We take a similar approach to the supplier selection problem in healthcare. Crama et al. (2004) study the purchasing decisions faced by a multi-factory chemical company. The company buys ingredients from multiple suppliers, each of which offers a comprehensive pricing scheme based on the total quantity purchased over a year. A factory receives two discount schedules from each supplier; a factory-level schedule determined by local purchases of the factory and a company-wide schedule determined by the consolidated purchases across all factories. The factory can choose whichever one yields the highest discount rate. The authors construct a mixed-integer nonlinear programming (MINLP) model and propose various ways to linearize the formulation. The linearized model is solved with the XA solver for a chemical company that has two factories and manufactures 37 products out of 25 ingredients.

Degraeve et al. (2004) study an airline selection problem from the perspective of a firm (Alcatel Bell). Airlines offer complex discounting systems, including route deals, volume discounts based on destination-bound market share, and additional absolute and relative volume discounts based on the overall travel volume of the firm. Some airlines also have discounts based on sales volume with the alliance(s) to which the airline belongs. The products (routes) and the number of flights provided by airlines vary each week. The goal is to minimize the total annual management and travel costs for the firm. The authors develop a MILP formulation solved with LINGO optimization modeling software for Alcatel Bell Belgium, which needs to select airlines from a pool of 34 carriers for 56 destinations. The results show 19.5% savings on travel costs.

Van de Klundert et al. (2005) investigate the carrier (supplier) selection problem in the telecommunication industry where mobile operators seek to decrease costs on international calls routed via wired network carriers. Carriers charge on call-minutes and the rate varies by destination. Volume discounts are offered on the total number of call-minutes received over all the destinations in a year. Each volume interval has a lower and upper annual threshold, and there are also monthly lower and upper bounds imposed by carriers on the total capacity available. The objective is to minimize annual procurement costs by selecting the optimal carriers for each destination and acquiring the optimal amount of capacity from each carrier. The authors suggest a min-cost flow enumeration approach and implement it in a case that has 5 carriers and 5,000 destinations using a min-cost flow solver, IG Systems CS2 program.

2.4 Mathematical Programming in Hospital Procurement

There is a growing interest in using mathematical programming to contain increasing material costs in hospital procurement and supply management, although the relevant literature is still scarce. Ross and Jayaraman (2009) develop a MIP model to help hospitals select bundled refurbished products from suppliers at the least total cost while meeting delivery time, quality, and service requirements of hospitals. Rego et al. (2014) present a decision support tool to identify the optimal cooperative purchasing structure among a set of hospitals to minimize shared supply chain costs. Li et al. (2021) study rebate contracts observed in hospital drug procurement and develop a multi-period optimization model to assess generic and rebate brands for minimizing total expected procurement costs.

The supplier selection and order quantity allocation problem based on tiered contracts in healthcare has, however, yet to be investigated. Table 1 summarizes the similarity and differences between our paper and aforementioned research.

Table 1 Summary of relevant research with contribution of this paper

	Research Focus	Model	Real-world challenges considered in the model: Buying more than required quantity	One-way substitutability	Combined market share over multiple suppliers	Multi-level Share requirements	Physician preferences
Crama and Torres [14]	Optimizing purchasing decisions faced by a multi-factory chemical company	Nonlinear	No	Yes	Yes	Yes, but not mutually exclusive	N/A
Degraeve et al. [16]	Airline selection problem from the perspective of a firm	Linear	No	N/A	Yes	No	N/A
Van de Klundert et al. [42]	Carrier selection problem in telecommunication industry	Linear	No	N/A	No	No	N/A
Goossens et al. [17]	Investigating variants of the basic TQD problem	Linear	Yes	N/A	N/A	N/A	N/A
Ross and Jayaraman [37]	Minimizing total acquisition cost of bundled refurbished products for hospitals	Linear	No	No	No	No	No
Manerba and Mansini [26]	Investigating general TQD problem with supplier capacity constraints	Linear	No	N/A	N/A	N/A	N/A
Mansini et al. [29]	Investigating general TQD problem with the consideration of procurement nd truckload shipping costs	Linear	No	N/A	N/A	N/A	N/A
Rego et al. [35]	Identifying optimal cooperative purchasing structure among hospitals to minimize shared supply chain costs	Nonlinear	No	No	No	No	No
Manerba and Perboli [28]	Investigating general TQD problem with stochastic demand or pricing	Nonlinear	No	N/A	N/A	N/A	N/A
Li et al. [25]	Assessing generic and rebate brands for minimizing total expected drug procurement costs in hospitals.	Linear	No	No	No	No	No
This paper	**Optimizing supplier selection and quantity allocation of hospital supplies under complex tiered hospital purchasing contracts**	**Linear**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**

3. OPTIMAL PROCUREMENT DECISION MODEL IN HEALTHCARE

3.1 Problem Description and Notations

We consider an IDN (Integrated Delivery Network) consisting of a set of hospitals (facilities), denoted by H. The purchasing decision is centralized at the IDN level. Let S be the set of suppliers. Each supplier $s \in S$ offers a discount schedule with max_s discount tiers in set $K_s = \{1, 2, \ldots, max_s\}$, indexed by k. One of the challenges in procurement optimization for clinical products is the diverse tier requirements that involve many aspects. To create a decision-support tool that can be used in practice, it is important to develop a standard structure that can define all the tiers offered by suppliers. After reviewing a number of tier contracts for various product categories, we propose a four-dimensional structure, $(u_k^s, v_k^s, w_k^s, z_k^s)$, to delineate tier $k \in K_s$ provided by supplier s. With this structure, u_k^s indicates the required minimum market share percentage of supplier s for tier k in a clinical product category; v_k^s and w_k^s together describe the requirements for tier k on the combined market share over multiple suppliers, where v_k^s represents the least combined market share percentage and w_k^s gives the maximum number of suppliers (including supplier s) allowed by supplier s; and z_k^s shows whether tier k is a facility (hospital) or IDN based measure. Rarely, if ever, does a supplier allow the maximum number of suppliers higher than three under the combined market share requirements; hence, the value of parameter w_k^s is typically {0, 2, or 3}, where “zero” indicates no requirements on combined market share and “two” (or “three”) shows the combined market share involving a maximum of two (or three) suppliers. For tier contracts negotiated by a GPO or a large IDN, the value of parameter z_k^s is typically {None, Facility, IDN}, where “None” indicates no market share requirements, “Facility” indicates the market share requirement is at the facility (e.g., hospital) level, and “IDN” indicates the market share requirement is at the IDN level.

Table 2 shows a typical tier contract between a supplier (denoted as ABC) and an IDN, in which price discriminates not only on the supplier’s own market share, but also on the combined market share over multiple suppliers. Market share is measured at individual hospitals and for the IDN as a whole. If an IDN-level tier is selected, all the hospitals in the IDN must adopt the same tier even though a hospital could be better off with its own facility-level tier. For example, with the four-dimensional structure, Tier 1 in Table 2 can be written as $\left(u_1^{ABC}, v_1^{ABC}, w_1^{ABC}, z_1^{ABC}\right) = (0\%, 0\%, 0, None)$, Tier 4 is $\left(u_4^{ABC}, v_4^{ABC}, w_4^{ABC}, z_4^{ABC}\right) = (0\%, 85\%, 3, Facility)$, and Tier 5 is $\left(u_5^{ABC}, v_5^{ABC}, w_5^{ABC}, z_5^{ABC}\right) = (5\%, 80\%, 2, IDN)$.

Table 2 An example tier contract offered by a clinical product supplier ABC

Tiers	Tier Description
Tier 1	Access - No Commitment
Tier 2	Facility level, ≥90% Unit Market Share committed to supplier ABC
Tier 3	Facility level, ≥80% Unit Market Share on Dual-Source including supplier ABC
Tier 4	Facility level, ≥85% Unit Market Share on Tri-Source including supplier ABC
Tier 5	IDN level, ≥80% Unit Market Share on Dual-Source, 5% to 25% committed to ABC
Tier 6	IDN level, ≥80% Unit Market Share on Dual-Source, 25% to 50% committed to ABC
Tier 7	IDN level, ≥80% Unit Market Share on Dual-Source, 50% to 75% committed to ABC
Tier 8	IDN level, ≥80% Unit Market Share on Dual-Source, ≥75% committed to ABC
Tier 9	IDN level, ≥85% Unit Market Share on Tri-Source including supplier ABC

Let I be the set of products including the items currently purchased by hospitals and all other products offered by suppliers. Supplier $s \in S$ offers a portfolio of products $I_s \subseteq I$, indexed by i. Each supplier has a unique set of products such that $I_s \cap I_{s'} = \emptyset$ for $s \neq s'$. A two-dimensional array R records the one-way product substitution relationship, where pair $(i, j) \in R$ indicates that product $j \in I$ is capable of substituting for product $i \in I$. We include every pair (i, i) in R to eliminate the need for additional decision variables in the model. The demand of a hospital $h \in H$ for an item $i \in I$ is described by d_{hi}, which could be forecast in various ways, including using actual consumptions from previous years. The price discount offered by a supplier often varies by product for the same tier; hence, we directly incorporate the price, p_{ik}^s, quoted by supplier s for an item $i \in I_s$ at a tier $k \in K_s$ in the model formulation. The goal is to minimize the total supply acquisition costs for the health system, which requires simultaneous decisions on which suppliers to select, which items and how many of each shall be substituted with which alternatives, and whether facility-level or IDN-level tiers shall be adopted.

Table 3 Notation for one product category

H: set of hospitals in an IDN
S: set of suppliers of a clinical product category
I: set of clinical products in the category
I_s: set of products provided by supplier s, $I_s \subseteq I, \forall s \in S$
K_s: set of tiers that define the discount schedule offered by supplier s, $\forall s \in S$
$(u_k^s, v_k^s, w_k^s, z_k^s)$: a four-dimensional structure that describes the requirements of tier k provided by supplier s, $\forall k \in K_s\ s \in S$
R: set of product pairs that identify one-way referencing relationships between products such that for $(i,j) \in R$, product j may substitute for product i, $\forall i,j \in I$
d_{hi}: forecast annual demand for product i at hospital h, $\forall h \in H, i \in I$
p_{ik}^s: price quoted for product i by supplier s at tier k, $\forall\ i \in I_s, k \in K_s, s \in S$

Decision Variables
x_{hik}^s: quantity of product i to be purchased by hospital h at tier price k from supplier s, $\forall h \in H, i \in I_s, k \in K_s, s \in S$
y_{hij}: quantity of product j to substitute for product i at hospital h, $\forall h \in H,\ i,j \in I,\ (i,j) \in R$
e_{hsk}: =1 if tier k of supplier s is adopted by facility h; 0 otherwise, $\forall h \in H,\ s \in S,\ k \in K_s$
q_{sk}: =1 if the IDN qualifies for tier k offered by supplier s; 0 otherwise, $\forall\ s \in S,\ k \in K_s$

3.2 MILP Formulation

Table 3 summarizes the aforementioned notation and the decision variables. We allow $i = j$ for y_{hij} if product i has no substitute or it is not economical to substitute i with alternatives. We consider a general case where hospitals may buy more items than strictly necessary if that can help achieve a lower total cost. The MILP formulation for optimal procurement decisions in the presence of TQD and one-way product substitution is written as:

$$\text{Min } \sum_{h\in H}\sum_{s\in S}\sum_{i\in I_s}\sum_{k\in K_s} x_{hik}^s\, p_{ik}^s \quad (1)$$

subject to:

$$\sum_{k\in K_s} e_{hsk} \le 1 \qquad \forall h \in H,\ s \in S \quad (2)$$
$$\sum_{i\in I_s} x_{hik}^s \le M \cdot e_{hsk} \qquad \forall h \in H,\ s \in S,\ k \in K_s \quad (3)$$
$$\sum_{j\in I|(i,j)\in R} y_{hij} \ge d_{hi} \qquad \forall h \in H,\ i \in I \quad (4)$$
$$\sum_{k\in K_s} x_{hjk}^s \ge \sum_{i\in I|(i,j)\in R} y_{hij} \qquad \forall h \in H,\ j \in I_s,\ s \in S \quad (5)$$

The objective function (1) minimizes total procurement costs. A facility in an IDN may qualify for multiple tiers offered by a supplier, but a facility shall be assigned at most one tier of a supplier. Constraint (2) achieves this purpose by restricting a facility from having more than one tier selected from any supplier. Constraint (3) guarantees that no quantity is allocated to a tier which the hospital does not qualify for or adopt. Parameter M is a big number, which shall be larger than the total quantity the hospital is expected to purchase. Constraints (4) and (5) state that all demands must be satisfied. In the case where product i has no substitutes or it is more cost-effective to continue with product i, constraint (4) will become:

$$y_{hii} \geq d_{hi}$$

Each tier in a contract generates 0 to 3 constraints based on the values of $(u_k^s, v_k^s, w_k^s, z_k^s)$. Tier 1 in Table 2, for example, does not require any additional constraint. Tiers that specify a minimum share of the supplier in a facility (e.g., Tier 2 in Table 2), require the following constraint:

$$\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s - \left(\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^\tau\right)\cdot u_k^s \geq (e_{hsk}-1)\cdot M$$
$$\forall h \in H,\ k \in K_s,\ s \in S,\ z_k^s = \textit{facility} \qquad (6)$$

If hospitals are restricted from purchasing more volume than the forecast demand d_{hi}, the minimum market share requirement in constraint (6) can be simplified to a fixed minimum quantity (expressed as a fraction of the annual demand) and the constraint is rewritten as

$$\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s \geq e_{hsk}\cdot\sum_{i\in I} d_{hi}\cdot u_k^s \quad \forall h \in H,\ k \in K_s,\ s \in S,\ z_k^s = \textit{facility} \qquad (6a)$$

Tiers that indicate the combined market share over multiple suppliers in a facility are described by the following constraints. For two suppliers:

$$\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s + \sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'} - \left(\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^\tau\right)\cdot v_k^s \geq (\ell_{hss'k}-1)\cdot M$$
$$\forall h \in H,\ k \in K_s,\ s,s' \in S,\ s \neq s',\ z_k^s = facility,\ w_k^s = 2 \qquad (7)$$
$$e_{hsk} \leq \sum_{s'\in S \cap s'\neq s} \ell_{hss'k} \qquad \forall h \in H,\ k \in K_s,\ s \in S, z_k^s = facility,\ w_k^s = 2 \qquad (8)$$

where binary decision variable $\ell_{hss'k}$ is 1 if the combined market share of suppliers s and s' is equal to or higher than the minimum market share requirement (v_k^s) placed on tier k by supplier s, and 0 otherwise. For three suppliers, the constraint is:

$$\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s + \sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'} + \sum_{i\in I_{s''}}\sum_{\xi\in K_{s''}} x_{hi\xi}^{s''} - \left(\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^\tau\right)\cdot v_k^s$$
$$\geq (g_{hss's''k}-1)\cdot M$$
$$\forall h \in H,\ k \in K^s,\ s,s',s'' \in S,\ s \neq s' \neq s'', z_k^s = facility,\ w_k^s = 3 \qquad (9)$$
$$e_{hsk} \leq \sum_{(s',s''\in S)\cap(s'\neq s''\neq s)} g_{hss's''k}$$
$$\forall h \in H,\ k \in K_s,\ s \in S,\ z_k^s = facility,\ w_k^s = 3 \qquad (10)$$

where binary decision variable $g_{hss's''k}$ is 1 if the combined market share of three suppliers (s, s', and s'') is equal to or higher than the minimum market share requirement placed on tier k by supplier s, and 0 otherwise.

Constraints (8) and (10) prevent a hospital from choosing a tier for which the minimum combined market share requirement is not achieved. Constraints (7) and (8) together satisfy Tier 3 in Table 2, while constraints (9) and (10) address Tier 4. We have not seen a case where a supplier is willing to consider the combined market share percentage beyond three suppliers, but it is easy to extend constraints (9) and (10) to accommodate more suppliers.

Consider now the IDN-based discount schedule. To qualify for an IDN tier, the consolidated purchase of all hospitals must meet the minimum single and/or combined market share requirements placed by the supplier. The following constraint addresses tiers requiring a minimum share of supplier s in an IDN:

$$\sum_{h\in H}\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s - \left(\sum_{h\in H}\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^\tau\right)\cdot u_k^s \geq (q_{sk}-1)\cdot M$$

$$\forall k \in K_s,\ s \in S,\ z_k^s = IDN \quad (11)$$

The combined market share requirement over two suppliers is addressed by the following constraints:

$$\sum_{h\in H}\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s + \sum_{h\in H}\sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'} - \left(\sum_{h\in H}\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\right)\cdot v_k^s \geq (\vartheta_{ss'k}-1)\cdot M \quad \forall k \in K_s,\ s,s' \in S,\ s \neq s',\ z_k^s = IDN,\ w_k^s = 2 \quad (12)$$

$$q_{sk} \leq \sum_{s'\in S \cap s' \neq s} \vartheta_{ss'k} \quad \forall k \in K_s,\ s \in S,\ z_k^s = IDN,\ w_k^s = 2 \quad (13)$$

where binary decision variable $\vartheta_{ss'k}$ is 1 if the combined market share of suppliers s and s' across all hospitals in an IDN meets the minimum market share requirement placed on tier k by supplier s, and 0 otherwise. For three suppliers:

$$\sum_{h\in H}\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^s + \sum_{h\in H}\sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'} + \sum_{h\in H}\sum_{i\in I_{s''}}\sum_{\xi\in K_{s''}} x_{hi\xi}^{s''} - \left(\sum_{h\in H}\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\right)\cdot v_k^s \geq (\delta_{ss's''k}-1)\cdot M \quad \forall k \in K_s,\ s,s',s'' \in S,\ s \neq s' \neq s'',\ z_k^s = IDN,\ w_k^s = 3 \quad (14)$$

$$q_{sk} \leq \sum_{(s',s''\in S)\cap(s'\neq s''\neq s)} \delta_{ss's''k} \quad \forall k \in K_s,\ s \in S, z_k^s = IDN,\ w_k^s = 3 \quad (15)$$

where $\delta_{ss's''k}$ is a binary decision variable, describing whether the combined market share of three suppliers (s, s', and s'') satisfies the minimum market share requirement placed on tier k by supplier s.

Constraints (13) and (15) guarantees that an IDN tier cannot be considered unless the minimum combined market share requirement is met. Tiers 5 – 8 in Table 2 are described by constraints (11) – (13), while Tier 9 is guaranteed by constraints (11), (14), and (15).

Another complication in the medical supply procurement contract is the mutually exclusive relationship between the IDN and the facility discount schedules. We add the following constraint, which, together with constraint (2), ensures that only one of the two discount schedules is selected.

$$\sum_{h\in H} e_{hsk} \leq |H|\cdot q_{sk} \quad \forall k \in K_s,\ s \in S,\ z_k^s = IDN \quad (16)$$

The MILP model (1) – (16) (with either constraint 6 or 6a) addresses the product substitution decision, quantity to be purchased from each supplier, and the optimal tier prices that each hospital shall adopt such that the total medical supply costs of the IDN are minimized. The proposed model can be solved using a standard mathematical programming package such as IBM ILOG CPLEX, Gurobi, FICOR Xpress, SCIP, etc., to find an optimal or near-optimal solution for a single stand-alone hospital, a regional IDN with dozens of facilities, or a nationwide IDN with over a hundred member hospitals.

3.3 Extension to Spend-based Tier Pricing

The proposed modeling structure can easily accommodate spend-based tier pricing, where market share is measured based upon the total spend on a clinical product category. To satisfy the minimum single market share requirement placed by supplier s on a facility and an IDN, constraints (6) and (11) are rewritten as:

$$\sum_{i\in I_s}\sum_{\zeta\in K_s} x_{hi\xi}^s\cdot p_{ik} - \sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\cdot p_{ik}\cdot u_k^s \geq (e_{hsk}-1)\cdot M \quad \forall h \in H,\ k \in K_s,\ s \in S,\ z_k^s = \textit{facility} \quad (17)$$

$$\sum_{h\in H}\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^{s}\cdot p_{ik} - \sum_{h\in H}\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\cdot p_{ik}\cdot u_k^s \geq (q_{sk}-1)\cdot M \quad \forall h\in H,\ k\in K_s,\ s\in S,\ z_k^s = IDN \tag{18}$$

To meet the minimum combined market share requirement that involves multiple suppliers including supplier s, constraints (7), (9), (12), and (14) are rewritten as:

$$\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^{s}\cdot p_{ik} + \sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'}\cdot p_{ik} - \sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\cdot p_{ik}\cdot v_k^s \geq (\ell_{hss'k}-1)\cdot M \quad \forall h\in H,\ k\in K_s,\ s,s'\in S,\ s\neq s',\ z_k^s = facility,\ w_k^s = 2 \tag{19}$$

$$\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^{s}\cdot p_{ik} + \sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'}\cdot p_{ik} + \sum_{i\in I_{s''}}\sum_{\xi\in K_{s''}} x_{hi\xi}^{s''}\cdot p_{ik} - \sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\cdot p_{ik}\cdot v_k^s \geq (g_{hss's''k}-1)\cdot M \quad \forall h\in H,\ k\in K_s,\ s,s',s''\in S,\ s\neq s'\neq s'', z_k^s = facility,\ w_k^s = 3 \tag{20}$$

$$\sum_{h\in H}\Big(\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^{s}\cdot p_{ik} + \sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'}\cdot p_{ik}\Big) - \sum_{h\in H}\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\cdot p_{ik}\cdot v_k^s \geq (\vartheta_{ss'k}-1)\cdot M \quad \forall k\in K_s,\ s,s'\in S,\ s\neq s', z_k^s = IDN,\ w_k^s = 2 \tag{21}$$

$$\sum_{h\in H}\Big(\sum_{i\in I_s}\sum_{\xi\in K_s} x_{hi\xi}^{s}\cdot p_{ik} + \sum_{i\in I_{s'}}\sum_{\xi\in K_{s'}} x_{hi\xi}^{s'}\cdot p_{ik} + \sum_{i\in I_{s''}}\sum_{\xi\in K_{s''}} x_{hi\xi}^{s''}\cdot p_{ik}\Big) - \sum_{h\in H}\sum_{\tau\in S}\sum_{i\in I_\tau}\sum_{\xi\in K_\tau} x_{hi\xi}^{\tau}\cdot p_{ik}\cdot v_k^s \geq (\delta_{ss's''k}-1)\cdot M \quad \forall k\in K_s,\ s,s',s''\in S,\ s\neq s'\neq s'', z_k^s = IDN,\ w_k^s = 3 \tag{22}$$

The MILP model (1) – (5), (8), (10), (13), (15) – (16), and (17) – (22) minimizes the total supply cost for an IDN when market share is calculated upon the total dollar value of purchases.

3.4 Validation of Current Purchasing

Validating or auditing current purchasing against prices agreed in tier contacts typically involves tedious calculations to identify the tiers for which hospitals qualify and then locating the tier that gives the lowest total cost for the IDN. Note that a hospital may qualify for multiple facility-level tiers and the IDN as a whole may qualify for one or more IDN-level tiers. The following steps are an example of how to manually validate current purchase prices:

a. Calculate the market share of each supplier in a clinical product category in each of the hospitals in an IDN
b. For each hospital and each supplier, calculate this supplier's combined market share with each of the other suppliers in the hospital
c. For each hospital and each supplier, calculate this supplier's combined market share with all pairs of two suppliers for the hospital
d. For each hospital and each supplier, identify the facility-level tiers for which the hospital qualifies based on the results from steps a, b, and c; locate the tier that provides the lowest cost; and calculate the total resulting cost of that tier
e. For each supplier, calculate the lowest possible cost for the IDN as a whole when all hospitals adopt facility-level tiers identified from step d
f. Calculate the market share of each supplier in the IDN
g. For each supplier, calculate its combined market share with each of the other suppliers in the IDN
h. For each supplier, calculate its combined market share with all pairs of two suppliers for the IDN
i. For each supplier, identify the IDN-level tiers for which the IDN qualifies based on the results from f, g, and h, locate the tier that gives the lowest cost, and calculate the total resulting cost of that tier

j. For each supplier, compare the results from steps e and i. If the cost from step e is smaller, the “optimal” tiers are facility-level tiers identified in step d; if the cost from step i is smaller, the “optimal” tier is an IDN tier.

These steps need to be repeated for each of the clinical product categories, which can be a very time-consuming process. Alternatively, we may adapt the proposed MILP model for validating the existing purchasing pattern by using actual purchases for x^s_{hik}, removing product substitution variable y_{hij}, and combining constraints (4) and (5) as the following:

$$\sum_{k \in K_s} x^s_{hik} = d_{hi} \qquad \forall h \in H,\ i \in I_s,\ s \in S \qquad (23)$$

4. CASE STUDIES

This section presents case studies where we apply the model to the heart valve category of four health systems of different sizes in the U.S., denoted as A, B, C, and D, which range from a one-facility system to a nationwide system. The supply chain of these four healthcare providers is managed by a GPO, which negotiates contracts with suppliers on behalf of its members. Provider A is located in the Southwest, with a teaching hospital and dozens of clinics. It has about 200 licensed beds, offering various residency and fellowship programs. It provides cardiology care and orthopedic surgery, among other services, serving about 150,000 patients each year throughout the system. It spends about $200,000 a year on heart valves and is the smallest health system in our case studies. Provider B is a self-funded IDN located in the Southeast with five hospitals and two long-term care and rehabilitation facilities, serving the residents in its home state. It has less than 10,000 employees and performs over 25,000 surgical procedures annually. The two locations with heart care centers spend over $1.5 million on heart valves and related products each year. Provider C is a regional health system also headquartered in the Southeast, with ten hospitals and nearly 2,000 licensed beds spread over two states. It employs over 10,000 employees and handles more than 200,000 emergency visits a year. The four locations that offer heart care services spend about $6 million on heart valves and related products each year. Headquartered in the Midwest, Provider D is one of the largest health systems in the U.S. with over 40 acute care and specialty hospitals across multiple states. It serves about three million patients and performs over 150,000 surgical procedures each year. It spends over $10 million a year on heart valves and related products alone. Data for the models were acquired for these four providers, and for five suppliers described below.

We consider five U.S.-based suppliers (denoted I -V) in the case studies. All five suppliers are publicly traded companies on U.S. stock exchanges. Supplier I specializes in artificial heart valve replacement and repair products, serving customers around the world. Suppliers III and V have a larger product portfolio, but with a significant focus on heart valves. Suppliers II and IV offer a much wider range of products in addition to cardiac devices and they both have extensive global footprints. Provider D is currently engaged with all five suppliers, while the other three providers purchase cardiac devices from Suppliers I – IV only. All five suppliers were asked to provide product substitution information concerning their competitors’ products, and all except Supplier V did so. Market share requirements posed by five suppliers are all based upon units purchased in the heart valve category. Supplier III offers only one price tier regardless of market share, and Suppliers I, II, IV, and V have 9, 4, 10, and 5 tiers, respectively.

All four healthcare providers have vigorous systems to forecast the number of clinical procedures and the required products in the coming year. To compare with the current approach and evaluate the impact of the model, we use the actual consumption data instead of the forecasts in the case studies. Table 4 shows the current annual expenditure of each provider on each supplier prior to the COVID and the corresponding market percentages.

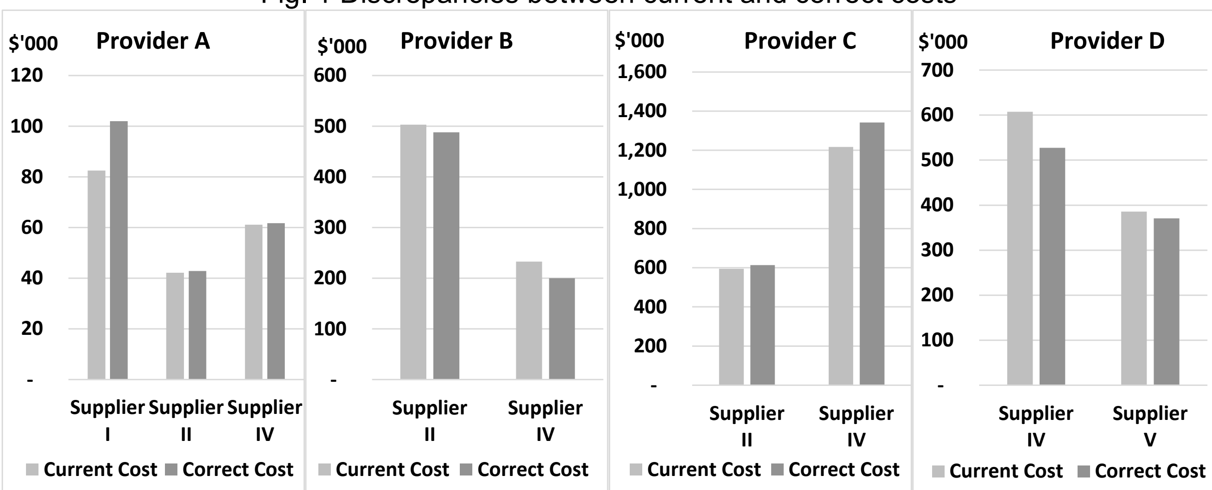
Table 4 Annual expenditure of each provider on each supplier in heart valve category

	Provider A		Provider B		Provider C		Provider D	
	$’000	%	$’000	%	$’000	%	$’000	%
Supplier I	83	42.0%	679	44.2%	3,875	64.3%	7,486	69.5%
Supplier II	42	21.4%	503	32.8%	594	9.9%	2,261	21.0%
Supplier III	11	5.4%	122	7.9%	342	5.7%	38	0.3%
Supplier IV	61	31.1%	233	15.1%	1,217	20.2%	607	5.6%
Supplier V	-	-	-	-	-	-	386	3.6%
Total	196	100.0%	1,536	100.0%	6,029	100.0%	10,778	100.0%

4.1 Tier Price Validation

We first utilize the model to *validate* the tier prices that healthcare providers are currently paying and compare the “current cost” with the “correct cost”. The “current cost” is the cost that providers have paid for the products purchased. We use “correct cost” to denote the cost that the providers should have paid if the least-cost tiers applicable to the existing purchases are correctly identified and implemented according to the contracts. Figure 1 highlights the discrepancies between the “current cost” and the “correct cost”. Both Providers A and C currently pay lower tier prices than what they qualify for, while Providers B and D are overcharged by some suppliers. For example, Provider A pays Supplier I Tier 8 prices, although it only qualifies for Tier 5. Tier 8 requires a minimum combined two-supplier market share of 80% and at least 50% purchased from Supplier I, while Tier 5 only requires a combined market share of 85% over three suppliers including Supplier I. We know from our work with the organization that this is due to a one-time special deal which Provider A had with Supplier I. In contrast, all the hospitals of Provider D are currently charged by Supplier IV at non-discounted prices of Tier 1, but in reality, Provider D qualifies for an IDN tier that offers much lower prices for most of the products. Providers B and D could save 3.1% (i.e., $48 million) and 1.0% (i.e., $105 million), respectively, if they were charged at the correct tier prices.

Fig. 1 Discrepancies between current and correct costs



4.2 Optimal Spend with "Quantity Restriction"

Next, we include product substitution data, limit the total quantity purchased to the exact demand (referred to as "quantity restriction") for each provider, and solve the proposed model with the branch-and-cut method using the GAMS/CPLEX 27.3 solver on a 2.10 GHz Intel Xeon 6130 with 32 GB RAM. The solution time varies from less than one CPU second (for Provider A) to four CPU seconds (for Provider D). The annual savings that a provider could realize in the heart valve category range from 13% to 35%, or $70,000 to nearly $1.5 million. Table 5 and Figure 2 show a comparison of the optimal spend with the current and correct costs. Provider A is a single facility and currently spreads its spending across four suppliers, none of which has a share of over 50%. As a result, Provider A cannot secure a favorable discount schedule from any supplier. The proposed optimization model suggests that Provider A form a close partnership with Supplier IV and substitute products from Supplier IV for Suppliers I and II where substitutes exist. This strategy allows Provider A to buy heart valve products at the most favorable prices offered by Supplier IV, reducing total supply costs by 34.9%. A similar strategy applies to Provider B. However, since not all products offered by Supplier II are substitutable in the case of Provider B, the model suggests maintaining a purchasing level that could secure Tier 2 pricing with Supplier II, while at the same time significantly increasing the volume to obtain a much more favorable price tier with Supplier IV. This could lead to a potential saving of 31.2% for Provider B. With Providers C and D, the number of suppliers remains the same after spend optimization; however, by re-allocating the procurement dollars among the existing suppliers, the two providers have the opportunity to save $857,000 to over a million dollars each year on heart valve related products. Figure 3 compares the spend distribution before and after optimization at each provider, showing a significant financial benefit if alternative products can be properly utilized.

Table 5 Annual savings by providers, with product substitution and quantity restriction

	Savings against Current Spend		Savings against Correct Spend	
	$'000	%	$'000	%
Provider A	$68	34.9%	$89	41.1%
Provider B	$480	31.2%	$432	29.0%
Provider C	$857	14.2%	$1,001	16.2%
Provider D	$1,418	13.2%	$1,323	12.4%

Fig. 2 Cost comparison: current, correct, and optimized Spend ($’000)

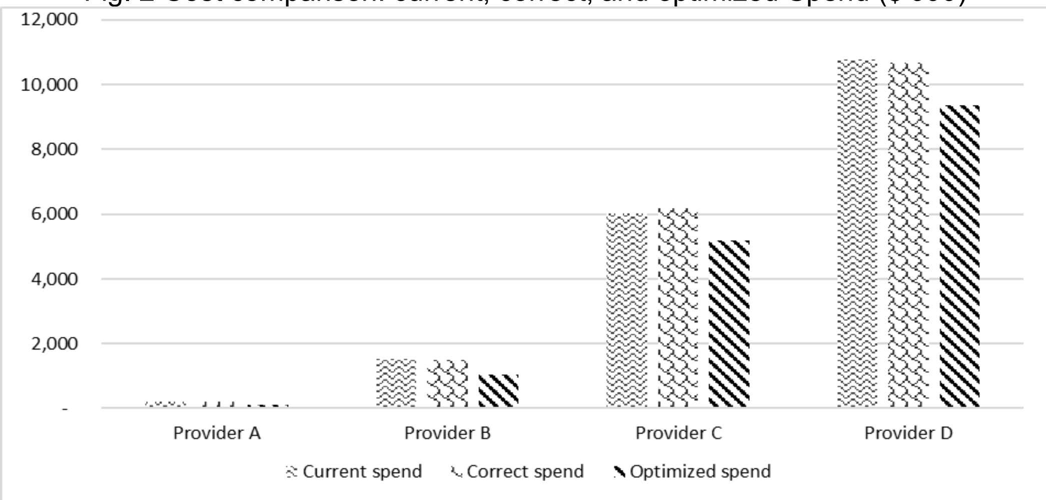
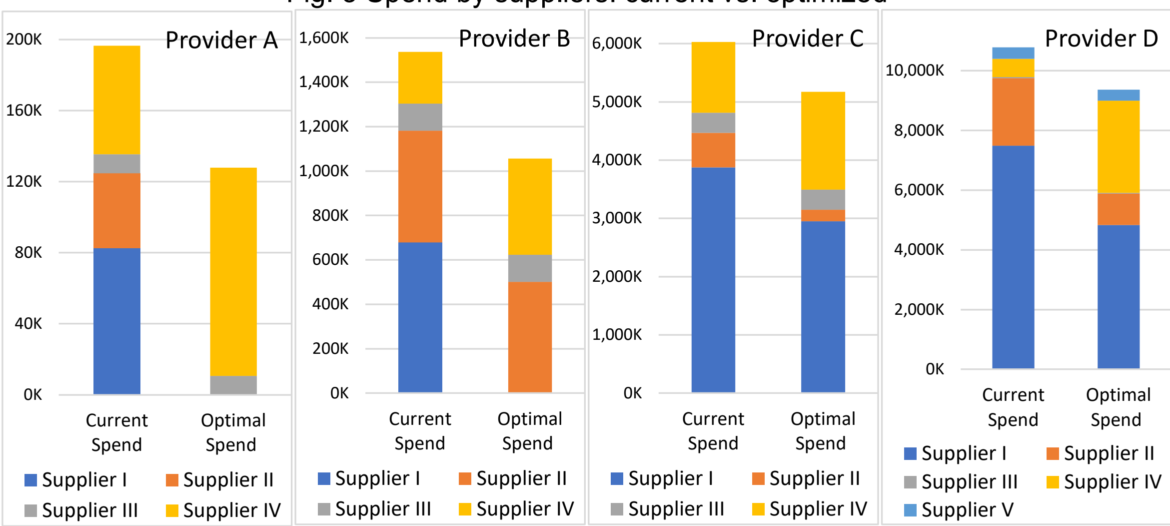


Fig. 3 Spend by suppliers: current vs. optimized



4.3 Optimal Spend without “Quantity Restriction”

In this section, we remove the quantity restriction and allow hospitals to purchase more than needed if lower costs can be achieved. Without considering the potential disposal costs of extra quantity, all four healthcare providers could benefit from purchasing more than the demand, although the additional savings range from nominal (at Provider A) to nearly 4% (at Provider C), as shown in Table 6. It is worth noting that Provider B could achieve additional 2.4% savings by adding just one more item than is needed. Without this additional item, Provider B cannot give Supplier IV 90% unit market share even if it is willing to substitute supplier IV for all possible items offered by other suppliers. The 90% market share qualifies Provider B for Tier 10 pricing, the second lowest pricing tier offered by Supplier IV.

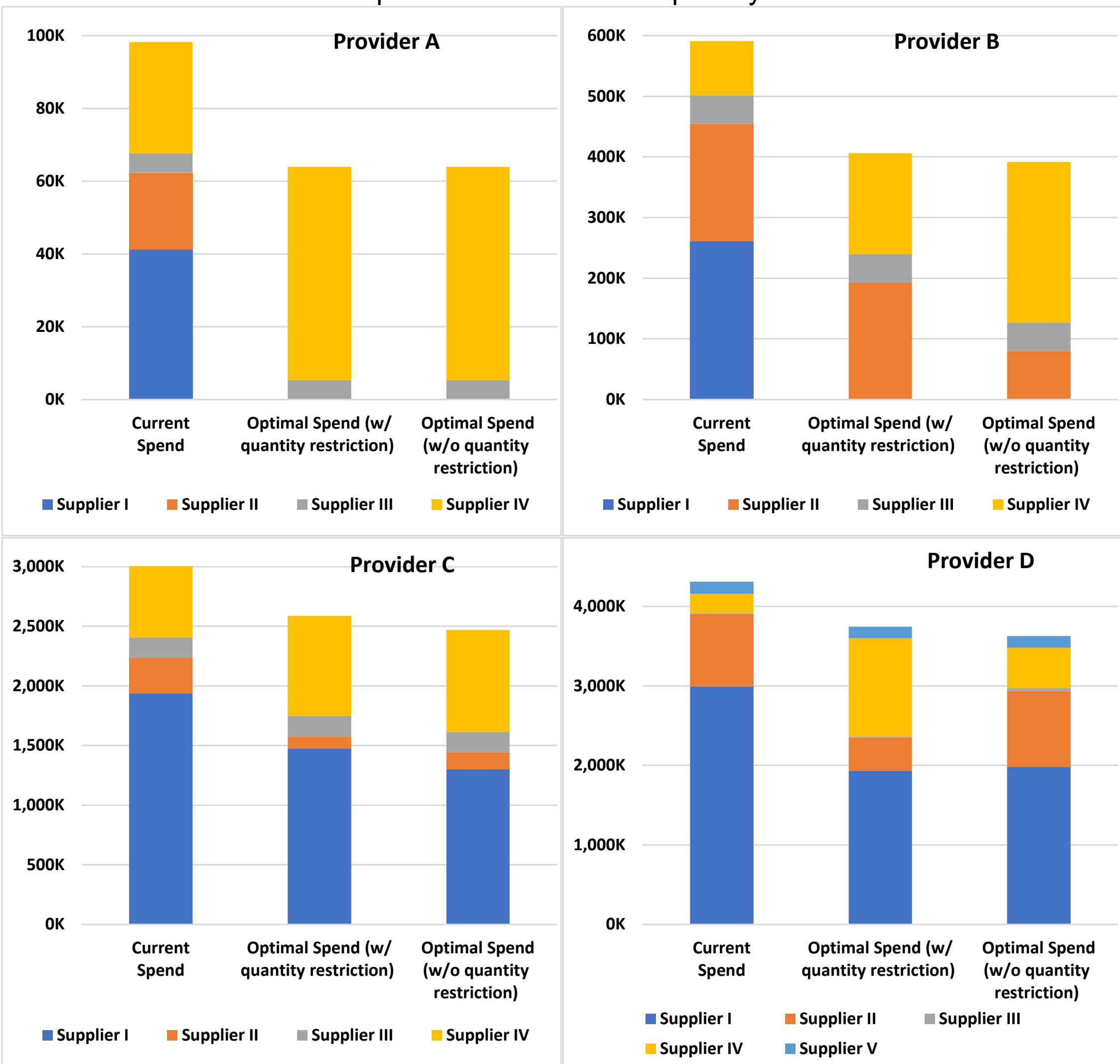
Different from Provider B, Providers C and D both have to purchase over 50% more items than needed in order to reduce total procurement costs. In the case of Provider C, it is able to substitute some of the products from Supplier I with less expensive items from Supplier II. But to maintain a favorable pricing tier with Supplier I for the remaining “non-substitutable” items, unneeded lower price products have to be purchased from Supplier I. Since the market share is measured against quantity, additional units from Supplier I change the previous market share structure, which means more items also have to be acquired from Supplier IV in order to retain Tier 10 prices. These shifts to achieve the lowest costs can affect all suppliers, and a new balance has to be reached among four suppliers. As seen in Figure 4, increased spending on Suppliers II and IV (compared with spending under restricted quantity) is, in the end, compensated by savings from Supplier I. Similar behavior is observed with Provider D, where more products from Suppliers I and IV are substituted by Supplier II for more favorable prices while unneeded lower-cost products are then purchased from Supplier I to attain a better tier.

We compare the solutions under restricted and unrestricted purchasing quantity and note that the additional savings at Providers C and D are mainly due to the significant price differences among products. For example, some products offered by Supplier I cost tens of thousands of dollars, while some cost only hundreds of dollars. The price difference between two tiers for a high-cost product could be over a thousand dollars; thus, it is well worth buying more lower-cost products to improve the tier, even if the products are not needed.

Table 6 Additional savings and changes in purchasing quantity when the amount purchased may exceed the demand

	Additional annual savings		Quantity required	Quantity purchased
	$'000	%		
Provider A	$0.2	0.1%	18	20
Provider B	$37.4	2.4%	117	118
Provider C	$231.2	3.8%	342	528
Provider D	$292.0	2.7%	598	952

Fig. 4 Comparison of current spend, optimized spend with restricted quantity, and optimized spend with unrestricted quantity



4.4 Product Substitution Decision

In this section, we review the product substitution decisions summarized in Table 7 and further analyze the results presented in Figure 4. The proposed model identifies which substitute products reduce costs and to what extent the cost can be minimized. Provider D, for example, currently purchases 105 different products from five suppliers, and about half of those products have substitutes. By moving to substitute products on 31 of them, Provider D can potentially reduce procurement costs by 13%. In the case of Provider A, 10 out of the 12 products have substitutes, and by opting for substitute products on six of the 10 products, Provider A can save up to 35% on the supply cost.

From Table 7, we find that standardizing products to a smaller number of SKUs may not necessarily result in lower cost procurement under the current contracting structure. Provider A presently uses 12 different products and after optimization, the number of SKUs remains the same. The optimal number of SKUs with Providers B, C, and D is less than the current number of SKUs that they are carrying, but the reduction in product variety is insignificant. From Figure 4, we observe that standardizing to fewer suppliers could potentially reduce procurement costs for smaller healthcare providers (such as A and B) but this strategy may not be feasible for larger providers (such as C and D). This may be explained by the relatively low product variety in smaller providers, which makes it easier to identify substitute products and more achievable to reduce the number of suppliers.

In the proposed model, we allow the demand for a product to be partially substituted and to be substituted by multiple suppliers. This might occur when the purchasing quantity is restricted to the demand. Substituting a product with different products certainly contradicts product standardization effort and adds additional complications to product management. This could be avoided by removing the quantity restriction constraint.

Table 7 Number of products before and after optimization

	Provider A	Provider B	Provider C	Provider D
# of different products currently used	12	42	84	105
# of products that could be substituted	10	27	44	50
# of products substituted under quantity restriction	6	17	13	31
# of products after optimization under quantity restriction	12	38	80	99

4.5 Quantify the Impact of PPIs

To account for physician preferences, the following constraint is added to the model.

$$\sum_{k \in K_s} x_{hik}^{s} \geq \theta_{hi} \qquad \forall h \in H,\ s \in S,\ i \in I_s \qquad (24)$$

where θ_{hi} is the forecast demand for PPI i at hospital h, $\forall h \in H, i \in I$.

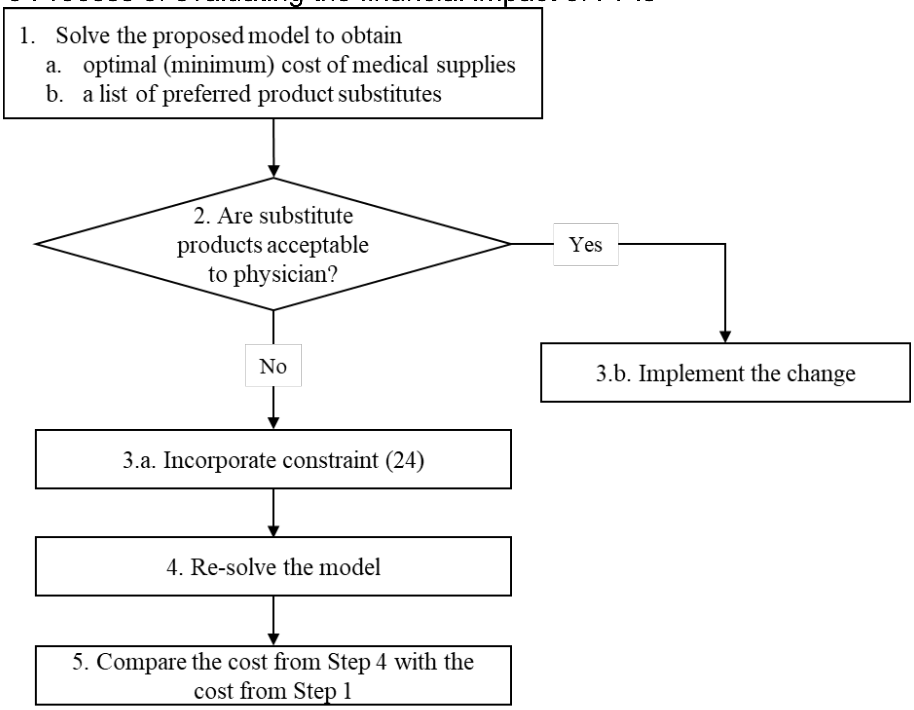
In most cases, a hospital's demand for item i (d_{hi}) is equivalent to θ_{hi}. The use of θ_{hi} accommodates the situation where one physician prefers item i but another physician is indifferent to using this item, so partially substituting item i could provide a cost-saving opportunity. From Table 7, not all PPIs have substitutes or inflate the procurement cost; for example, only 44 out of the 84 items used by Provider C have substitutes, and only 13 of those 44 items impact the procurement cost. These 13 items span over four product series in the heart valve category. To evaluate the impact of a PPI on material cost, we include constraint (24) for each of the four product series one at a time. The results (as shown in Table 8) confirm that the impact of PPIs on costs varies, ranging from less than 1% to over 13%. The PPIs in product series 3 alone could affect 13% of supply costs. In contrast, the PPIs in product series 1 and 2 only have a marginal effect, and may not warrant the effort to onboard substitute products in the near future.

Figure 5 describes a process of evaluating the financial impact of PPIs. By solving the proposed model without PPI restrictions, healthcare providers obtain an optimal (minimum) supply cost, which could be used as a benchmark in evaluating the impact of PPIs. For the scope to be manageable, we suggest limiting product substitution to the target list of products identified at step 1 (in Figure 5) and incorporating constraint (24), one at a time, for each product or a product series that is physician preferred. This prevents additional products from being substituted when restricting certain products as PPIs, which may simplify the review process for healthcare providers.

Table 8 Impact of PPIs

PPIs in	Impact on the total supply cost (% increase over optimal cost)
Product Series 1	0.98%
Product Series 2	3.25%
Product Series 3	13.10%
Product Series 4	0.17%

Fig. 5 Process of evaluating the financial impact of PPIs



4.6 Discussion

Our research identifies three levels of savings in material acquisition costs through price validation and procurement optimization under the agreed tier contracts. The first source of savings is from auditing the tier prices applied to the current purchases. Presently many healthcare organizations cannot effectively validate whether all purchasing prices are correct due to the complex and diverse nature of tier contracts. The proposed model helps identify the least-cost tiers for which hospitals in a health system qualifies. This process does not require the adoption of alternative products or make any changes to PPIs, but is shown to deliver more than 3% savings in procurement costs in the case studies for some health systems.

The second source of cost savings is from optimizing supplier selection and quantity allocation with the proposed model to take advantage of the complex volume discounts offered in tier contracts. This process is shown to reduce medical supply costs by up to 35% by identifying the items for substitution and the substituted items. For the PPIs that are candidate for alternative products in order to lower the total procurement costs, the proposed model enables hospital executives and physicians to compare the costs with the alternative products. From the research by Guzman et al. (2015), this is critical to motivate physicians to use alternative products without implementing any incentive or punitive measures.

The third source of cost savings is from buying more than the expected demand to exploit the tiered pricing. Unit-market-share-based tier contracts, coupled with large price gaps among different products, present an opportunity to achieve lower total cost by “over” purchasing some (usually less expensive) items. This strategy, however, may require careful considerations as over-purchased items will require handling and additional storage space. And for items with short lifespans, the disposal cost and the environmental impact must also be accounted for.

5. CONCLUSIONS

In response to the growing calls for reducing operational costs in the U.S. health systems, especially medical supply costs, we present a decision model and a method to validate and optimize medical supply procurement decisions, and to identify the “critical” PPIs by quantifying their financial impacts. The model formulation and findings from this study offer several new insights to hospital procurement and contracting. First, we demonstrate that mathematical programming has the potential to (i) address the high acquisition cost of hospital supplies, and (ii) facilitate the standardization of PPIs by informing physicians the financial implications of PPIs. Second, we show that not all PPIs inflate the procurement costs; the impact of a PPI ranges from none to 13% on the total cost of a clinical product category. Third, contrary to the general belief that supplier concentration may reduce material acquisition costs, we observe mixed results with some healthcare providers benefiting greatly from fewer suppliers while other providers are better with a larger pool of suppliers. This requires GPOs to have a tailored solution to its member healthcare providers. And finally, results show that the least acquisition cost option is not necessarily a result of decreasing product variety and that the current contracting structure may not encourage product standardization which hospitals have been trying to achieve. This calls for a better alignment of procurement contracts with a healthcare organization’s operations and development strategies.

Our research, while addressing a practical topic important to the healthcare sector, has some limitations that may be addressed in future research. First, the impact on supply costs and the sourcing strategy of different pricing schemes, particularly, spend-based and volume-based market share tier pricing, is unclear and would benefit from further research. Second, our approach addresses deterministic demand. Future research could extend the model to consider stochastic demand in a multi-period setting. Finally, the proposed decision model optimizes procurement decisions for health systems without considering potential counterstrategies from suppliers. A holistic approach to maximizing the joint profits of suppliers and health systems would offer valuable insights into the healthcare supply management literature and practice.

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DECISION SCIENCES INSTITUTE

Using Problem-Based Learning (PBL) Continuum in Teaching Governmental Accounting

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ABSTRACT

Several accounting professional organizations have emphasized the need for students entering the business/accounting profession to be able to solve problems, communicate, work on teams, and do analytical thinking. To incorporate these professional skills into the Governmental Accounting course, six continuum PBL approaches (e.g., problem-initiated learning) have been successfully used at several universities in different regions of the country. The PBL projects/cases were located/created using the Backward Design method (e.g., starting with the accounting professional skill sets). An educator can use one or more of these teaching approaches to assist students in learning.

KEYWORDS: Governmental accounting course, Problem-based learning, Backward design

INTRODUCTION

Several accounting organizations and committees have advocated change in accounting teaching approaches and curriculum for more than three decades. Recently, a set of skills-based competencies that are necessary for accounting students (public/industry/government/ not-for-profit) who are starting their professional career has been recommended by the *AICPA Pre-Certification Core Competency Framework* (2019) [AICPA 2019 Framework]. In addition, skills that are considered necessary for managerial accountants were endorsed by the Association of International Certified Professional Accountants in their *CGMA Competency Framework: 2019 Update* (2019) [CGMA Framework]. Also, the International Federation of Accountants (IFAC) identified professional skills that are essential for individuals desiring to enter the accounting profession in its International Education Standard 3 (IES3), *Professional Skills and General Education* (2019). Further, the Pathways Commission (2015) encouraged approaches or learning experiences that are expected to inspire students to think, perform, and make decisions that are comparable to the decisions of accounting professionals. Several teaching approaches (e.g., problem-based learning) are presented in this paper that can be utilized in teaching a Governmental Accounting course.

One of the characteristics of signature pedagogy specified by Schulman (2005, pp. 56-57) involves learning experiences that ensure students are active and interactive. According to Jackson and Durkee (2008), to assist students in attaining the critical professional skills, the instructor's task needs to become a facilitator of active learning (e.g., problem-based learning) from merely being a presenter of facts. Also, Bandura and Lyons (2012) recommended that instructors should incorporate different learning approaches (e.g., lecture, problem-solving, or problem-centered learning) in their courses. Further, Wessels (2010) suggested that the instructor’s primary role is to motivate students to use learning activities (e.g., problem solving learning) that will result in the desired learning course outcomes.

THEORIES

Learning Theories

Taylor and Hamdy (2013) stated that “learning” involves the acquisition of domains (i.e., knowledge, skills, and attitudes). Ideally, any learning theory should encompass each of these domains. Presently, adult learning theories can be divided or clustered into groups or categories (e.g., instrumental theories, humanistic theories). There can be, however, some overlap between theories and clusters of theories. Further, it has been inferred that learning commences with the learner’s existing knowledge [e.g., Vygotsky (1997), Taylor and Hamdy (2013)].

Instrumental Learning Theories

Instrumental learning theories focus on individual experiences in learning. This group covers cognitive, behavioral, and experiential theories. Behavioral theory entails competency-based training or learning, which results in a change in behavior. Skinner (1954) is a well-known behavioralist.

Cognitive theory relates well with the concept that learning begins with the learner’s existing knowledge. However, Taylor and Hamdy (2013) have indicated that the new knowledge must be sufficiently similar to previous knowledge to permit its relevance to be recognized. For example, students can tie the modified accrual basis of accounting used by governmental funds to the full accrual basis of accounting reflected in financial statements prepared under GAAP.

The experiential learning theory [e.g., Bruner’s (1966) and Davidson’s (1990) discovery learning] is included in the instrumental learning cluster. Under this theory, the students’ role includes active participation (engage) in experiences that construct their knowledge base. The experiential theory appears to be applicable to accounting education since it places emphasis on the development of competencies (e.g., governmental accounting topic(s), problem solving) and integrates skills of practicing accountants (e.g., decision making, communication) in stipulated situations.

Humanistic Theories

Humanistic theories promote individual development such as self-actualization and internal motivation [e.g., Knowles’ (1988) ‘‘andragogy’’ concept]. This group of theories is learner centered (i.e., self-directed learning). Self-directed learning focuses on adults who are planning, conducting, and evaluating their own learning. However, as pertaining to students, Norman (1999) and Hoban et. al. (2005) implied that it really should be “directed self-learning” instead of “self-directed learning.” Directed self-learning, which can inspire students to take more responsibility in their own learning, could prepare students for life-long learning as advocated by various organizations such as the CPA Vision Project (2017), Pathways Commission (2014), International Federation of Accountants [IFAC] (2019), and Association of International Certified Professional Accountants (2019).

Portions of the Instrumental Learning Theories and the Humanistic Theories are embedded in the Problem-Based Learning (PBL) teaching approach. PBL is student/learner motivated and involves directed self-learning (i.e., Humanistic Theories). PBL combines the Cognitive Theory by having the students utilize their existing knowledge when they recognize what still needs to be acquired or learned and the Experiential Theory when the instructor coordinates the students' activities to generate the desired learning experience (i.e., Instrumental Learning Theories).

PROBLEM-BASED LEARNING (PBL)

Problem-Based Learning encompasses the principles that learning develops from cognitive and social interactions in problem centered situations (e.g., Evensen and Hmelo 2000; Savery and Duffy 2001). PBL is a learning technique that requires students to be actively engaged in collaborative team or group projects. Under PBL students have to take considerable responsibility for their learning. Bates *et. al.* (2013) indicated that PBL results in students becoming active learners in their learning and not passive recipients of information. This is precisely what the Accounting Education Change Commission (1990) endorsed.

Under the PBL approach the starting point for learning is a problem or query that the students endeavor to solve according to Boud (1985). The idea of the PBL concept is that students as they work on solving the problem or query will have to identify and search for the knowledge needed in order to attempt to solve the problem.

Bates *et. al.* (2013) suggested that the essential factors to attain the desired learning objectives is for both the students and faculty to comprehend how the learning process works and their roles in this process. Under the PBL approach, the learning environment should be aligned with the learning outcomes, which should give the foundation for independent learning.

Educator's Responsibilities

Albrecht and Sack (2000) implied that accounting educators need to assist students in the development of their ability-to-learn skills. In order to expedite learning using the PBL approach, educators need to (1) create the desired learning experience (e.g., project, case, module), (2) facilitate students access to the experience, (3) organize the experience and (4) provide feedback and assessment. In developing the project/case to use in the PBL approach, Wiggins and McTighe (1998) advocated using a process called the "Backward Design" (i.e., outcome-based approach). Under this method, the starting point is to identify the desired learning goal(s) of the project/case (e.g., starting with the accounting profession's learning objectives/elements). Next, the feedback and assessment activities should be established while designing a meaningful PBL project/case.

Student's Responsibilities

As mentioned previously, students should know their role in a PBL exercise and/or assignment. The role of learners according to the constructive learning theory is to actively participate in activities that construct their knowledge base. Taylor and Hamdy (2013) suggested that students while working on a PBL project should (1) expect to have to perform some searching for needed information, (2) expect to be mentally challenged, (3) construct new knowledge, and (4) hopefully have their perception, views, and beliefs supported and/or changed.

What are the benefits of utilizing the PBL approach? Allen (1992) indicated that this approach encourages the acquisition of generic or soft competences (e.g., problem solving, communication, teamwork), which are essential skills according to the Pathways Commission

Learning Objectives (2015), CGMA Framework Knowledge Areas (2019), and the AICPA Framework Core Competencies (2019 and 1999 versions). PBL can be used as a strategy to encourage deep learning by the students instead of surface learning. Further, the PBL approach should permit students to activate previous learning while permitting them to incorporate or link the new knowledge with their prior learning.

PBL Continuum of Approaches

Davis and Harden (2009) have implied that PBL is not solely one approach but rather a continuum of approaches to be used by educators in teaching (e.g., problem-assisted learning, problem-centered learning, problem-based learning). An educator can use one or more of these approaches in helping students in learning. According to Barrows (1986) the PBL approach selected to be used varies with the desired learning goals or objectives (e.g., development of self-directed learning skills; increase students' motivation to learn).

Research has suggested that instructors need to establish different learning opportunities to accomplish different types of learning objectives [Anderson (1995), Driscoll (1994), Gagné and Medsker (1996), Gredler (2009), and Schunk (2020)]. Boh *et al*. (2001) indicated that lecture-based training may not be an adequate transfer technique when complexity of knowledge is high. Bonner (1999, p. 11) suggested that "learning objectives involving complex skills require teaching methods that promote active learning on the part of the students, while learning objectives involving simpler skills can be achieved with more passive teaching methods."

Harden and Davis (1998) discussed the various PBL approaches based on the relationship between the scenario/problem and the learning that can be derived from studying that problem. These authors developed an eleven-step continuum between the problem and expected learning experience by the students (e.g., theoretical learning, task-based learning).

TEACHING USING PBL

To incorporate several of the Pathways Commission's Learning Objectives (2015), CGMA Framework Knowledge Areas (2019), IFAC's IES3 Professional Skills (2019), and the AICPA Framework Core Competencies (2019 and 1999 versions) into student learning experiences, the authors have utilized several of the continuum PBL approaches in teaching Governmental Accounting. The continuum of PBL approaches have been successfully employed in teaching Governmental Accounting at several universities (e.g., large urban, regional state, small state) in different regions of the country (e.g., Illinois, Colorado, Texas) are presented below.

Theoretical Learning Approach

During the first day of the Governmental Accounting class, students are introduced to PBL by first using the Harden and Davis (1998) "theoretical learning approach" and then their "problem-assisted learning approach." Since most of the students will not have acquired the textbook and very few of the students will have read the required chapter, the educator uses the "theoretical learning approach" (i.e., traditional lecture). The educator uses PowerPoints for about ten minutes to introduce the students to the characteristics of governmental and not-for-profit organizations (NFP) and the authoritative bodies for NFPs, state and local governments, and federal government that they will need to do their first homework assignment.

During the first-class session, the students were informed that they will be held responsible to read the chapter for the next class period. In addition, they were told to prepare the assigned homework problems and to be ready to explain or justify their answers.

Problem-Assisted Learning Approach

Immediately after the PowerPoint presentation during the first-class session, the educator to further assist students in using PBL employed the "problem-assisted learning approach." The educator selected a multifaceted problem or a series of brief exercises from the textbook to help the students first in identifying keywords or features in the problem situation that may be useful in answering the question(s) (e.g., general purpose government, special purpose government). The educator suggested to the students that as they read the problem information, they should underline or highlight the word(s) or dollar amounts that may have an impact in answering a section of the problem(s).

After emphasizing the keywords in the problem, the educator asked the students what characteristic or responsibility may apply to the situation (e.g., operational accountability, fiscal accountability). Next,the students were asked to discuss with neighboring classmates what they think should be the answer(s) considering facts stated in the particular situation. Finally, a volunteer was asked to give their conclusion and the reasoning for the answer. This approach is utilized each time to introduce the students to new topics in the subsequent chapters in the textbook.

Problem-Solving Learning Approach

During the second-class session, the educator introduced the students to the next step in the Harden and Davis (1998) PBL continuum (i.e., "problem-solving learning"). Under this approach, the students orally present their justification or reasoning along with the calculation procedure for each problem/situation to their classmates. This permits the students under friendly conditions to start to improve their oral communication skills as recommended by the AICPA Framework (2019), CPA Vision Project (2017), Pathways Commission (2015), IFAC's IES3 (2019), and CGMA Framework (2019). The problem-centered learning approach is utilized for most class sessions during the semester.

Note: To hold each student accountable, they were previously informed that each student must give an answer or explanation each class period on a voluntary basis and if necessary, by using at the end of the class period the "army volunteer basis." To persuade the students to participate, about 4% of their grade is based on cheerfulness and quality of class discussion by each student.

Problem-Initiated Learning Approach

The problem-initiated learning approach is another type of PBL assignment that can be used in governmental accounting classes. Under this approach, the problem or project should act as a trigger to start the students learning on the assigned topic(s) according to Harden and Davis (1998). This approach can be used as either a team or individual student project. This learning approach has been integrated into the governmental accounting course a couple times a semester (i.e., Topic Project, Journal Article Project).

Topic Project

The students are given once a semester an outside of class problem-initiated learning assignment (i.e., Topic Project) to be completed in one week by each student. The students received a governmental accounting topic [e.g., general capital assets; capital projects funds; internal service funds; enterprise funds] to organize before any class discussion on that topic.

This Topic Project was assigned to encourage the students to learn how to organize topics, which is one of the skill sets (i.e., ability to organize information) recommended by the AECC (1990) and AICPA Framework (1999). The Topic Project enabled each student to organize the topic(s) using a checklist, chart, graph, grid, flowchart, outline, or other approach that will help them understand the assigned topic(s). The AICPA Framework (1999) specified the need for accounting professionals to express information and concepts in a clear and concise written manner. As a result, the Topic Project was limited to 1 1/2 pages in length.

Journal Article Project

After completing the Topic Project, the students were requested to read an assigned recent professional journal article (e.g., from the Journal of Accountancy). Since the selected article should be of interest to the students, this should help them become interested in learning the topics discussed in the article.

The Journal Article Project required each student to summarize the article, indicate how it relates to their governmental accounting course, and discuss the most pertinent information in the article in 2 to 3 pages. Further, this assignment could be expanded by requesting a team of students to find a recent journal article on their assigned selected topic (e.g., financial statements, fiduciary activities, performance effectiveness) to be presented in class, which permits experience in oral communication.

Problem-Centered Learning Approach

After the students start to feel comfortable using the Problem-Solving Learning Approach, they are assigned a project that involves the Problem-Centered Learning Approach. Under this approach, preparation of the project introduces the students to principles or specific procedures or rules (e.g., GASB ASC) related to completing the accounting cycle of a city (i.e., Computerized City Cycle Problem Project). This project was expected to be completed outside of class throughout the semester. Teams of three to four students worked on the City Cycle Problem Project (CCP Project).

To make sure that each team was making satisfactory progress on the CCP Project, each team was required to hand in their project eight times during the semester. Further, the educator encouraged the students to ask questions about the project before and after class, in an email, or during office hours.

Problem-Centered Discovery Approach

As previously discussed, Bonner (1999) believes that learning complex topics requires teaching techniques that have the students actively learning by discovering the answer. When the topic being taught is complex (e.g., bonds), another PBL approach needs to be employed in place of the problem-solving learning approach. In this case, the problem-centered discovery approach could be applied. In this situation, the educator could utilize an instructor-prepared checklist along with a complex textbook problem in class to assist the students to discover or rediscover and organize a complex topic (e.g., cash flows from operating activities).

Under the problem centered discovery learning approach, the students by using the checklist could discover or refresh their memories of the cash flow classification for each transaction or situation in the problem. Then, the students could use this checklist to recall or discover (i.e., determine) the classification treatment (i.e., increase or decrease in cash flows) for the specific transaction before the transactions' information data is entered in the appropriate cash flow statement category (e.g., operating activities, investing activities). After all the transactions have been classified and entered under the appropriate category (e.g., capital and related financing activities) as an increase or decrease, the students can remember or discover how each of the transactions affect cash flows. Finally, the students can reflect or discover after netting the various cash flow categories that the ending cash balance on the Cash Flow Statement is the same dollar amount balance as in the ledger Cash account. It was suggested to the students to utilize the checklist in doing their homework assignments and preparing for the quiz/exam on the topic(s).

RESEARCH METHODS

One of the limitations of educational research that is performed at only one university is whether the results will apply to other university settings. Accounting educators should be interested in teaching techniques or methods that might be successfully applied in different university environments. The continuum of PBL approaches used in teaching Governmental Accounting in this research have been utilized at several universities (e.g., large urban, regional state, small state) in different regions of the country (e.g., IL, CO, TX). At several of these universities, English was the second language of the students (i.e., 30% - 95%). In addition, at some of these universities, the students were of diverse backgrounds. All of the governmental accounting classes studied were taught by one of the researchers.

At the beginning of the semester, the students were requested to complete a personal data sheet (e.g., classification, university GPA, accounting GPA, credit hours enrolled, work hours, number of accounting course(s) enrolled in during that semester, number of previous accounting courses, and gender). There were no significant differences between the two experimental groups (Project Topic A and Project Topic B) on the reported demographic information at any of the universities.

Topic Project

Every other student in the class was assigned to Group A. In Group A the students were asked to prepare a project to assist them in learning about Project Topic A (e.g., general capital assets [GCA]). On the same day, the other students in the class (Group B) were asked to prepare a project to assist them in learning about Project Topic B (e.g., capital projects funds [CPF]). The students in both groups were told they could use a checklist, chart, graph, grid, flowchart, outline, or other approach that would help them understand the topics. The project was not to be more than 1 1/2 pages in length. The students were given one week to prepare the project. The students were instructed to make copies of their projects, which were to be used in preparing their homework assignments related to the topics. Both groups received the same class discussion and were assigned the same homework problems for these topics.

To motivate the students to complete the project, the project was assigned 25 points, which represented about 4 percent of their grade. The Topic Project was graded based on (1) how beneficial their project would be in doing their homework assignments and preparing for the quiz/exam (e.g., if there was sufficient information presented to earn an "A" on the quiz/exam, the students received the entire 25 points), (2) how well organized the information was presented, and (3) how creative was the presentation of the Topic Project. This creativity factor was employed to encourage the students to think outside of the box (i.e., outline presentation) and attempt to use other methods of organization (e.g., a flowchart).

Testing

About two weeks following the discussion of the homework problems on these topics, a common exam (Exam II) was administered. In the class period before Exam II, the instructor suggested that the students use their projects to help them study for this exam. On this exam there were 11 points related to the GCA topics and 12 points pertaining to the CPF topics. The results of this exam were used to measure the effect of this teaching technique.

RESULTS

As previously mentioned, the students in various locations (e.g., IL, CO, TX) took Exam II, which was used to determine the effectiveness of their Topic Project. The results of Exam II at two of these universities will be discussed.

Exam II

The students with the Topic Projects at University B scored higher than the students without this project for both the GCA Project topics (77.3% > 64.5%) and for the CPF Project topics (75.0% > 67.4%). However, for University A, there were different results depending on the project assigned. For the CPF Project, like the Topic Projects at University B, the students with the project scored higher than the students without the project on the CPF questions (73.8% > 66.7%), but for the University A GCA Project, the students without the project scored higher than those students with the project. However, the chi-square test indicated that the effect of the Topic Projects' results was not statistically significant.

If a teaching technique or method is to be beneficial to accounting educators, it should have similar results at different university situations. Also, the Topic Project Exam II score at both universities for both the GCA Project and the CPF Project were similar (ranging from 78.8% to 73.8%). The GCA Project Exam II percentage score results were very similar. The same was true of the percentage score for the CPF Project at both universities. However, the GCA Project scores at both universities were slightly higher than the CPF Project scores. Except for the score for the No Project at University A, the No Project scores for both Topic Projects were similar (ranging from 67.4% to 64.5%). Therefore, it appears that the Topic Projects can be used to successfully teach selected governmental and NFP accounting topics.

SUMMARY

The AICPA, CGMA, IFAC, and the Pathways Commission have all specified the need for accounting students entering the profession to be able to solve problems, work on teams, communicate in writing, and show leadership. The question accounting educators face is how can these learning objectives, knowledge areas, professional skills, and core competencies be integrated into accounting courses (e.g., Governmental Accounting)?

To undertake this, adult learning theories embracing instrumental theories (e.g., cognitive, behavioral, experiential) and humanistic theories (e.g., self-actualization, internal motivation) were investigated. Parts of both of these learning theories are assimilated in the Problem-Based Learning (PBL) teaching approach.

The researchers discussed six of Davis and Harden's (2009) eleven-step continuum PBL approaches (e.g., problem-assisted learning, problem-centered learning, problem-centered discovery learning) that have been successfully employed at several universities in different regions of the country in teaching Governmental Accounting. As recommended by the Accounting Education Change Commission [AECC] (1990), students should become active learners not passive recipients of information according to Bates *et. al.* (2013).

In the preparation of this Project, the students were active participants in the learning process as suggested by the AECC (1990). In addition, the Topic Project was beneficial because the Project did give the students experience in organizing information as recommended by the AECC (1990). Further, the Topic Project gave the students an opportunity to improve their written communication skills as recommended by the Pathways Commission (2012) and the International Federation of Accountants in IES3 (2008).

Since there are definitely several PBL approaches that can be easily integrated into Governmental Accounting and other accounting courses, why not try using one or two of these approaches next semester?

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Who speaks? Individual and institutional predictors of CEO activism

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ABSTRACT

CEOs increasingly take public stands on social and political issues tangential to their corporation's core mission. Emergent research on this phenomenon has explored the prevalence, impacts and risks of increasing CEO activism for firms. However, very little research has explored the individual and institutional factors that motivate CEO activism. This project attempts to refocus this nascent field by exploring the gendered, racial, sexual and organizational factors that motivate leaders to speak out on issues ranging from DEI, gun control, climate change, Black Lives Matter and #MeToo.

KEYWORDS: women CEOs, CEO activism, women on boards, diversity, inclusion

INTRODUCTION

The public role of corporate CEOs has evolved in recent years. Increasingly, CEOs of major companies taking public stances on controversial political and social issues not necessarily related to core business needs, a phenomenon termed CEO activism (Chatterji and Toffel 2016; Hambrick and Wowak 2021). Corporate leaders have long sought to influence the political process. Companies routinely pursue political influence through lobbying, political contributions and other means of influencing policy outcomes so as to support and advance their core business interests on issues ranging from deregulation to labor issues to tax benefits (Hillman, Keim and Schuler 2004; Lawton, McGuire and Rajwani 2013). The evolution of the public role of CEOs represents a shift from relatively covert forms of political engagement around traditional business issues to highly visible forms of political engagement on controversial social issues, including gun control, immigration, racial justice and LGBTQ+ rights.

The increasing political activism of CEOs represents a response to and shift in changing expectations and demands for public figures, including corporate leaders (Chatterji and Toffel 2018). While the rise of CEO activism has been criticized as superficial, duplicitous and even politically dangerous (Ramaswamy 2021; Rhodes 2021), analyzing this phenomenon is important for understanding the evolution of corporate power generally and CEOs specifically.

Existing research on CEO activism centers on two key questions: what factors are driving the increasing prevalence of CEO activism and what are its consequences for public opinion and firms? Must less research has centered on the predictors of *who speaks* on controversial political issues. In their recent review of this field, Branicki et al. (2021) suggest that the field lacks theoretically motivated empirical analyses of the predictors of activism. The current study responds to this call to advance the field by examining the individual and institutional predictors of CEO activism. We seek to bridge research on non-traditional CEOs, including women, racial/ethnic minority and LGBTQ+ corporate leaders, with research on CEO activism by exploring whether gender, race, and sexuality shape the likelihood of speaking out on controversial political issues.

To analyze whether historically underrepresented CEOs are more or less likely to engage in CEO activism, we rely on data on CEO activism among CEOs in the S&P 1500 between 2015 and 2018 and in the Fortune 500 and S&P500 between 2019-2021. We find that women CEOs are more likely to engage in activism compared to men CEOs and that, among women CEOs, BIPOC and LGBTQ+ CEOs are most likely to speak out. We also find that CEOs of larger firms and firms with gender diverse boards are more likely to engage in activism compared to other CEOs. We discuss the implications of these findings for the appointment, tenure and visibility of underrepresented CEOs.

Drivers and Impacts of CEO Activism

To understand the spike in CEO activism in recent years, scholars have analyzed factors that may be driving the evolution in CEO's public engagement with political issues. Research has identified changing social attitudes and expectations as facilitative of CEO activism.

Surveys of young people consistently document growing expectations that CEOs have a responsibility to speak out on important issues. In the U.S., over 70% of millennials strongly favor CEO activism (Larcker et al. 2018). Thus, CEO activism—including but not limited to statements expressed through social medial channels—may be viewed as a means of connecting with new stakeholders. Indeed, there is mounting evidence that CEO activism may positively influence current and potential workers and customers. Voegtlin et al. (2019) found that CEOs who take a position on current political issues may increase young professional's desire to work for their company, while Mkrtchyan et al. (2020) found that activist CEOs increase individuals' intention to apply for employment with the focal company. And there is evidence that consumers are more likely to purchase products from a company whose CEO is outspoken on issues important to them. Korschun et al. (2016) found that consumers' positive attitude toward a company is enhanced when they view the CEO's public stance as an extension of the company's values.

In addition to tracing the factors influencing the spike in CEO activism, scholars have also begun to identify the real and potential risks and rewards associated with this phenomenon (Brown et al. 2020; Bedendo and Siming 2020; Chatterji & Toffel 2019; Mkrtchyan et al. 2021). Recent experimental evidence suggests that CEOs may actually influence public opinion and improve consumer attitudes, thereby enhancing the overall reputation of the firm (Chatterji and

Toffel 2019). Chatterji and Toffel (2019) suggest that CEO activism may serve as a signal to the public that galvanizes support and generates positive attitudes toward the company. Research also finds that CEO activism may result in positive market returns and higher valuation, thereby potentially enhancing CEO job security and future opportunities (Mrtchyan, Sandvik and Zhu 2020).

Despite these potential rewards, CEO activism is not without risk (Chatterji and Toffel 2018). Though still in early stages, research on CEO activism finds that engagement with political and controversial issues may lead to negative responses by employees, consumers and shareholders alike. Emergent research finds that when employees disagree with a public position taken by the CEO, workplace culture can be negatively impacted in ways that harm recruitment and retention and increase turnover (Babenko et al. 2020; Brown, Manegold and Marquardt 2020).

CEO activism can also result in negative market reactions, placing the firm at risk of consumer boycotts and/or shareholder or board sanctions (Diermeier 2012). Bedendo and Siming (2020) analyzed the market response to CEOs who publicly resigned from then-President Trump's advisory council in 2017 in response to inflammatory statements regarding the white supremacist violence in Charlottesville, Virginia. Several CEOs who resigned did so by making a public statement condemning the violence in Charlottesville. The companies of those executives experienced a negative market reaction due to shareholder fears that their resignations would reduce the political influence of the firm (Bedendo and Siming 2020). Though the authors found no such negative market response to more muted actions, such as signing a collective letter, the highly visible and politicized nature of the resignations proved risky for firms. Finally, scholars have suggested that CEOs who wade into controversial political topics risk backlash that challenges CEO's authenticity, legitimacy and credibility (Gregory 2020; Gaines-Ross 2016).

Individual & Institutional Predictors of CEO Activism

Various approaches to understanding why CEOs engage in activism have been offered (Acharya and Adebe 2021). The first perspective posits that CEO activism is an expression of the personal morality or political convictions of CEOs (Bedendo and Siming 2020; Korschun et al. 2016; Chaterji and Toeffel 2018). Thus, CEOs who speak out do so because they feel passionately about and issue. The second perspective, Hambrick and Wowak's (2021) stakeholder alignment model, connects individual motivations to leaders' perception of the alignment of their own views with that of key stakeholders. Hambrick and Wowak (2021) posit that while activism may stem primary from CEO's personal convictions, public expressions in support of or against a political issue is "facilitated (or suppressed) by the CEO's expectations of support from stakeholders, particularly employees and customers" (pg. 33). Thus, CEOs may take positions so as to associate their company's brand with certain values (Leak et al. 2015), enhance the retention of key employee groups (Branicki et al. 2021) and/or signal a certain value orientation to shareholders (Mkrtchyan et al. 2020).

While these perspectives have merit, we seek to analyze CEO activism as a contingent and heterogeneous phenomenon that varies significantly by institutional context (Branicki, Brammer, Pullen and Rhodes 2021). While all CEOs have political views and convictions, not all CEOs articulate those views publicly. Similarly, extant research has not yet demonstrated that CEOs who speak publicly necessarily are doing so in ways that align with the views or preferences of key stakeholders. Instead, there is mounting evidence that CEO identity as well as key institutional factors can shape the probability and consequences of activism. For example, Melloni et al. (2019) find that activism that is perceived as an expression of CEO values is viewed as more credible compared to activism that is perceived to be profit-orientated. CEO activism that is viewed as inauthentic risks reducing the legitimacy and the credibility of the

CEO. (Melloni et al. 2019). However, the identity of the CEO combined with the relationship of the issue to the identity of the firm can enhance the perceived credibility of CEO action (Gregory 2020; Gaines-Ross 2016).

Taken together, this emerging research suggests that the probability and impact of CEO activism is highly contingent on individual identity, status and institutional context. We build on this emergent field by developing and testing a model of CEO activism that draws on token theory and Puwar's bodies out of place perspective. Specifically, we consider how the risk burden, hyper visibility and unequal expectations facing non-traditional CEOs, including women, racial/ethnic minority and LGBTQ+ CEOs, may enhance the pressures these leaders face to engage in activism on key issues.

Toward an Institutional Model of CEO Activism

Kanter's (1977) classic theory of tokenism articulates the challenges numerical minorities face in work organizations. According to token theory, the experience of being a solo or token includes surveillance, scrutiny, performance pressures and a burden of doubt with regard to competence and ability (Kanter 1977; Wingfield 2013; Bell and Nkomo 2003). Such pressures are exacerbated for individuals who achieve highly visible leadership roles (Glass and Cook 2020); as the spotlight gets bigger, so too does the intense scrutiny. Research finds that white women and men and women of color CEOs often experience performance pressures, resulting in a perceived standard of perfection for professional deportment and performance (Glass and Cook 2021). Such leaders are also often viewed as "agentically deficient", lacking the skills and experience necessary to lead effectively (Eagly and Karau 2002; Rosette et al. 2016).

While Kanter's theory of tokenism elaborates the scrutiny and pressures non-traditional leaders encounter, Puwar's (2004) space invaders perspective suggests that status as well as representation shape the experience of professionals from historically underrepresented groups. According to Puwar, the entrance of non-traditional incumbents – including women, people of color and LGBTQ+ individuals – into traditional professional settings represents a disruption of the status quo that results in amplified scrutiny, suspicion and doubt. Such individuals are visibly invisible in that they are highly visible for their difference but relatively invisible for their competence, experience and capability. Settles et al. (2019) refer to this tendency as the experience of being "scrutinized by not recognized" by peers, superiors and other stakeholders.

As a result of these pressures, non-traditional leaders must navigate their roles in ways that avoid reinforcing stereotypes and negative evaluations while establishing their credibility, legitimacy and commitment to the organization. While these pressures often limit the mobility of non-traditional individuals into senior leadership roles, leaders who overcome these challenges must navigate their roles in ways that accommodate the oft competing and contradictory expectations of a range of stakeholders.

One of the mechanisms that enable these leaders to achieve legitimacy as leaders is by undertaking a significant risk burden. Research finds that leaders from historically underrepresented groups must seek high-risk appointments, assignments, and roles to demonstrate their competence and capability as leaders, a phenomenon termed the risk tax (Glass & Cook 2019). These leaders perceive that recognition of their leadership mettle is dependent on their ability to prove their competence again and again by taking on the riskiest jobs. Consistent with these findings, research finds that white women and men and women of color are more likely to be appointed CEO during times of crisis compared to white men, a phenomenon termed the glass cliff (Ryan and Haslam 2007; Cook and Glass 2014). Crisis appointments serve to enhance the hyper visibility and scrutiny these leaders face. While often serving as the first or one of the first CEOs of their demographic, they are expected to lead the firm out of crisis and/or to restore the firm's positive reputation. The glass cliff increases the risks these individuals face in leading the firms and navigating their organizations out of crisis.

Finally, there is mounting research that non-traditional CEOs face greater threat of shareholder activism and less investor support, factors that can greatly increase the risk and performance pressures they face (Cowan et al. 2021; Gupta et al. 2018)

These risk burdens combined with the hyper visibility and scrutiny these leaders face affect the expectations stakeholders have for the ways these individuals enact leadership. Non-traditional CEOs face expectations to do the “heavy lifting” of diversity work, including advocacy related to equity and inclusion as well as the often hidden, invisible and laborious work required to offset structural inequalities, what Choroszwicz and Adams (2019) refer to as “meta-work”. These expectations grow out of assumptions about that non-typical leaders more committed to diversity, equity and inclusion and thus expected to serve as stronger advocates in these areas. For instance, gender stereotypes hold that women are more altruistic and communal, thus women leaders are expected to engage in more humanistic and pro-social behaviors (Heilman and Chen 2005; Voegtlin et al. 2019). Similarly white women and men and women of color are expected to perform more diversity-oriented labor, which leads to their being channeled into community outreach and diversity management roles, which tend to be less valued and rewarded (Collins 1997). As a result of these expectations, these leaders often demonstrate a greater commitment to fairness and equity in practice. For instance, companies with women and people of color in senior leadership roles are more likely to have stronger records on family friendliness, environmental sustainability, LGBTQ+-inclusion, community engagement and good governance (Cook and Glass 2018; Glass, Cook and Ingersoll 2015).

We expect that the scrutiny and performance pressures that non-traditional leaders confront – combined with a greater burden engage in high-risk roles and to serve as an advocate for equity issues – will increase the probability that underrepresented CEOs will be more likely to engage in activism, particularly related to progressive social issues related to fairness, equity and inclusion. Intense pressures associated with token status will encourage non-traditional leaders to conform, assimilate and accommodate the expectations of diverse constituencies. To test this prediction, we posit the following hypothesis:

> **Hypothesis 1**: *CEOs from historically marginalized groups will be more likely to engage in political activism.*

While we expect token status and the burden of high and unequal expectations will enhance pressures to speak out on political issues, we also recognize that institutional factors, including status, visibility and leader support, will affect CEOs ability to engage in activism. CEOs of large companies often serve as the bellwethers of change and innovation. Indeed, many of the highly publicized examples of CEO activism center highlight CEOs of large, highly visible companies including Apple, Starbucks and Disney (Chatterji and Toffel 2018). Scholarly research finds that large, highly visible firms tend to initiate changes that are then adopted by smaller and less visible firms in the sector or field, a process termed mimetic change (Haveman 1993). Thus, we predict that firm status can enhance CEO visibility and influence and provide relative support for engaging in actions that fall outside the status quo.

Beyond firm size and value, CEO power and influence likely predicts the ability of CEOs—including non-traditional CEOs—to engage in activism (Bedendo and Siming 2020; Brown et al. 2020). Influence, seniority and organizational power are likely to facilitate CEO activism by reducing the potential risks of backlash. Thus, we test whether firm and CEO status predict activism:

> **Hypothesis 2**: *Among underrepresented CEOs, firm status and executive influence will increase the likelihood of engaging in activism.*

Finally, we expect that the degree of institutional support CEOs receive will enhance their willingness to engage in activism (Brown et al. 2020). Board diversity is associated with a range of organizational outcomes, including stronger corporate social responsibility, more diverse executive teams and stronger DEI records (Cook and Glass 2018). Board support is particularly important for non-traditional CEOs. For example, in firms with gender diverse boards, women CEOs are less likely to face glass cliff appointments and enjoy longer tenures (Cook and Glass 2014). Gender diverse boards are also more likely to enhance the performance of firms led by women CEOs (Cook and Glass 2015). Therefore, we test the influence of board composition on CEO activism:

> **Hypothesis 3:** *Gender diverse boards will increase the likelihood of underrepresented CEOs engaging in activism.*

DATA AND METHODS

Procedure

As a precursor to our primary research study, we first conducted an exploratory study of random women and men CEOs in the S&P 1500 between 2015 and 2018. The large random sample resulted in 1224 men and 62 women. Using the Proquest Newsstand Database, we searched the CEO name, the company name, and various social issues that were prominent at that time. Specifically, we searched for gun control, LGBTQ+, immigration, equal pay, and climate change. We coded each issue as to whether the CEO had made a public statement about it or not. Our searches were quite exhaustive in that we inputted iterations of the CEO's name and company to ensure all appropriate articles would be found. The Proquest Newsstand Database is one of the most comprehensive news databases available with all of the major news sources in the United States represented.

We conducted the exploratory study to determine if there was a difference between men and women CEOs with regard to speaking out on political issues. A marginally significant difference was found (p=.084) indicating women CEOs were slightly more likely to speak out than men CEOs. With this difference, we pursued an in-depth analysis of women CEOs and the institutional factors of their organization. We also updated the social issues under consideration. For example, the tragic death of George Floyd had not occurred when we conducted our initial collection, yet the prominence of the Black Lives Matter movement has been undeniable the past few years. Hence, we searched for Black Lives Matter (BLM), D&I (diversity and inclusion), gun control, climate change, Capitol riots, voting rights, and the Me, Too movement.

To investigate our research questions, we examined women CEOs of the Fortune 500 and S&P 500 between 2019 and 2021. This resulted in 58 total women. As with the exploratory study, we used the Proquest Newsstand Database to search for the social issues and the women CEOs. We inputted iterations of their names and firms to ensure all appropriate articles were found. For instance, Susan Patricia Griffith is the CEO of Progressive Insurance. The name she goes by is Tricia. To ensure accuracy, we searched Susan Griffith, Patricia Griffith, and Tricia Griffith. For Lisa T. Su, the CEO of Advanced Micro Devices (AMD), we searched Lisa Su, Lisa T. Su, and Dr. Su since she is also holds a Ph.D. Since Advanced Micro Devices also goes by AMD, we used both in our searches. The same would be true for General Motors or GM. Simple calculations of CEO activism were possible with all 58 women; however, detailed analyses with company information was not available for nine of the women. The missing information is due to the fact that several companies are not publicly traded, and as such, the information is not publicly available. Hence, our sample size for the full analyses was 49.

Company information, CEO information, and board of director demographics were acquired from the CompuStat and ExecuComp databases available through WRDS at Wharton.

Specifically, we collected company information related to the size of the organization and its corresponding market value; we collected CEO information of age, tenure in the position, and duality of CEO/Chairperson; and for the board of directors, we collected the total number of women on the board. To assess additional demographic information for the CEO, we searched biographical websites to confirm underrepresented group membership. This resulted in three Black CEOs, three Indian CEOs, one Chinese CEO, one Taiwanese CEO, and one openly gay CEO.

Measures

The dependent variables are the individual social issues examined—gun control, Black Lives Matter, Me Too, Capitol riots, voting rights, diversity and inclusion, climate change—as well as the total sum of all those issues. For each issue, we coded a CEO speaking up or taking a stand as 1 and silence or no action as 0. The total sum was merely the addition of all 1s across each issue.

For our predictor variables, we examined CEOs from underrepresented groups, the number of women on the board of directors, the size and value of the firm, age of the CEO, CEO duality, and tenure of the CEO. Specifically, for Hypothesis 1, we examined factors that could lead to higher status. We examined the age and tenure of the CEO both coded as the actual number, the duality of the CEO coded as 1 if the CEO also served as the Chairperson of the Board, the size of the firm as determined by the number of employees and examined as the natural log of employees, and the market value of the firm as examined by the natural log of shares outstanding times price per share. We transformed both firm size and firm value to the natural log since the standard deviation of each was greater than the mean.

For Hypothesis 2, we coded underrepresented women CEOs as 1. As noted above, we have three Black, three Indian, one Chinese, one Taiwanese, and one lesbian CEO in the sample. CEOs from underrepresented groups may be more likely to be aware of issues even if those issues do not directly affect them. And for Hypothesis 3, the number of women on the board was coded as the actual number on the board. Having women on the board likely serves as a support to the CEO and may enable her to speak out on issues she deems important.

Analyses

We tested our hypotheses using Poisson and logistic regression. In analyzing the dependent variable that assessed the total sum of all issues examined, we used Poisson regression. Poisson regression is well suited for our total sum analysis since the dependent variable is a count variable. Also, we did not have an overdispersion of zeros, so Poisson regression was more appropriate than negative binomial regression for this particular analysis. For the analyses of the individual issues, we used logistic regression. Given our dependent variables were dichotomous, logistic regression was fitting. In our exploratory study, we used negative binomial regression. This proved to be the most appropriate analysis given the dependent variable was a count variable, and overdispersion was present.

RESULTS

Our analyses examine the following research questions. First, are women CEOs more likely than men CEOs to speak up on political issues. Second, in analyzing women CEOs, what factors lead to some women engaging in political activism more than other women. For the first question, we relied on a large random sample from the S&P 1500 companies. Our resulting sample included 1224 men and 62 women. Conducting a negative binomial regression (due to overdispersion), results suggest that women CEOs speak up slightly more than men CEOs

Cook et al. Women CEOs and Political Activism

Table 1. Descriptives and Correlations

Variable	n	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.CEO in Underrepresented Group	58	.15	.37	-----													
2.CEO Age	49	55	5.33	-.17	-----												
3.Tenure as CEO	49	4.51	4.11	-.02	.43**	-----											
4.CEO/Chair Duality	49	.24	.43	-.21	.35*	.49**	-----										
5.LN (Number of Employees)	52	3.32	1.68	.07	.10	-.28	-.04	-----									
6.LN (Market Value of Firm)	49	9.91	1.34	-.06	.06	.02	.05	.45**	-----								
7.Number of Women on the Board	49	3.45	1.60	.13	-.10	-.19	-.04	.48**	.03	-----							
8.BLM (Black Lives Matter)	58	.31	.47	.43**	-.27	-.02	-.17	.28*	.26	.29*	-----						
9.Capitol Riots	58	.07	.26	-.12	-.02	-.02	.00	.36**	.40**	.29*	.26*	-----					
10.Climate Change	58	.52	.50	.03	-.27	.08	-.15	.08	.36*	.21	.28*	.26*	-----				
11.Gun Control	58	.03	.18	-.08	.00	.03	.12	.18	.01	.07	.08	-.05	-.01	-----			
12.Inclusion	58	.71	.46	.07	-.36*	-.10	.02	.05	.21	.20	.35	.03	.52**	.12	-----		
13.Me, Too	58	.03	.18	-.08	.04	-.10	-.12	.06	.12	.07	.08	-.05	.18	-.04	.12	-----	
14.Voting Rights	58	.09	.28	-.13	-.08	-.16	-.04	.43**	.34*	.50**	.33*	.64**	.30*	-.06	.20	.28*	-----
15.Total Sum of Issues	58	1.76	1.41	.11	-.31*	-.06	-.11	.33*	.44**	.41**	.68**	.49**	.75**	.17	.70**	.30*	63**

(marginal significance at p=.084 with a beta of .53, standard error of .31, and an odds ratio of 1.7). Given this preliminary analysis, our second part examined women CEOs in greater depth. Descriptives and correlations of the in-depth analysis are presented in Table 1.

Our first hypothesis suggests that women CEOs who have higher status will be more likely to engage in political activism than women CEOs with lower status. We assessed status by the following measures: age of the CEO, tenure as a CEO, CEO/Chair duality, firm size as measured by the number of employees, and firm value as measured by the number of shares outstanding times the share price. Findings were mixed for this hypothesis. As illustrated in Table 2, results from the Poisson regression analysis suggest a significant relationship between CEO tenure and the total number of issues being examined ($p<.01$). Findings also illustrate a significant relationship between market value of the firm and the total number of issues being examined ($p<.001$). Contrary to our prediction, though, age is inversely related and significant to the total number of issues being examined ($p<.01$). Specifically, younger CEOs are more likely to speak out on political issues than older CEOs.

Table 2. Poisson Regression.

DV=Summation of all the Issues Examined (BLM, Capitol Riots, Climate Change, Gun Control, Inclusion, Me Too, and Voting Rights)

	Total Number of Issues		
IVs	B	SE	IRR
CEO in Underrepresented Group	-.03	(1.25)	.75
CEO Age	**-.05****	(.02)	.95
Tenure as CEO	**.05****	(.02)	1.05
CEO/Chair Duality	-.24	(.23)	.79
LN (Number of Employees)	.02	(.07)	1.02
LN (Market Value of Firm)	**.30*****	(.07)	1.34
Number of Women on the Board	**.16****	(.06)	1.18
Constant	-.28	(1.31)	.75

N = 49 ** p<.01 *** p<.001

In the logistic regressions examining individual issues (refer to Tables 3 and 4), age is significantly related to a CEO speaking out on BLM, climate change, and D&I ($p<.05$). Again, results affirm that *younger* rather than *older* CEOs are more likely to speak out on political issues. For specific issues with our other examined variables of status, only the market value of the firm reaches a level of significance (refer to Tables 3 and 4). The market value of the firm is significantly related to a CEO speaking out on D&I ($p<.05$) and climate change ($p<.01$). Thus, our results show mixed findings for higher status CEOs being more likely to engage in political activism.

Table 3. Logistic Regression. *Dependent Variables of Black Lives Matter and Inclusion*

	Black Lives Matter			*Inclusion*		
IVs	B	SE	Odds Ratio	B	SE	Odds Ratio
CEO in Underrepresented Group	**3.22***	(1.45)	25.09	-1.05	(1.28)	.35
CEO Age	**-.23***	(.10)	.79	**-.29***	(.12)	.75
Tenure as CEO	.30	(.16)	1.35	-.05	(.14)	.95
CEO/Chair Duality	-1.35	(1.23)	.26	1.16	(1.27)	3.18
LN (Number of Employees)	.72	(.43)	2.06	-.60	(.42)	.55
LN (Market Value of Firm)	.67	(.44)	1.96	**.89***	(.43)	2.42
Number of Women on the Board	.21	(.30)	1.23	**.71***	(.36)	2.03

N = 49 * p<.05

Table 4. Logistic Regression. *Dependent Variable of Climate Change*

	Climate Change		
IVs	B	SE	Odds Ratio
CEO in Underrepresented Group	-1.94	(1.39)	.14
CEO Age	**-.22***	(.10)	.80
Tenure as CEO	.27	(.16)	1.31
CEO/Chair Duality	-2.15	(1.14)	.12
LN (Number of Employees)	-.45	(.34)	.64
LN (Market Value of Firm)	**1.23****	(.46)	3.43
Number of Women on the Board	**.81***	(.36)	2.24

N = 49 * p<.05 ** p<.01

Hypothesis 2 suggests that women CEOs from underrepresented groups will be more likely to speak out than other women CEOs. In the rough calculations examining all women CEOs in the sample, 78 percent of underrepresented CEOs spoke up regarding BLM compared to 31 percent in the overall sample. With regard to D&I, 78 percent of the underrepresented CEOs spoke up compared to 71 percent of the overall sample. And with regard to climate change, 56 percent of the underrepresented CEOs spoke up compared to 52 percent of the overall sample. As is clear with the raw numbers, the biggest discrepancy between the underrepresented CEOs and the overall group is in regard to engaging in political activism for Black Lives Matter. This finding is also consistent in the logistic regression analysis examining BLM ($p<.05$). In the overall Poisson regression analysis examining all issues in total, findings do not support this hypothesis. Thus, we suggest limited support for Hypothesis 2.

And Hypothesis 3 suggests that the greater number of women on the board, the greater likelihood the woman CEO will engage in political activism. Results from the Poisson regression analysis support this hypothesis in the examination of all total issues (refer to Table 2) with a significance level of $p<.01$. Further, the number of women on the board and the individual issues of D&I and climate change are positively and significantly related in the logistic regressions at a level of $p<.05$ (refer to Tables 3 and 4). Hence, we suggest support for Hypothesis 3 and assert that the greater number of women on the board allows for women CEOs to speak up on issues they deem important.

DISCUSSION & CONCLUSION

The aim of this study was to explore the individual and institutional predictors of CEO activism so as to advance scholarship on this emergent phenomenon via theoretically motivated empirical analyses (Branicki et al. 2021). Our analysis draws on token theory and bodies out of place perspectives (Kanter 1977; Puwar 2004), to understand the factors that may lead non-traditional CEOs, including women, racial/ethnic minorities and LGBTQ+ individuals, to engage in activism at higher rates than white men CEOs. Our analysis reveals that CEOs from historically marginalized groups are more likely to engage in activism than more traditional CEOs. We further find that, among women, CEOs with longer tenures and those leading firms with a higher market value are more likely to engage in activism. This suggests that even among token CEOs, firm status and tenure encourage more political engagement. Finally, we find that gender diversity on the board is associated with a higher likelihood of activism among women CEOs.

Our findings have important implications for research on CEO activism and for understanding the potential impact of CEO activism on underrepresented CEOs. CEOs who speak out are increasingly subject to scrutiny and suspicion regarding their ethical and moral motivations for engaging in activism, pejoratively termed “woke capitalism” (e.g., Lewis 2020). External observers are increasingly invested in holding CEOs accountable for adopting substantive change in line with their public words and gestures, viewing activist statements as branding tools aimed at attracting a broader consumer base rather than as signaling a commitment to structural change. Thus, activism CEOs are likely to be increasingly accountable to act in ways that are in accordance with their public positions. A recent example illustrating this tendency is the overwhelming backlash leveled against Bob Chapek, the CEO of Disney, who refused to actively and publicly oppose a bill in the Florida legislature restricting teaching about sexual orientation in public schools despite years of public statements in support of the LGBTQ+ community. Chapek’s failure to engage politically in ways that accorded with Disney’s stated values led to a walkout of employees and harsh public criticism from Disney’s major suppliers, including Marvel, Pixar and Lucasfilms, which led the company to cancel a planned leadership retreat.

Disney’s example illustrates the potential risks CEOs face for engaging in activism. These risks are likely to be greater for CEOs from historically underrepresented and marginalized groups, who face greater scrutiny and performance pressures than their white men peers. For instance, previous research finds that non-traditional leaders face scrutiny, criticism and negative evaluation bias for engaging in DEI advocacy. Token pressures enhance these penalties by reinforcing stereotypes that such leaders are unfairly biased toward members of their own group, that they have an agenda or that they are seeking to “rock the boat” (Duguid 2011). For instance, Johnson and Heckman (2016) found that women and non-white executives are critiqued for their competence and performance as a result of engaging in diversity-valuing behaviors. Similarly, Ahmed (2021) finds that engaging in diversity and inclusion work – particularly for members of historically underrepresented groups – enhances the scrutiny, surveillance and the amplification of difference these individuals experience in the workplace. She writes that such activity can reinforce assumptions that such individuals are “not meant to be here” (Ahmed 2021, p. 158).

To the extent that non-traditional leaders face similar penalties for engaging in activism, we expect that the pressures to do so may harm the long-term leadership trajectory of women CEOs, including women of color and LGBTQ+ individuals. Thus, such CEOs may be in a Catch-22, facing high expectations to speak out on important political issues but facing penalties for doing so. Thus, while non-traditional CEOs are expected to be on the front lines of public engagement with highly politicized issues, they may bear unequal burdens of speaking out. The tenuous nature of their leadership suggests that they may face greater backlash from suppliers, shareholders, and others for engaging in activism. Thus, in the case of non-traditional CEOs, activism may make their firms more vulnerable to market and consumer backlash (Bedendo and Siming 2020).

On the other hand, these CEOs may enjoy more legitimacy and credibility for engaging in activism. Extant research finds that backlash against CEOs for engaging in political campaigns is reduced when CEOs are viewed as authentic, legitimate and credible with regard to the political issue (Gregory 2020; Gaines-Ross 2016). Thus, Black CEOs who speak out in support of Black Lives Matter or women CEOs who speak out on behalf of survivors of sexual misconduct may be less likely than other CEOs to experience backlash because they are viewed as authentically engaged in a political issue.

Future research should focus on elaborating the individual and institutional predictors and consequences of CEO activism in order to better understand the evolving role of contemporary CEOs.

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