CLOUD COMPUTING: SUPPLY CHAIN APPLICATIONS AND IMPLEMENTATION ISSUES - AN AGENT BASED SIMULATION APPROACH

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ABSTRACT

We investigate the impact of cloud computing on bullwhip effect and supply chain performance. Using multi-agent simulation, we find that cloud computing provides an effective solution to reduce bullwhip effect and improve supply chain performance in a 4-tier supply chain via savings of up to 105% inventory and backorder cost.

Keywords: Cloud computing; Supply chain management; Bullwhip effect; Information sharing

1. Introduction

An increasingly competitive and globalized business environment has caused supply chains to grow rapidly and as such supply chains are becoming more complex over time. Because of this, there is an increased need to coordinate and share information. In a competitive environment firms find it tempting and necessary to invest in information technology (Wang & Tadisina, 2007). Previous studies have examined the use of information technology such as telecommunications and electronic data interchange (EDI) to enhance supply chain performance (e.g. Kaefer & Bendoly, 2000; Segev et al., 1997). EDI is an older computing paradigm that is the direct routing of information from one computer to another and requires information must be structured within a specific computer format (Strader et al., 1998). Cloud computing, arguably one of the major advances in the history of computing (Marston et al., 2011), however, is a new information technology that offers more flexibility through the use of internet and being able to access information from a variety of technologies (Rochwerger et al., 2009).Thus, we believe cloud computing technology has a strong potential to improve information sharing and collaboration and also indirectly impact bullwhip effect.

Despite research attempting to investigate the mitigation of problems associated with complex supply chains using information technology, some have suggested fresh investigative efforts to focus on viable cutting-edge information technology, how it impacts communication in the supply chain, as well as problems associated with a lack of communication (Thomas et al., 2011), including the bullwhip effect. While previous literature has defined how older information technologies can impact information flow (i.e. Kaefer & Bendoly, 2000; Segev et al., 1997), there is very little insight into state of the art information technology and its impact on the supply chain. Given the growing complexity in supply chains, supply chain professionals, now more than ever, need to understand how to optimize supply chain performance through greater information sharing and collaboration as well as tools available to them including cloud computing technology.

In attempting to fill the current cloud computing void in supply chain literature as well as providing supply chain professionals a tool for optimizing supply chain performance via cloud computing, we use multi-agent simulation to answer two research questions: (1) Do cloud computing and its impact on greater information sharing and collaboration alleviate the bullwhip effect? And (2) Do the use of cloud computing and its impact on information sharing, collaboration and bullwhip effect alleviation have an impact on supply chain performance?

To answer these research questions we use multi-agent simulation. This type of simulation provides researchers the ability to capture complex structures, behaviors, communication and interaction of complex domains including supply chain management (Sierhuis et al., 2003). As such it provides SCM researchers a better technique for simulating a typical 4-tier supply chain structure. After simulating a supply chain using three scenarios (e.g. base scenario without cloud computing, cloud computing with information sharing and cloud computing with both information sharing and collaboration) our simulation results show that inventory, backlogs and orders increase upstream in the supply chain when cloud computing is not present. Inventory and backorder costs also decrease with greater use of cloud computing. To further our research, we also duplicate our simulation using three sets of parameters including a different number of agents in a 4-tier supply chain. The results were the same despite changing the number of agents and thus provide us validation of our results.

Thus, the main contributions of our research are four-fold. First, to the best of our knowledge, it is the first attempt to explore the impact of cloud computing on both bullwhip effect and supply chain performance in a 4-tier supply chain using simulation. Second, we endeavor to lay a foundation for future empirical research on the use of cloud computing in the supply chain management area. Third, we also increase supply chain management professionals' awareness of SCM benefits associated with using cloud computing including reduction of bullwhip effect, inventory and backorder costs. Finally, we provide a viable simulation tool for both SCM researchers and practitioners to evaluate the cutting edge information technology's impact on SCM.

The remainder of this paper is organized as follows. First, we will describe our models as well as theoretical foundations and previous literature on each construct. Next, we will describe our basic design of the simulation. Then we will present the results and analyses of our simulation. Finally, we will provide a discussion of the implications as well as concluding remarks of this study and future research opportunities.

2. Model and Theory

Our study attempts to analyze the relationships between five different constructs: cloud computing, information sharing, collaboration, bullwhip effect and supply chain performance in a 4-tier supply chain. The relationships between our constructs are depicted below in Figure 1.

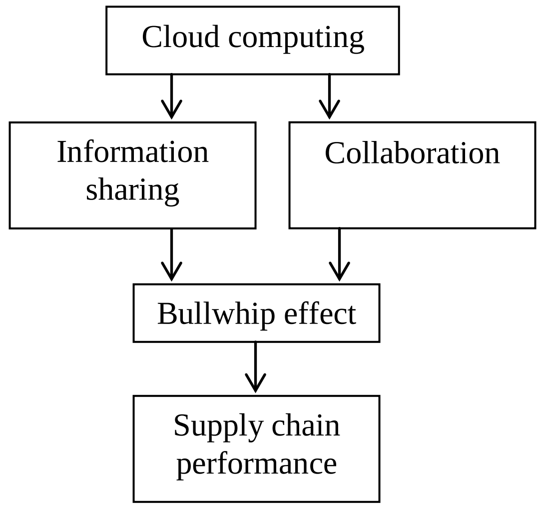

Figure 1. Conceptual model

In this study we use a combination of transaction cost economics, principal-agent theory and social capital theory to explain the relationships between our constructs. Transaction cost economics posits that transactions determine what constitutes the efficient governance structures (Williamson, 1975). There are four primary factors that produce transaction difficulties: bounded rationality which produces cognitive limitations of the human mind; opportunism which refers to an actor acting in self-interest; small numbers bargaining which is the degree to which the buyer has many sources of supply to meet product demand of the consumer, and information impact which is the information asymmetries between entities in the supply chain (McIvor, 2009). Cloud computing can be used as a tool to reduce information asymmetries between entities in the supply chain in a cost efficient manner through the pay-as-you-go service. Companies are given the opportunity to gain access to information via the internet and only pay for the services that they use when they need it. Not only does this reduce paper costs but also companies no longer have to invest in their own data centers improving cost savings over time.

Principal-agent theory is concerned with resolving two problems occurring due to asymmetrical information: the first problem occurs when the goals of the principal and agent conflict and the second problem refers to when it is difficult or expensive for the principal to verify what the agent is doing (Eisenhardt, 1989). These two problems including imperfect goal alignment and information asymmetry raise agency risk (Eisenhardt, 1989). Often organizations will turn to costly control mechanisms to avert opportunistic behavior (Handley & Benton, Jr., 2012; Parkhe, 1993). Cloud computing can help improve information flow which reduces the opportunistic behavior resulting from principal-agent problems. Cloud computing can also reduce other problems associated with information asymmetry including the bullwhip effect which in return decreases inventory and backorder costs for firms.

Social network theory posits that a social network not only consists of the individual actors but also the relationships between these actors (Ibarra, 1995). Weak ties with distant contacts can facilitate information and resource exchange (Evans & Davis, 2005; Granovetter, 1973; Sparrowe & Liden, 1997). Weak ties also tend to facilitate the search for information using resources and innovation between groups (Hansen, 1999; Granovetter, 1973). Based on this reasoning, supply chain partners, can use cloud computing to enhance information sharing and collaboration between entities which in return reduces the bullwhip effect which ultimately reduces inventory and backorder costs (Lee et al., 1997a,b).

Based on a combination of transaction cost economics, principal-agent theory and social network theory we have formulated the conceptual model depicted in Figure 1 which will be later analyzed using agent-based simulation. Before our simulation we will further describe the development of our conceptual model drawn upon previous literature.

3. Literature Review

Bullwhip effect is a phenomenon whereby demand order variability has oscillating demand amplification as it moves up in the supply chain (Lee et al., 1997a). This phenomenon is a well-recognized metric for information distortion and is referred to as “the first law of supply chain dynamics” (Lee et al., 1997b; Lee et al., 2004; Kouvelis et al., 2006). Sterman (1989) was one of the first to report evidence of the bullwhip effect using the “beer distribution game”. The game involves four players in a supply chain that make dependent inventory decisions without any information from other members. The simulation demonstrates that by only relying on orders from the neighboring player, under a linear cost structure, variance of orders amplify upstream in a four member supply chain. Based on this notion, recent literature calls for the need to examine not only the variance increase caused by the bullwhip effect, but its underlying information distortion and the impact this has on physical flows and financial implications for the supply chain.

To answer this call for research we use the beer distribution game as a prototype to observe how the bullwhip effect is impacted through greater information sharing and collaboration.

There are four main causes of the bullwhip effect, including demand signal processing coupled with long lead times, rationing game, order batching, and price variations (Lee et al., 1999a,b). Demand signal processing occurs when a downstream member places an order, and the upstream member processes that information as a signal of future demand (Lee et al., 1997a). With this signal the upstream person adjusts demand forecasts and orders placed with suppliers. Often the future demand and safety stock are updated with long lead times, which results in fluctuations in order quantities over time, thus leading to the bullwhip effect (Lee et al., 1997a). One way to alleviate demand signal processing is to share inventory and sales data (Lee et al., 1997b), share point of sales (Akkermans & Vos, 2003), and use information technology to facilitate information transmission among members in the supply chain (Lee et al., 1997a). Non-zero lead times are also shown to be a cause of the bullwhip effect when coupled with demand signal processing (Lee et al., 1997b). The use of information sharing, can improve decision making in regard to ordering, capacity allocation and production/material planning in orders thereby alleviating demand signal processing (Huang et al., 2003).

Rationing game, also known as shortage game, occurs when a product’s demand exceeds its supply, so in response an upstream member rations its product to its customers (Lee et al., 1997a). If a product is in short supply, customers will exaggerate their real needs. When demand inevitably lessens, orders suddenly disappear and cancellations occur rapidly (Lee et al., 1997b).

Customer orders do not provide the supplier with information on the product's real demand, which causes demand amplifications upstream in the supply chain (Lee et al., 1997a). One way to alleviate the rationing game is to have manufacturers share production and inventory information with downstream members (Lee et al., 1997b). This reduces rationing game because of the retailer's self-protection against imaginary shortages (Lee et al., 1997b). It also alleviates customer anxieties and lessens their need to over exaggerate demand through greater knowledge of supply (Lee et al., 1997a). Undistorted and up-to-date information at every node in the supply chain creates superior performance and allows supply chain partners to work together in order to reduce problems (Li et al., 2005; Balsmeier & Voisin, 1996; Towill, 1997; Stein & Sweat, 1998).

Order batching is the third cause of bullwhip effect and occurs when an upstream member attempts to take advantage of transportation economies by batching or accumulating demand before issuing an order (Lee et al., 1997a). Ultimately, order batching leads to a gap in information flow amongst supply chain partners, and in turn results in increased amplification of demand variability upstream in a supply chain. One way to alleviate order batching is to have upstream members receive consumption data on fixed, periodic schedules in order for them not to be surprised by unusually large batches of orders due to a demand surge (Lee et al., 1997a). Additionally, order batching can be eliminated by providing the manufacturer access to inventory data at the retail level, which allows the firm to use this information to create production schedules determined by sales instead of orders (Lee et al., 1997b).

Price variations is the fourth cause of bullwhip effect and occurs when manufacturers and distributors periodically use special promotions, including price discounts, special package deals, quantity discounts, coupons and rebates (Akkermans & Vos, 2000). The use of price variations perpetuate forward buying, whereby items are bought in quantities that do not reflect the immediate needs of customers in an attempt to take advantage of cost savings (Lee et al., 1997a). Although information sharing and collaboration may not directly impact price variations, information sharing and greater collaboration via an information technology that reduces cost may eliminate incentive to reduce cost through the use of price variations.

Various studies have identified the benefits and problems associated with bullwhip effect on supply chain performance (e.g. Swaminathan & Tayur, 2003; Lee et al., 1997a,b; Chen et al., 2000). Some problems associated with the bullwhip effect include poor customer service due to unavailable products or backlogs, excessive revisions to production planning, poor product forecasts and expedited shipments, and overtime (Lee et al., 1997a). Studies have suggested reducing the bullwhip effect allows companies to not only benefit from total cost reduction, but also increased service to customers, thereby improving overall supply chain performance (Croom, 2005; Leeuw & Fransoo, 2009; Dejonckheere et al., 2004; Emerson et al., 2009; Ouyang, 2007).

The fill-rate, a common measurement of supply chain performance, is the probability of meeting demand with on hand inventory and can be measured using inventory and backorder costs (Li et al., 2006). Reduction of the bullwhip effect reduces order variance, which allows every tier in the supply chain to carry less safety stock, thus reducing inventory cost (Li et al., 2006). Some other problems associated with the bullwhip effect include problems with inventory and safety stock, excessive backorders, inefficient use of resources, poor customer service due to unavailable products or backlogs, excessive revisions to production planning, poor product forecasts and expedited shipments and overtime (Ozelkan & Cakanyildirim, 2009; Lee et al., 1997a). Lower order variance in time increases the fill-rate (Li et al., 2006) thereby leading to an improvement in supply chain performance. Information sharing reduces uncertainty at each stage in the supply chain, thereby reducing order variance and bullwhip effect, which in turn leads to an increased fill-rate (Li et al., 2006).

In order to optimize supply chain performance by increasing the fill-rate bullwhip effect needs to be reduced (Lee et al., 1997a,b). Overall previous research indicates that information sharing and collaboration are key parts of a solid supply chain relationship (Li et al., 2005; Lalonde, 1998). Information sharing in the supply chain is defined as the extent to which critical information is communicated to one's supply chain partner (Li et al., 2005). The integration provided by information sharing leads to operational performance including, process efficiency and logistics service performance (Flynn et al., 2010; Saeed et al., 2005; Germain & Iyer, 2006; Stank et al., 2001 a, b), thereby helping to eliminate the core causes of bullwhip effect. Cloud computing also promotes greater collaboration between supply chain partners. Collaboration in the supply chain involves both information sharing as well as an element of trust (Ashleigh & Nandhakumar, 2007). Collaboration between supply chain partners reduces the information asymmetry thereby decreasing chances for order variability (Lee et al., 1997a,b).

Both information sharing and collaboration are enhanced by information technology (Zhou & Benton, Jr., 2007; Angerhofer & Angelides, 2006). Cloud computing technology is a state of the art information technology that offers on-demand, pay-as-you-go, massively scalable services where companies can share different information with one another at any time or any place (Rochwerger et al., 2009; Foster, 2002). The on-demand access to information provided by cloud computing provides infinite computing resources to help facilitate collaboration among supply chain partners (Armbrust et al., 2009). It also provides users the ability to access information in a real time manner regardless of where they are without having to manage and maintain computing system platforms (Chan, 2011). Cloud computing also offers a massively scalable service either through software, infrastructure and platforms or by private, public or hybrid cloud, based on the information or security needs of the user (Rochwerger et al., 2009; Vouk, 2008). Cloud computing also offers pay-as-you-go resources and as such eliminating up-front costs and making it less expensive to share information (Rochwerger et al., 2009).

Based on this previous literature cloud computing enhances information flow in two ways: (1) through greater flexibility and (2) through greater cost savings. Greater flexibility is facilitated through the massively scalable services that allow users to define how they would prefer to use the cloud. On-demand access provides cloud computing users the ability to access inventory, safety stock and order information at any time. Cost savings are introduced to users via the pay-as-you-go service provided which allows for greater resource utilization and reduced waste in time and monetary resources.

Cloud computing facilitates greater collaboration among supply chain partners. Previous research suggests that information technology can be vital in impacting planning activities for collaboration (Lockamy III & McCormack, 2004; Corbett et al., 1999; Narasimhan & Das, 1999; Raghunathan, 1999; Boddy et al., 2000; Ellinger, 20000; Kaufman et al., 2000; Waller et al., 2000). However, collaboration via enabling technology can also be expensive for companies by increasing either implementation, maintenance, hardware, software or transaction processing costs (Angerhofer & Angelides, 2006). Cloud computing's pay-as-you-go service, in response provides various cost reductions by eliminating the need for hardware and software costs, since companies no longer have to maintain their own data centers (Rochwerger et al., 2009). This in essence not only improves overall collaboration, but does so inexpensively thereby not only reducing the bullwhip effect but also decreasing the cost structure in supply chains and improving performance.

In order to further analyze the relationships depicted in Figure 1 we use multi-agent simulation which aids us in answering complex research questions with various elements including: does cloud computing impact the bullwhip effect? And does the use of cloud computing have an impact on supply chain performance in a 4-tier supply chain? Overall, the use of multi-agent simulation should improve the results of these questions based on the realistic environment that it provides. We also will further validate our answers to these questions by simulating the use of cloud computing on bullwhip effect and supply chain performance on a 4-tier supply chain using different parameter sets.

4. Methodology

Simulation models are used when certain characteristics of the supply chain cannot easily be modeled with analytical tools such as regression, queuing and optimization or when stochastic variables are present (Riddalls et al., 2000). Using simulation also makes it easier to conceptualize links between model and the real system. In this study we simulate the effect of cloud computing on a 4-tier supply chain.

Previous research defines supply chains as "systems." For instance, Choi et al. (2001) point out that a supply network is a complex adaptive system (CAS). Based on complexity theory and from a system perspective, a system is "complex" and "dynamic" when it has a large amount of variables and interacting forces that it is difficult to understand or optimized by traditional vertical approaches such as top-down or bottom up (Holland, 1992). The term "adaptive" means that all of the participants in the system are learning from experience and adjusting their behaviors to adapt to the dynamic environment (Juarrero, 2000). Every CAS is more than the sum of its constituting agents and its behavior and properties cannot be predicted from the behaviors and properties of the agents. CAS is characterized by diffused (distributed) and non-centralized control. In the real business world many phenomena behave like CAS, such as fashion trends, stock markets, traffic jams (Choi et al., 2001; Surana et al., 2005). Based on the literature and the characteristics of a supply chain system, we consider a 4-tier supply chain a complex adaptive system in our model.

Agent-based is potentially a powerful approach to understanding complex adaptive systems (Tesfatsion, 2003). Shalizi (2006) defines an agent as a persistent and relevant entity which interacts with other agents in a mutually modifying context. An agent based model is a collection of agents, their states, the rules governing interaction and an environment in which they live (Shalizi, 2006). In agent-based simulation, low level entities with relatively simple attributes and behaviors can collectively generate complex and realistic system behaviors. A multi-agent system (MAS) is composed of multiple interacting agents, which can be used to solve problems that are difficult for an individual agent (Yoav Shoham and Kevin Leyton-Brown, 2008).

For example, a widely used agent-based system is an "SIR" model, which depicts the spread of a disease through a population. There are three classes of people, the susceptible, who have yet to be exposed to the disease, the infected, who have it and can pass it on and the resistant or the recovered, who have survived the disease and cannot be re-infected. Three variables, S(t), I(t) and R(t), represent the number of people in each of the three categories that are defined using deterministic or stochastic dynamics. These deterministic or stochastic dynamics are interpreted using several simple rules: 1) People have contact with each other at a certain rate. 2) If an infectious person contacts a susceptible one, the latter will be infected at a certain probability. And 3) the infectious people recover after a certain amount of time and become immune to the disease. In an agent-based model given the same dynamics, each individual in the population is represented as a distinct agent, in one of three states: S, I and R. An example of a simple interaction rule would be that at each time-step, an agent selects another from the population entirely at random. If a susceptible agent (i.e., one in state S) picks an infectious agent (i.e., one in state I), it becomes infected with probability “a”. Infectious agents die with probability “b” and recover with probability “c”; recovered agents never change their state. When more interaction rules are implemented, the power of agent-based modeling increases. The SIR model shows the basic procedures of multi-agent based CAS simulation. Following this workflow we have developed our own multi-agent based system to simulate a 4-tier supply chain system.

We identify different agents in the supply chain and provide each agent with an ability to utilize a subset of internal mechanism. The internal mechanism helps in decision making at the agent level by utilizing basic rules or polices (e.g. inventory polices, shipping rules and replenishment algorithms) for demand, supply, information and material control within the supply chain. We assume that the supply chain system is represented as a chronological sequence of events, in which each event occurs at an instant in time and marks a change of the state in the system. Thus, we utilize the discrete event simulation to mimic events in the whole system.

5. Simulation implementation

5.1 Model description and base assumptions

Using rules set forth by the beer distribution game, our model’s supply chain consists of four kinds of agents: retailers, wholesalers, distributors and factories. Based on the AnyLogic[1] simulation tool, Figure 2 illustrates our simulated multi-agent supply chain and the factors impacted by information sharing and collaboration. On the system configuration page, we can adjust the initial parameters as we want such as initial inventory, replenishment rules and storage or backlog cost.

5.1.1. Uncertainty in supply chain

[1] AnyLogic (http://www.xjtek.com) is a multi-method simulation modeling tool developed by XJ Technologies. It supports modeling approaches such as system dynamics, discrete event simulation and agent-based modeling.

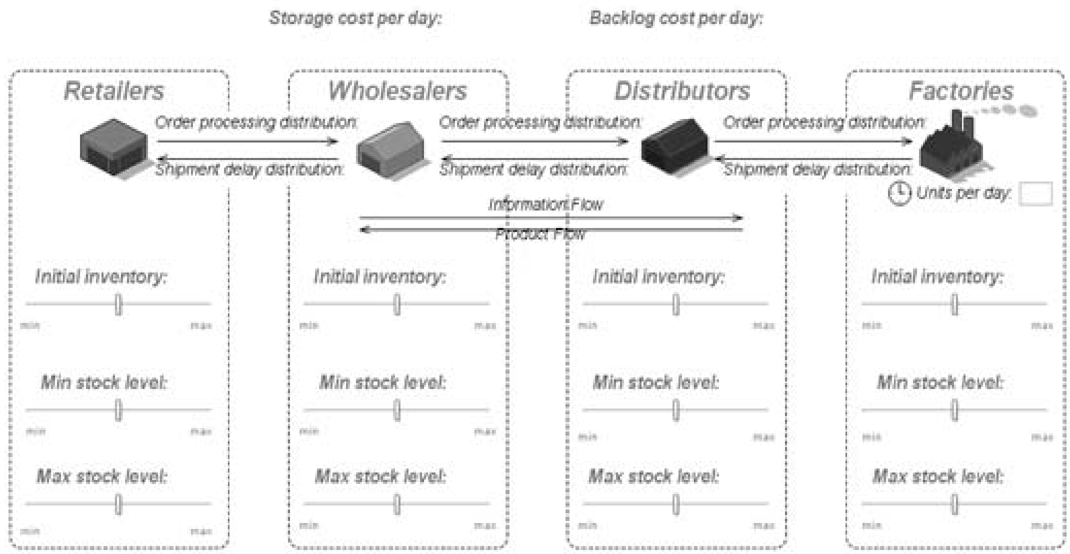

Figure 2. Multi-agent supply chain configuration

There are a lot of uncertainties in supply chain system. Uncertainty in customer demand, quantity, quality, shipping time are major concerns and prevalent in supply chain literature (van der Vorst and Beulens, 2002; Davis, 1993). Unfortunately, previous supply chain literature has often ignored uncertainty in order processing, production and transportation time. In our simulation model we consider all three sources, which are highly related to the information sharing and collaboration that we identify in our model, as uncertainty. Considering these sources of uncertainty helps us to simulate a realistic 4-tier supply chain.

Uncertainties are usually reported as stochastic processes using probability distributions. A probability distribution is derived from evidence recorded from past experience. For example: based on history records, the shipping time is nearX_m, most of them are no less than X_l and no longer than X_u. This example represents a situation where triangular distribution can be used. The triangular distribution is useful in representing these approximate qualifiers, due to their conceptual and computational simplicity. Generally, when only a small amount of the distribution of an outcome is known, for example the smallest and largest values, it is possible to use the uniform distribution. However, if the most likely outcome is known, then the distribution is best simulated by a triangular distribution (Jognson, 1997).

5.1.2. Agents

Using the beer distribution game as a prototype for our agent-based supply chain model, we setup four groups of agents: retailers, wholesalers, distributors and factories. Each agent makes dependent inventory decisions without any information from other members in the supply chain.

5.1.2.1. Retailer

Demand begins at the consumer level. Demand at the consumer level is satisfied if the inventory level (*I*) at the retailer level is as large as or greater than the demand. If the demand exceeds the inventory level, the customer takes the currently available items and the excess of demand over supply is backlogged and increased by future deliveries from the wholesaler.

A retailer reviews its inventory level and decides how many items to order from the wholesaler. An (S, s) inventory policy was imported as the retailer's decision rule (Arrow et al., 1951). To pursue an (S, s) inventory policy, the retailer establishes a lower stock point s and an upper stock point S. No order is placed until inventories fall to s or below, whereupon they are restored to the maximum of S. The retailer *i* calculates its inventory backlog IB_i as formula 1:

$$IB_i = (I_i + S_i - B_i) \quad (1)$$

Where S_i denotes the expected shipments of retailer *i* and B_i represents the backlogged orders. The retailer will send an order message to wholesaler if $IB_i < s$. When a shipment arrives from the wholesaler, we assume for simplicity that it is used immediately to satisfy any backlogged customers. Furthermore, we assume that a backlogged customer is willing to accept their item(s) at the time that the order arrives and there is no travel time taken into account.

5.1.2.2. Wholesaler

When a wholesaler receives an order from the retailer, it ships products following a first in, first out (FIFO) method if it has enough inventory. In this simulation, partial orders are not shipped. We refer to processing time and shipping time as uncertainty and further assume they follow triangular distributions. We use triangular distribution because it is good to representative of the processing and shipping time in a typical 4-tier supply chain. .

The new inventory level at the wholesaler *j* is calculated as:

$$I_{j,t+1} = I_{j,t} - S_t \quad (2)$$

Where $I_{j,t+1}$ denotes new inventory level of wholesaler j, $I_{j,t}$ represents the previous inventory level, and S_t is the unit number of shipped products.

Any order that is not shipped is counted into backlog. After any orders are shipped to the retailer, the wholesaler reviews its current inventory level and decides how many items to order from the distributor. Similar to the retailer level, a stationary policy (S, s) is used to help the wholesaler decide how much to order. When a shipment arrives from the distributor, the items in the shipment are added to the wholesaler's inventory.

5.1.2.3. Distributor

When the distributor receives a message from wholesaler, it will also follow a FIFO method in shipping orders if there is enough inventory. We assume that the processing time and shipping time follows triangular distribution which again represents a typical distribution in processing and shipping times in a 4-tier supply chain. The new inventory level is calculated and any order that is not shipped is backlogged.

After the orders are shipped to the wholesaler, the distributor reviews its current inventory level and decides how many items to order from the factory. Similar to the wholesaler, a stationary policy (S, s) is used to help the distributor decide how much to order.

5.1.2.4. Factory

The factory uses a FIFO method to ship orders if it has enough inventory. The processing and lead time distributions are the same as wholesaler's and distributor's.

After orders are shipped to the distributor, the factory reviews its current inventory level and decides how many item to manufacture. In this simulation, we assume that raw materials are always available. The time required to manufacture T is given as:

$$T = e + k \times M \qquad (3)$$

where *e* is the time to setup the manufacturing line, *k* is the time to manufacture each item and *M* is the number of product. When a batch of items has been manufactured, the items are added to the factory's inventory.

5.1.3. Internal mechanism

Internal mechanism is defined as process used to facilitate production and transportation of products within the supply chain. Design of appropriate internal mechanism is the objective of problems related to supply chain contracts and supply chain coordination (Swaminathan et al.1998). To simulate the essence of agents in a 4-tier supply chain, we design two internal mechanisms for each agent in this model: order processing and routing control (Min and Zhou, 2002). The first mechanism reflects the operation process inside each agent and the latter one decides the communication among agents.

5.1.3.1. Order processing

Each agent in our model has a workflow of its own. At the beginning of a time cycle, each agent checks the order waiting list, tries to satisfy the last backorder first, than considers replenishment of new orders based on inventory level. If inventory is lower than their safety stock level, it will send an order message to the upstream agent.

The upstream agents will then receive the order information and process that order at the beginning of its next time cycle. Based on this, there are two kinds of delay, shipment delay (time required to ship the item) and information delay (time to send, receive and process information). These delays are simulated and depicted in Figure 3. Delivery cost will be aggregated after every shipment event happens. Delivery cost (D) is calculated by (4):

$$D_{t+1} = D_t + S_f + S_v \times N \qquad (4)$$

Where D_{t+1} and D_t denotes the current and previous delivery cost respectively, S_f is the fixed cost for each shipment, S_v is the shipping cost per unit and N is the delivery size.

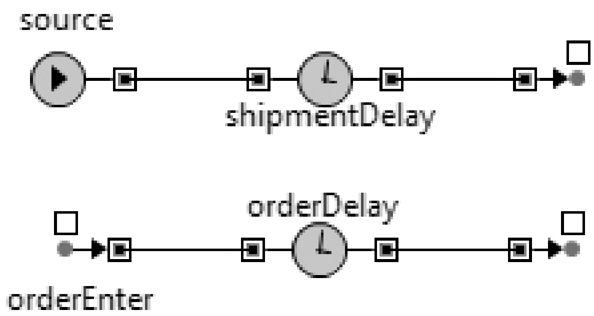

Figure 3. Shipment and order information delay

5.1.3.2. Routing control

We generate multiple agents to represent a medium-sized 4-tier supply chain.. For example, in the configuration, we include 5 distributors and 10 wholesalers to emulate multi-tier parties in an agent layer. Routing control decides the sequence and path in which products and information are delivered. For routing control we set a rule: an agent always sends order information to the nearest upstream agent first.

5.1.4 Performance measures

Supply chain performance measures can be classified into two categories, qualitative and quantitative. Qualitative performance measures relate to customer satisfaction, integration of information and material flow, and effective risk management. Quantitative performance measures relate to cost, profit, fill-rate, customer response-time, supplier reliability and lead-time (Swaminathan et al., 1998). In this study, we consider system level quantitative performance measures only, which includes inventory cost and backorder cost. We also considered the cost of cloud computing usage. Inventory costs represents the cost associated with holding particular items in inventory per day and is calculated as:

$$IC_{t+1} = IC_t + S_{t+1} \times VC_I \tag{5}$$

Where IC_{t+1} and IC_t denotes the current and previous inventory cost respectively, S_{t+1} represent the product number in stock at *t+1* and VC_I is the stock cost per unit per day.

When items are unavailable they are often put on backorder. Backorder costs are calculated as:

$$BC_{t+1} = BC_t + B_{t+1} \times VC_B \tag{6}$$

Where BC_{t+1} and BC_t denotes the current and previous backorder cost respectively, B_{t+1} represent the product number in backorder at *t+1* and VC_B is the backorder cost per unit per day.

Cloud computing technology is a pay-as you go service. Cloud provider often charge based on amount of storage and service provided as well as a pay by the hour fee (Armbrust et al., 2009). As such, the cost of using cloud computing is calculated as:

$$CC_t = a + b \times Z \tag{7}$$

where a is a constant that denotes the set up cost of cloud computing, b is the service cost per day and Z is the total days of use.

5.2. Scenarios design and simulation results

In order to examine the impact of cloud computing on supply chain system performance we have simulated three different scenarios: base scenario with no cloud computing, cloud computing with full information sharing and cloud computing with full collaboration.

5.2.1. Base scenario: No cloud computing

In the base scenario, we assume that there is no cloud computing used to facilitate information sharing and collaboration. All the information sending follows the traditional way. For example, while an order is sent by a downstream agent, the information will take some time to get to its destination and the upstream agent will not begin to process the order until the next working day.

5.2.2. Cloud computing scenario I: full information sharing

In the second scenario, we assume all of the agents can gain access to information from the cloud computing in real time. Thus, there is no information delay in the entire system. When a downstream agent sends the order, the upstream agent will put it in the order waiting list at the same time. Furthermore, the information flow with cloud computing is considered to be two-way communication between supply chain partners.

5.2.3. Cloud computing scenario II: full information sharing and full collaboration

In the third scenario, we add collaboration into consideration, where each agent has full access to real time information. Collaboration is different from simple information sharing as it involves all supply chain partners interacting and working towards the same goal in mind (Angerhofer & Angelides, 2006). Collaboration in this model represents full disclosure of information and an element of trust is vital for facilitating cohesive collaboration (Ashleigh & Nandhakumar, 2007). Since disclosure of information and trust between supply chain partners has been tied to greater accuracy of demand (Akkermans et al., 2004), we adapt our simulation based on this previous literature. In this scenario, the downstream and upstream members have more accurate demand forecasts due to full information sharing and collaboration capabilities.

6. Simulation Results and Discussion: A Numerical Example

As shown in Table1, there are fifteen basic parameters defined by us before running the model. We design our supply chain based on a typical supply chain where the number of retailers exceeds wholesalers, the number of wholesalers exceeds distributors and the number of distributors exceeds suppliers.

We evaluate the performance of the entire supply chain, by performance measures after the system fulfills 10,000 products to the customers. Customers randomly choose a retailer and we assume a triangular distribution $(2,10,5)$ to describe the customer demand. This distribution is chosen because it is representative of a typical 4-tier supply chain customer demand. All of the other parameters are assumed to be fixed.

Table 1. Parameters configuration				
	Retailer	Wholesaler	Distributor	Factory
Simulation repeat times	100			
Number of Agents	20	10	5	2
Customer Demand	$triangl ar(2,10,5)$ $f(x\|2,10,5) = \begin{cases} 0 & for\ x < 2, \\ \frac{(x-2)}{12} & for\ 2 \le x \le 5, \\ \frac{(10-x)}{20} & for\ 5 < x \le 10, \\ 0 & for\ 10 < x \end{cases}$			
Products Number (Unit)	10,000			
Initial Inventory (Unit)	50	50	50	50
Minimum Stock (Unit)	20	20	20	20
Maximum Stock(Unit)	80	80	80	80
Inventory Cost($)	0.5	0.5	0.5	0.5
Backorder Cost($)	1	1	1	1
Initial Manufacturing Line (hour)	NA	NA	NA	1
Produce One Item (hour)	NA	NA	NA	0.01
Fixed Shipping Cost ($)	50	50	50	50
Shipping Cost per Unit ($)	0.5	0.5	0.5	0.5
Cloud Computing Initial Cost ($)	100	100	100	100
Cloud Computing Service Cost ($)	0.1	0.1	0.1	0.1

As shown in Figure 4, both inventory and backlog increase from downstream to upstream in the supply chain. This shows the sign of the bullwhip effect which is prevalent when cloud computing is not used to facilitate information sharing and collaboration among supply chain partners.

The resulting bullwhip effect has caused a considerable increase in inventory and backorder cost as demonstrated in Table 2. Our base scenario, which depicts a situation in which there is no cloud computing use (e.g. cloud computing cost = 0), has a resulting inventory cost of

$24,734.71 and a resulting backorder cost of $9,547.26 with a total cost calculated at $34,281.79. In scenario I, where cloud computing is used to initiate full information sharing cloud computing cost increases to $579.42, yet inventory and backorder cost significantly decrease. Thus the resulting cost totals $20,666.01. The use of cloud computing in this scenario renders a $14,195.38 worth of savings in inventory and backorder cost alone. In scenario II cloud computing usage cost increases to $784.52 however inventory and backorder cost reduce to a total of $15,895.29 resulting in a savings of $18,286.68 through the use of cloud computing. Both scenarios I and II reduced total cost by 65% and 105% consecutively in comparison with the base scenario.

Insert Table 2 here

Our simulation results show that cloud computing provides a foundation for greater information sharing and collaboration among supply chain partners resulting in better SCM performance in a typical 4-tier supply chain. Not only does cloud computing offer an environment for greater information flow, but it does so cost efficiently through its pay-as-you-go service.

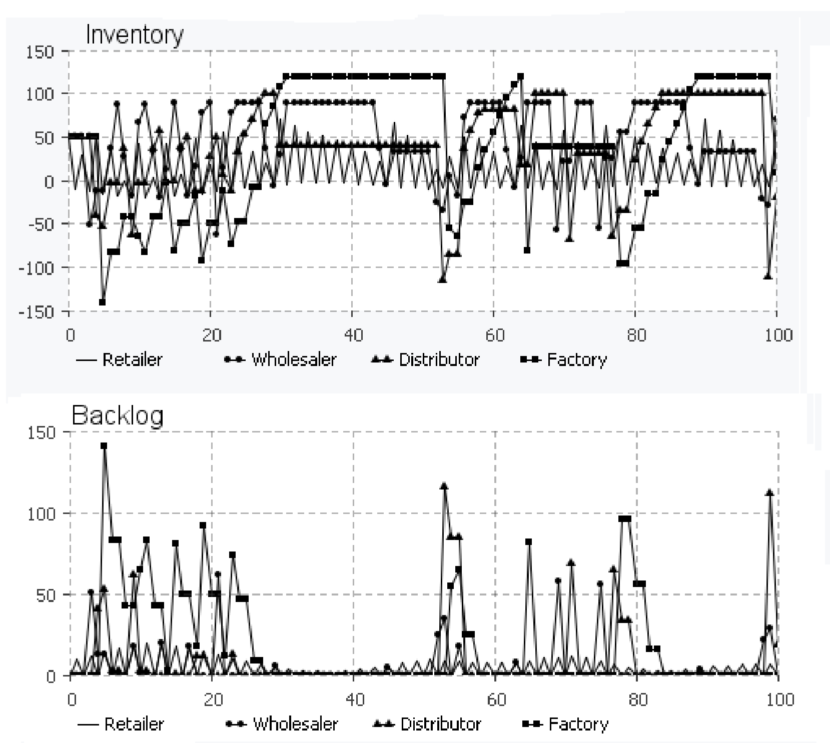

Figure 4. Bullwhip effect under base scenario

To the best of our knowledge, this paper is the first to explore the impact of cloud computing in the supply chain management area using simulation approach. Our simulation results revealed that cloud computing can reduce bullwhip effect and improve supply chain performance via a savings of up to 105% in inventory and backorder cost. These not only provide SCM professionals information on the impact of cloud computing but also provides the SCM research community general foundations for further empirical research dealing with cloud computing's impact in the supply chain management area.

7. Conclusion

Cloud computing overall provides fast deployment, dynamic elasticity, automated and continuous optimization and virtualization technology independence which allows companies to easily gain access to information while simultaneously eliminating the need for large capital investments and reducing costs via the pay-as-you-go service. Current supply chain literature calls for research in new information technologys' impact on information sharing and ultimately supply chain performance (Thomas et al., 2011). Despite the array of benefits provided by cloud computing in information sharing and collaboration, very little research has simulated the impact of cloud computing in the supply chain management area.

In order to fill this gap in literature and provide SCM professionals a viable tool to optimize supply chain performance we used multi agent simulation to simulate cloud computing's impact on bullwhip effect and supply chain performance. Multi-agent simulation provides SCM scholars a more realistic view of cloud computing's potential impact on a 4-tier supply chain. Overall, our simulation results revealed that cloud computing reduces the bullwhip effect and improves supply chain performance by reducing inventory and backorder cost up to 105%.

While this simulation has provided a foundation for future research in cloud computing it is not without certain limitations that should be further discussed. First, in order to simplify the simulation, there were three specific assumptions that were made. (1) The market was stable and there was no price volatility taken into account in our simulation. (2) We assumed a triangular distribution in customer demand and the same replenishment policy was used for each agent. (3) We assumed no information delay and a small mean triangular distribution for shipment delay. While these assumptions were made and may present bias, simplification was unavoidable and estimates remained conservative and based on a typical 4-tier supply chain. Second, while we found cloud computing can enhance information sharing and collaboration; other factors may impact this relationship including reliability and security of the cloud. Future research should look into how inter organizational trust impacts the use of cloud computing. Similarly, supply chain performance is a multi-faceted construct that can be measured in a myriad of ways. For example, Kroes & Ghosh (2010) defines supply chain performance using: manufacturing cycle time, delivery cycle time, whether or not the product is shipped on time, quality of the product shipped and warranty and returns processing cost. Moreover, Chen & Paulraj (2004) identify relational metrics to supply chain performance including communication, interdependence, involvement of supply chain partners and integration of logistics. Each of these dimensions may be impacted through the use of cloud computing and should further be considered in future research.

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Table 2. Inventory, backorder and cloud computing cost in three scenarios

Scenarios	Information sharing configuration	Collaboration configuration	Performance measure item	Mean	Standard Deviation
Base scenario	Triangular [0.5, 2, 1]	Triangular [0.5, 2, 1]	Inventory cost	$24,734.71	$6,415.37
			Backorder cost	$9,547.26	$2,049.49
			Cloud computing cost	$0.00	$0.00
			Sum	$34,281.97	
Cloud computing scenario I	0	Triangular [0.5, 2, 1]	Inventory cost	$14,347.45	$1,618.49
			Backorder cost	$5,739.14	$984.12
			Cloud computing cost	$579.42	$41.05
			Sum	$20,666.01	
Cloud computing scenario II	0	Triangular [0.2,0.5,0.3]	Inventory cost	$12,078.50	$1,014.82
			Backorder cost	$3,816.79	$678.24
			Cloud computing cost	$784.52	$38.46
			Sum	$16,679.81	