DECISION SCIENCES INSTITUTE

A Multi-Objective Decision Model for Supply Chain Collaboration Programs

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ABSTRACT

This paper develops a multi-objective decision model that incorporates quantitative and qualitative decision objectives of two potential business partners that aim to start a supply chain collaboration program. The model enables the partners to evaluate the trade-offs between conflicting objectives of the decision. It also helps them quantify and communicate their views and preferences on key decision factors. The results of implementing the model for two major partners in health care supply chain reveal the value of different decision outcomes and the sensitivity of key decision variables from the perspective of each stakeholder.

KEYWORDS: Multi-objective decision analysis, Supply chain collaboration, Value modeling, Healthcare supply chain, Multi-criteria decision making

INTRODUCTION

The decision of entering into a supply chain collaboration program, such as Continuous Replenishment Program (CRP), or Vendor Managed Inventory (VMI), or Collaborative Planning Forecasting and Replenishment (CPFR), could be challenging. These collaboration initiatives allow the organizations to share demand, forecast, sales and policy information in order to reduce the total cost of the supply chain. The cost savings come from different cost components and with different proportion depending on various supply chain parameters. Although the expected cost savings are sometimes tempting for the involved organizations, the decision makers do not base their decisions solely on the cost savings. We call the cost related decision factors “quantitative factors” while there are other decision factors that are mostly qualitative and could have greater impacts especially among the high level decision makers. We conducted a case study in healthcare supply chain in which the process of reaching an agreement over a CRP relationship between a major manufacturer and a distributor is modeled using multi-objective decision analysis (MODA). MODA is a decision making process which inherently involves a combination of approaches to assess the candidate solutions. In this paper we present how we integrated the quantitative and qualitative decision factors of starting a CRP into a single decision making framework. The key decision factors were collected from the medium-high level managers of both organizations. Then, a comprehensive value tree that represents the views of the decision makers was created. The results provide useful insights on how close the positions of both organizations are with regard to starting a CRP relationship. The model helped both parties to engage in a constructive negotiation process towards a sustainable agreement.

The remainder of this paper is organized as follows. The next section reviews the related literature. The problem description section focuses on the problem and its challenges. Then, the methodology section explains MODA in general and how a model is developed for the problem. The outcome of the model and the perspective of stakeholders on critical decision factors are discussed in results and discussion section. Finally, conclusions and future work are addressed in the last section.

LITERATURE REVIEW

This section provides a brief overview on the history of supply chain collaboration (SCC) followed by a discussion on the relevant research articles. Table 1 provides a summarized history of SCC paradigms from when they emerged in late 80’s until the last major advancements in Late 90’s. SCC programs have faced various changes over time but they can be categorized into the four major paradigms presented in Table 1.

Table 1: Summary of supply chain collaboration paradigms

SCC paradigm	Emergence period	Pioneers	Relevant Papers	Motivation & Summary
Quick Response (QR)	Late 80’s - Early 90’s	JC Penny, Walmart	(Iyer and Bergen 1997)	Shorten the lead time in apparel industry. Retail Link platform is created in Walmart to connect the suppliers with end customer demand data
Efficient Customer Response (ECR)	Mid 90’s	Grocery Industry (Spartan, HEB, Campbell Soup, P&G)	(Schiano and McKenney 1996), (Clark et al. 1994), (Keh and Park 1997), (Sahin and Robinson 2002)	The main purpose of ECR was to improve the responsiveness of SC to consumer demand in the grocery sector. CRP accounts for 38% of the total grocery industry ECR savings
Continuous Replenishment Program (CRP) & Vendor Managed Inventory (VMI)	Mid 90’s	Grocery Industry	(Cachon and Fisher 1997), (Waller et al. 1999)	Since the implementation of CRP in the grocery industry, CRP has been implemented in many other SC sectors often under the name of Vendor Managed Inventory (VMI). VMI extends the collaboration area further to various supply chain functions.
Collaborative Planning, Forecasting and Replenishment (CPFR)	Late 90’s	Walmart	(Sherman 1998), (Fliedner 2003) (Sari 2008)	CPFR engages all the partners of supply chain all the way from supplier to end customer in order to make the supply chain as efficient as possible by collaborating intensively. While CPFR generally results in higher benefits, the conditions that rationalize upgrading from CRP to CPFR should be justified.

Research in the area of supply chain collaboration (SCC) can be classified as either conceptual or analytical. Conceptual works mostly defined the required framework for implementing, maintaining and improving SCC initiatives (Simatupang and Sridharan 2005,Doukidis et al. 2007,Cao et al. 2010). On the other hand, analytical studies have focused on quantifying the performance of SCC programs. They mostly used simulation or mathematical modeling to evaluate the impact of supply chain parameters on the performance of SCC programs under certain assumptions (Cachon and Fisher 1997,Lee et al. 2000,Cachon and Fisher 2000,Cheung and Lee 2002,Çetinkaya and Lee 2000,Chen and Chen 2005,Yao et al. 2007,Southard and Swenseth 2008,Ramanathan 2014). Although such assumptions limit the applicability of the models, the pool of such studies has played a significant role in the advancement of SCC programs in different supply chain sectors. Parsa et al. (2016) provide a data-driven model that estimates the cost savings of CRP relationships for both partners. The application of the model in a healthcare supply chain case study is thoroughly discussed in the paper. The analytical studies that quantify the benefits of SCC programs under separate cost components are good complements to this work since they provide useful insights into the quantitative decision factors of starting a SCC program.

Multiple criteria decision making (MCDM) methodologies have been used and implemented in a variety of problem areas such as: forest management and planning (Ananda and Herath 2009), ABC inventory classification (Ramanathan 2006), selecting and evaluating suppliers in supply chain management (Zaeri et al. 2011,Vijayvagy 2012), in technology selection (Ghazinoory et al. 2012), in civil engineering problems like seismic structural retrofitting (Caterino et al. 2009), as well as healthcare: a bibliometric analysis on using Multi-criteria decision analysis techniques can be found in Diaby et al. (2013).

A problem's characteristics determine the most appropriate MCDM technique to be used, since different techniques have different capabilities. A review of MCDM techniques and classification can be found in Triantaphyllou et al. (1998). Common MCDM techniques were discussed through the literature review performed by Velasquez and Hester (2013), showing their applications, strengths and weaknesses.

The closest research stream to this paper is the supplier selection problem, which is a very common problem in the supply chain space. MCDM techniques have been used in this domain extensively. Agarwal et al. (2011) reviewed literature for most popular techniques used for this problem. They found in more than 60 articles that the most common methods are data envelopment analysis (DEA), mathematical programming (linear programming, integer-linear programming, integer-non-linear programming, goal programming, and multi-objective programming), analytical hierarchy process (AHP), case based reasoning (CBR), analytic network process (ANP), fuzzy set theory, multi-attribute rating technique (SMART), genetic algorithm, and criteria based decision making methods (ELECTREE and PROMETHEE), with DEA as the most prominent one.

According to Belton and Stewart (2002), it is not recommended to fragment methods and use them separately, instead, they recommend using more than one technique to produce a more solid framework of approaching the decision. The reason behind this is to eliminate weaknesses of techniques and benefit from their strong points. For example, goal programming does not weight coefficients, and a method like AHP does weight coefficients, and then use the goal programming to choose from a large set of alternatives (Velasquez and Hester 2013). Supplier selection is approached using a combination of AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in a consolidated decision model by Vijayvagy (2012). The evaluation of suppliers in the auto industry using the ANP-TOPSIS approach was performed by Shahroudi and Rouydel (2012). Another combination between multi-attribute utility theory and linear programming was proposed by Sanayei et al. (2008) as an integrated group decision-making process for supplier selection and order allocation. The additive utility model was used in his research. In this work, we used multi-objective decision analysis (MODA) with an additive value model to evaluate alternatives. MODA is a decision making process which involves inherently a combination of approaches to assess the modeling elements.

Decisions can be made either individually or by a group, with the group decision making being difficult to consolidate. A study on multi-criteria group decision making based on bilateral agreements was conducted by Xia and Chen (2015). There is no right answer to the decision problem, since it is based on subjectivity (Belton and Stewart 2002). MCDM will guide the decision process, and provide a more transparent decision through focusing on trade-offs of different objectives. This paper proposes a multi-objective decision making model that integrates both the quantitative and qualitative decision factors that are involved in the decision making process from the perspective of both the manufacturer and the distributor. A range of decision factors from operational to strategic levels are identified and considered in the model.

PROBLEM DESCRIPTION

Supply chain collaboration programs such as CRP proved their capabilities in reducing the cost of operating the supply chain. However the potential partners might consider other factors that outweigh the cost savings of a CRP. Those factors are generally qualitative factors and may have considerable influence during the decision making process. Factors such as trust, team attitude, cooperation, power shift, implementation capability and shared business philosophies are all potential factors in the decision. Quantitative and qualitative decision factors cannot be combined easily from the perspective of a decision maker because some factors may conflict with others. Therefore, potential business partners often have difficulty in analyzing a potential CRP relationship considering all the positive and risky consequences. They sometimes have opposite opinions about the possibility of certain consequences. In this paper, we propose a decision model that integrates both quantitative and qualitative decision factors, prioritize them and enable the decision makers to investigate the trade-offs between conflicting objectives. The model can be used by each potential partner separately and the output is a value that reflects the preferences of each partner with regards to the decision factors. Obviously, closer numerical values mean closer perspectives from the stakeholders to the decision problem.

METHODOLOGY

In this section we first discuss the components of MODA in general and how they support the decision making process. The second part of this section is focused on applying MODA on the problem to integrate quantitative and qualitative decision factors of starting a supply chain collaboration program between two partners.

Multiple Objective Decision Analysis (MODA)

MODA is an evaluation methodology that uses the information developed from stakeholder analysis to measure how well candidate solutions satisfy the fundamental objective of the stakeholders in a decision making problem. In essence, it measures the future value of an implemented solution to the decision problem (Parnell et al. 2011). Prior to measuring the value of any candidate solution, a qualitative model must be constructed that captures the critical objectives of the stakeholders. Once the qualitative model is completed, MODA will quantify the value of each candidate solution with respect to the objectives that are identified in the qualitative model. Therefore the process can be listed as follows:

1. *Collect the views of stakeholders*
   The stakeholders of a decision problem are the parties that are influenced by the decision.
2. *Determine the fundamental objective*
   The most basic and high level objective the stakeholders are trying to achieve.
3. *Determine the objectives and sub-objectives*
   Any fundamental objective contains different aspects so it can be broken out to specific objectives that each points out to one aspect of the fundamental objective.
4. *Construct the value tree*

A pictorial representation of hierarchy of identified objectives. The fundamental objective is placed on the top of the tree while the relations between objectives and sub-objectives shape the value tree.

5. *Determine the value measures*
   Each objective at the lowest level of the value tree needs a value measure. A measure, with natural or constructed scales, assesses how well each candidate solution attains the corresponding objective.

6. *Determine the value functions*
   Each value measure has a different scale with different units. Value functions are used to convert candidate solution scores on the value measures to a standard unit.

7. *Weights*
   A value, usually between 0 and 1, that represents the importance of an objective to stakeholders. The weights of sub-objectives under one objective should sum to 1, while the weights of objectives under the fundamental objective should also sum to 1.

8. *Quantitative value model*
   This is a quantitative method for trading off conflicting objectives (Kirkwood 1996). Although different mathematical relationships can achieve this, we use the most common method called the additive value model to calculate the value of each candidate solution.

A complete review of MODA can be found at (Parnell et al. 2011) where different aspects of the methodology are investigated along with examples from various application areas.

Model Development

This section is focused on developing a MODA model by following the steps mentioned above. As stated before, this work is motivated by a disagreement that existed between two major partners in healthcare sector over the value of a continuous replenishment program (CRP). They apparently had different views on the benefits of CRP. In order to propose a constructive approach towards reaching an agreement, MODA was selected to help in this process.

After series of interviews with key decision makers at both sides, a set of questions were designed on the issues that appeared during the interviews and also discussed in the literature as critical points of agreement for future success in CRP relationships. The questions were then distributed to a wide range of responders within both organizations including middle to top-level managers. Based on the responses, the most important objectives of the stakeholders were identified, which led to determining the fundamental objective, objectives and eventually the value tree. The value tree was then slightly modified through joint discussion sessions with individuals from both organizations. The involvement of both sides in this effort is critical for making it a successful path towards a sustainable agreement. Figure 1 illustrates the final version of the value tree. Objectives 1 through 4 are focused on quantitative impacts of CRP while objectives 5 & 6 are qualitative. In this hierarchy, the sub-objectives support the objectives and objectives support the fundamental objective. In other words, each objective can be achieved if its sub-objectives are achieved and likewise, the fundamental objective would be achieved if the objectives are satisfied.

The next step is to determine value measures with appropriate scales for each sub-objective. Value measures are developed based on their alignment with the objective and their scale of measurement. Value measure scales are either natural or constructed scales (Parnell et al.

2011). For example, “days on hand” is a natural scale for sub-objective 2.1 in Figure 1. On the other hand, constructed scale is required for sub-objective 5.2 because trust cannot be naturally measured. Table 2 lists the value measures, their corresponding scales and general shape of the value functions.

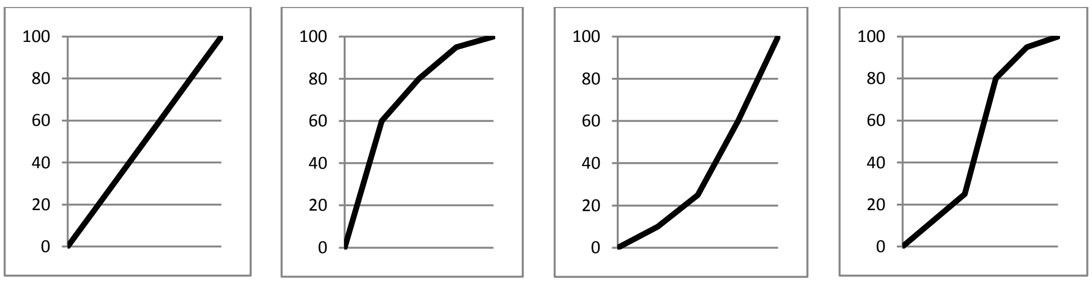
Figure 1: Value tree

Table 2: Value measures, scales and functions

Sub-objective	Value measure	Type	Scale	Value function type
1.1	Avg back order time	Natural	[0, 30] days	Decreasing S shape
2.1	Avg days on hand	Natural	[20, 30] days	Decreasing concave
2.2	MAPE	Natural	[0%, 20%]	Decreasing linear
3.1	Avg vehicle utilization	Natural	[30%, 80%]	Increasing concave
3.2	Avg percentage of FTL shipments	Natural	[0%, 100%]	Increasing linear
3.3	Avg percentage of damaged goods	Natural	[0%, 10%]	Decreasing linear
4.1	Avg weekly order frequency	Natural	[0.5, 5]	Decreasing S shape
4.2	Avg weekly quantity per line	Natural	[1, 50] lines	Increasing linear
4.3	Automation level	Constructed	5 levels	Increasing concave
4.4	Communication level	Constructed	5 levels	Increasing linear
4.5	Percentage of delivery within the window	Natural	[60%, 100%]	Increasing convex
5.1	Execution capability level	Constructed	5 levels	Increasing linear
5.2	Trust	Constructed	5 levels	Increasing linear
5.3	Coordination	Constructed	5 levels	Increasing linear
6.1	Level of affiliation	Constructed	4 levels	Increasing linear
6.2	Avg distance traveled per ton	Natural	[250, 1000]	Decreasing linear

Once the value measures and their scales are determined, the corresponding value functions should be identified. For a single-dimensional value function, the x-axis is the scale of the value measure (e.g., days on hand) and y-axis is a standard unit of value scaled from 0 to 100. Continuous value functions typically follow four basic shapes of linear, concave, convex, and S curve (Figure 2). Depending on the impact of each value measure, value functions could be either monotonically increasing, as indicated in Figure 2, or decreasing. As suggested in (Kirkwood 1996), the shape of value functions are determined by consulting with subject experts. Once the general shape is determined, the experts should identify the increase/decrease in value from a specific incremental increase in the measure scale. Doing this multiple times up to the maximum on the measure scale will produce a piecewise linear function. The instance functions in Figure 2 are produced in linear piecewise fashion.

Figure 2: Value function types



As Table 2 shows, appropriate scales must be constructed for the value measures that do not have natural scales. The scales need to be sufficiently clear and specific so the decision makers can determine the score of each candidate solution (Table 3). Constructing piecewise linear value functions for each value measure is the next step.

There are sixteen value measures in the model and each needs a value function. Although the general shapes are determined with the help of subject experts, the piecewise linear functions need to be constructed. This process is discussed in this paper for one value measure and the same approach could be used for developing similar functions for others. Note that the rest of the discussion represents ongoing work and has not been confirmed with the stakeholders.

As an example, consider the value measure of sub-objective 2.1, days on hand, from Table 2. Since the objective is to minimize days on hand, less days on hand is better. We first set the limits of the x-axis of the function for days on hand. These limits are determined based on what is expected as an ideal solution and worst feasible solution for average days of on hand inventory. Based on experts' opinions, the best we can achieve is 20 days and the maximum acceptable days of inventory is 30 days due to the distribution center capacity. Experts say the general shape of the value curve is decreasing concave. With 24 or less days, the candidate solution has a high value of 90 or above, but the value decreases rapidly beyond 24 days. The resulting value function (Figure 3) is piecewise linear, generally following the concave shape. Once this process is complete for every measure, a candidate solution's value for each measure can be derived from the constructed value functions using the candidate solution score. This process is the same for measures with constructed scales.

$\boldsymbol{x_i}$ is the score of measure $\boldsymbol{i}$ on the x-axis of value function $\boldsymbol{i}$k

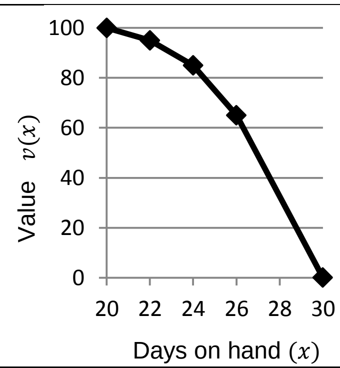
$\boldsymbol{v_i(x_i)}$ is the value of measure $\boldsymbol{i}$ on the y-axis of value function $\boldsymbol{i}$i-j

Table 3: Constructed scales for value measure with no natural scales

Automation level	
Level 0	Paper based methods for ordering, handling and receiving (OHR) activities. No telephone or fax
Level 1	Telephone and fax for ordering + paper based receiving (no scanning device)
Level 2	Email or GHX ordering and online shipment release confirmation + manual receiving (no scanning device)
Level 3	EDI ordering and ASN capability + minimal scanning in receiving (pallet level scanning)
Level 4	EDI ordering and ASN capability + full scanning capability in receiving (case level scanning)
Communication level	
Level 0	Indirect contact with customer service representatives (Email, Fax)
Level 1	Direct, real-time contact with customer service representatives (Telephone)
Level 2	Dedicated customer service representative (single point of contact)
Level 3	Highly skilled planner
Level 4	Dedicated highly skilled planner
Execution capability	
Level 0	Not capable: no experience
Level 1	Beginner: less than 1 year experience
Level 2	Intermediate: between 1 and 5 years of experience
Level 3	Good: between 5 and 10 years of experience with proven results
Level 4	Mastery: More than 10 years of experience with proven results
Trust	
Level 0	Opposite values and strong competition, Not mutual interests, One tries to have the upper hand
Level 1	Competition exists, transparency will harm, confidentiality provides an edge
Level 2	Neutral, partners are not willing to give aid to each other
Level 3	Partners are concerned about the shortcomings of each other and they are willing help sincerely
Level 4	Fully aligned goals, full transparency with minimal confidentiality
Coordination	
Level 0	No meeting and no coordination in failure occasions
Level 1	Occasional meetings for report exchange but no cooperative tactical planning
Level 2	Regular meeting to reactively tackle the problems
Level 3	Regular meeting with pro-active attitudes to avoid problems
Level 4	Regular and engaged meetings for cooperative tactical planning for production and distribution
Level of affiliation	
Level 0	No business affiliation
Level 1	Regular business relationship with no long term commitment
Level 2	Strategic business relationship with commitment
Level 3	Long term partnership agreement

Figure 3: value function for minimizing days of on hand inventory

x	$v(x)$
20	100
22	98
24	90
26	65
30	0



Typically, stakeholders do not view all value measures equally. In this problem, there are two stakeholders (i.e., manufacturer and distributor) and each has a different point of view and preferences towards the value measures of the model. Each stakeholder assigns different weights to the measures and also different scores to the measures which eventually produce two different overall values for each candidate solution. The weights depend on both the importance of the value measure and the impact of varying the score of value measures. We assess measure weights using the swing weight method by “swinging” the value measure score from its worst to its best. There are various ways to elicit weights from stakeholders which are discussed in (Kirkwood 1996,Clemen and Reilly 1999).

To develop weights, a matrix can be constructed in which the columns define the importance of the measures and rows define the impact of changing the value measures over their range (Table 4 and Table 5). A measure that is very important in arriving at a solution and any change across its range has a large impact on the decision should be placed on top left corner of the matrix. Also a measure with the opposite of such characteristics should be placed at the bottom right corner of the matrix. An arbitrary high number such as 100 should be assigned to the measure at the top left corner and an arbitrary low number such as 10 will be assigned to the measure at the bottom right corner. This arbitrary number is notated as $\boldsymbol{f_i}$ in the matrix. Once the measures are placed in the matrix and $\boldsymbol{f_i}$ values are determined, the measure weights ($\boldsymbol{w_i}$), that are normalized values of $\boldsymbol{f_i}$, can be computed using the following formula:

$$\boldsymbol{w_i} = \frac{\boldsymbol{f_i}}{\sum_{i=1}^{n} \boldsymbol{f_i}}$$

Table 4: Swing weight matrix for determining measure weights (Manufacturer)

		Level of importance of the value measure								
		Critical			Important			Useful		
		Measure	f_i	w_i	Measure	f_i	w_i	Measure	f_i	w_i
Variation in measure range	Significant impact	3.2	100	0.10	4.3	80	0.08	5.2	65	0.07
		3.1	85	0.09	5.3	72	0.08	4.5	60	0.06
	Some impact	4.1	77	0.08	3.3	65	0.07	4.4	50	0.05
		4.2	70	0.07	1.1	55	0.06	5.1	35	0.04
	Minor impact	2.2	55	0.06	6.1	45	0.05			
					2.1	30	0.03	6.2	10	0.01

Table 5: Swing weight matrix for determining measure weights (Distributor)

		Level of importance of the value measure								
		Critical			Important			Useful		
		Measure	f_i	w_i	Measure	f_i	w_i	Measure	f_i	w_i
Variation in measure range	Significant impact	2.1	100	0.11	5.1	80	0.09	5.2	65	0.07
		4.2	85	0.09	4.5	72	0.08	4.1	60	0.06
	Some impact	1.1	77	0.08	4.4	60	0.06	3.1	35	0.04
		2.2	65	0.07	4.3	55	0.06			
	Minor impact	3.3	60	0.06	3.2	35	0.04			
		5.3	45	0.05	6.2	25	0.03	6.1	10	0.01

Once the measure weights for both stakeholders are determined, the quantitative value model can be formed for each stakeholder. The values of candidate solutions from the standpoint of each stakeholder can then be compared. The additive value model, which is the most common value model, is used here to compute the final value of the solutions. The candidate solutions that stakeholders consider in this decision making problem are two alternatives. They can either choose to start a CRP relationship or continue to have a non-CRP relationship.

RESULTS AND DISCUSSION

In this section, we compare the values of both candidate solutions (i.e., CRP and non-CRP) from the perspectives of both stakeholders (i.e., manufacturer and distributor). Table 6 shows the differences between stakeholders' views on each sub-objective with regard to both solutions. Total value of the solutions from the perspective of each stakeholder is computed in the last row of the table. Note that the total value of each solution can vary between 0 and 100.

As Figure 4 shows, the non-CRP relationship has an approximately equal overall appeal to both stakeholders. This might be the reason that they have sustained this relationship for a long time. However, the overall value of 62.04 and 64.83 are not very satisfying since there is a significant room for improvement in this business relationship. This is why they are looking for an alternative arrangement that can improve the value of their relationship. CRP as a general practice has been very appealing to many business partners in various sectors but the result of this study shows that there is a disagreement between the partners on the future value of CRP. While CRP increases the value of this business relationship for the manufacturer by 16 points ($\cong \mathbf{26}\%$), the distributor does not expect any overall increase. However, as both Figure 4 and Table 6 indicate, with the exception of a few value measures, the distributor's value on every value measure slightly increases or stays at the same level by moving from non-CRP to CRP. This means those few measures are the main reason for the slight decrease in the overall value for the distributor.

$\boldsymbol{V_m(CRP)}$: is the total value of CRP from the perspective of manufacturerk
$\boldsymbol{V_m(NonCRP)}$: is the total value of non-CRP from the perspective of manufacturer
$\boldsymbol{V_d(CRP)}$: is the total value of CRP from the perspective of distributor
$\boldsymbol{V_d(NonCRP)}$: is the total value of non-CRP from the perspective of distributor

Figure 4: Distribution of values between the value measures

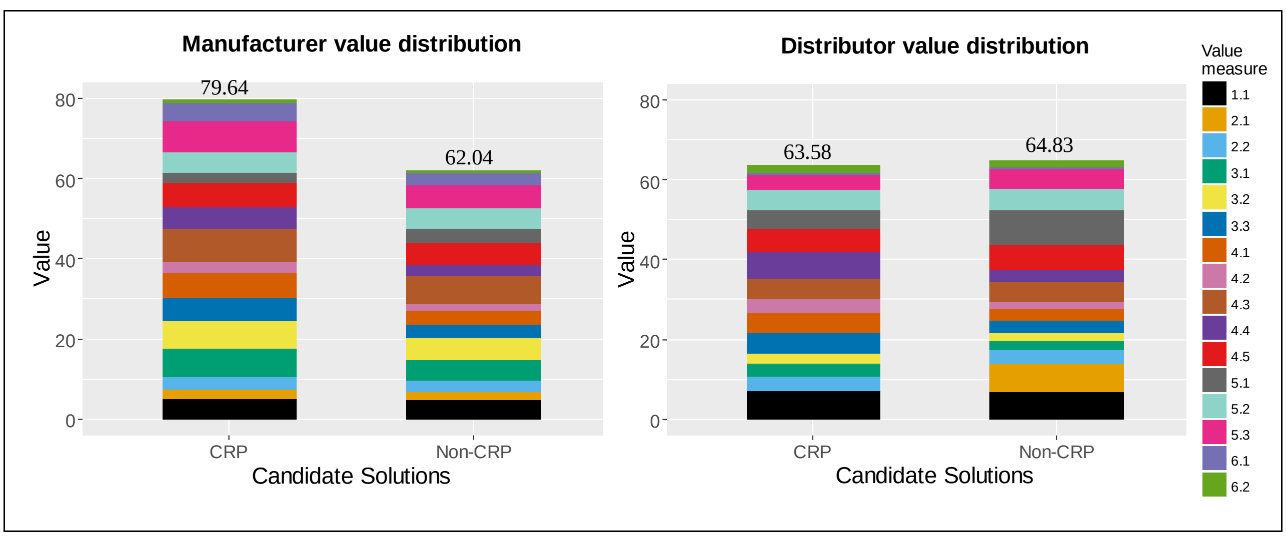
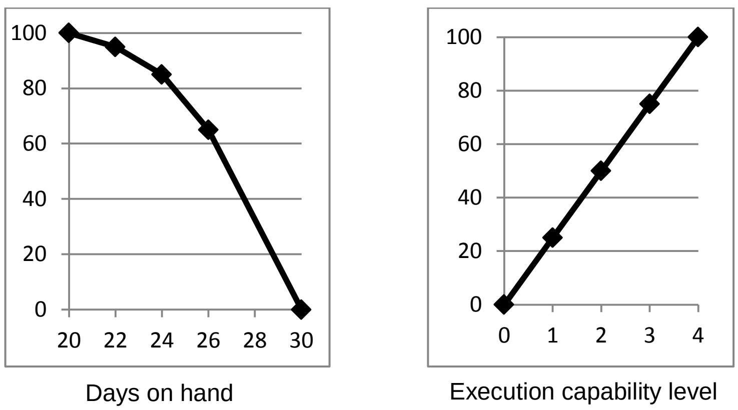


Table 6: Values of each candidate solution from the perspective of stakeholders

Stakeholder:	Manufacturer							Distributor						
Solution:		Non-CRP			CRP				Non-CRP			CRP		
Sub objective / Measure	Weight (w_i)	Score (x_i)	Value $v_i(x_i)$	$w_i v_i(x_i)$	Score (x_i)	Value $v_i(x_i)$	$w_i v_i(x_i)$	Weight (w_i)	Score (x_i)	Value $v_i(x_i)$	$w_i v_i(x_i)$	Score (x_i)	Value $v_i(x_i)$	$w_i v_i(x_i)$
1.1	.0577	10	82.5	4.76	7	90	5.19	.0829	10	82.5	6.84	9	85	7.05
2.1	.0314	26	65	2.04	26	65	2.04	.1076	26	65	7.00	30	0	0
2.2	.0577	0.1	50	2.88	0.09	55	3.17	.0700	0.1	50	3.50	0.09	55	3.85
3.1	.0891	0.5	58.34	5.20	0.65	80	7.13	.0377	0.5	58.34	2.20	0.65	80	3.01
3.2	.1048	0.51	51	5.35	0.67	67	7.02	.0377	0.51	51	1.92	0.67	67	2.52
3.3	.0681	0.05	50	3.41	0.02	80	5.45	.0646	0.05	50	3.23	0.02	80	5.17
4.1	.0807	3	42.5	3.43	2	80	6.46	.0646	3	42.5	2.74	2	80	5.17
4.2	.0734	10.5	21	1.54	18.76	37.52	2.75	.0915	10.5	21	1.92	18.76	37.52	3.43
4.3	.0839	3	85	7.13	4	100	8.39	.0592	3	85	5.03	3	85	5.03
4.4	.0524	2	50	2.62	4	100	5.24	.0646	2	50	3.23	4	100	6.46
4.5	.0629	0.85	87.5	5.50	0.9	95	5.97	.0775	0.8	80	6.20	0.8	80	6.2
5.1	.0367	4	100	3.67	3	75	2.75	.0861	4	100	8.61	2	50	4.31
5.2	.0681	3	75	5.11	3	75	5.11	.0700	3	75	5.25	3	75	5.25
5.3	.0755	3	75	5.66	4	100	7.55	.0484	4	100	4.84	3	75	3.63
6.1	.0472	2	66	3.11	3	100	4.72	.0108	2	66	0.71	2	66	0.71
6.2	.0105	550	60	0.63	500	66.67	0.70	.0269	550	60	1.61	500	66.67	1.79
		$V_m(nonCRP) =$		62.04	$V_m(CRP) =$		79.64		$V_d(nonCRP) =$		64.83	$V_d(CRP) =$		63.58

The value measures for sub-objectives 2.1 and 5.1 are negatively affected by significant margins. As Figure 1 shows, sub-objective 2.1 is minimizing on hand inventory and sub-objective 5.1 is maximizing execution capability. Apparently, the distributor believes CRP increases the inventory levels from average of 26 days of demand (current, non-CRP status) to 30 days. Also, the distributor is skeptical about the manufacturer's execution capability in CRP as opposed to non-CRP. Based on the measure weights, these two sub-objectives are the most important and the third most important objectives from the perspective of distributor therefore any change in their scores has a significant impact on the overall value. The value functions of these two measures are shown in Figure **5**.

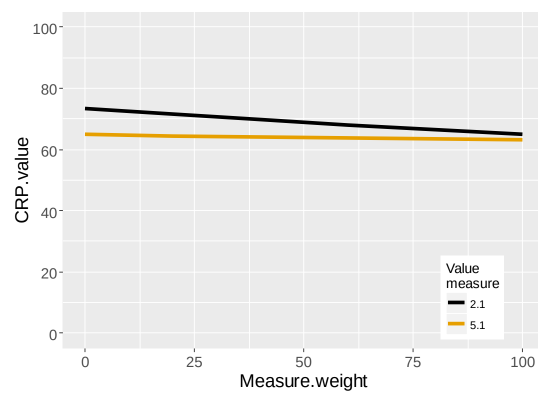
Figure 5: Value function of average inventory days on hand (left) and execution capability (right)



The impact of assigned weights to these measures is illustrated in Figure 6. While reducing the measure weight (f_i) of sub-objective 2.1 from 100 to zero can increase the overall value of CRP by almost 9 points, the weight of sub-objective 5.1 does not have a significant impact. The measure weights are varied one at a time assuming the weights of the other measures stay at the original level.

Figure 6: Sensitivity of CRP value to critical measure weights

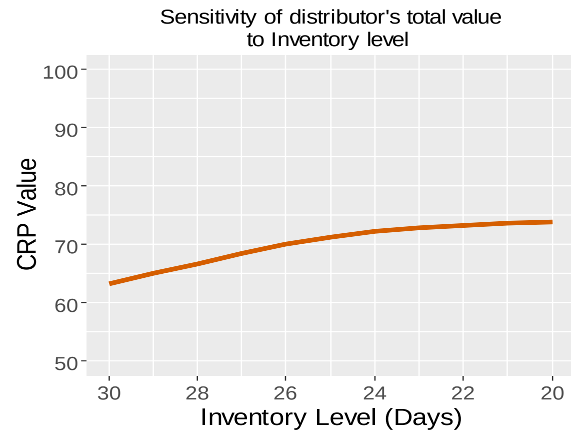
Measure weight (f_i)	Obj 2.1	Obj 5.1
0	73.52	64.86
20	71.61	64.52
40	69.79	64.19
60	68.07	63.88
80	66.42	63.58
100	64.86	63.29



Similarly, the impact of average days of on hand inventory on the value of CRP is illustrated in Figure 7. Sub objective 2.1, minimizing on hand inventory, is the most important sub-objective for distributor (**Table 5**) and is negatively affected the most from the perspective of distributor in CRP (Figure 4.). The sensitivity analysis on this value measure shows that by reducing days of on hand inventory from 30 days, the value of CRP increases quickly until approximately 24 days where the slope of increase in value of CRP is significantly reduced. This analysis provides useful information to both partners about the difference of views on the most controversial objective. This motivates a constructive negotiation process on this objective which can lead to a guaranteed level of on hand inventory level from the manufacturer.

Figure 7: Sensitivity of CRP value to average days of on hand inventory

Measure score (x_i)	CRP value $v(x)$
30	63.58
29	65.01
28	66.72
27	68.43
26	70.14
25	71.20
24	72.25
23	72.78
22	73.30
21	73.57
20	73.83



CONCLUSIONS AND FUTURE WORK

There are conflicting objectives associated with starting a supply chain collaboration program such as CRP. In addition, the stakeholders do not have the same view on the consequences of such programs. Therefore, reaching a sustainable agreement is very challenging and sometimes discourages both potential partners from the program. This paper models this decision making process by integrating the qualitative and quantitative decision factors in an framework that enables the stakeholders to quantify and communicate their views and preferences with each other. The model is in implementation process in a case study that involves a manufacturer and a distributor from healthcare sector. The preliminary results indicate that the stakeholders hold different views on each objective. The disagreement areas as well as critical sub-objectives that have significant impact on the decision outcome are identified.

One of the future research topics related to this paper is separating the analysis of quantitative (cost related) objectives and qualitative objectives. This way, the value should only represent the qualitative aspects of a candidate solution. Thus, cost of each solution will be evaluated across its value not as a part of it. Therefore, each solution will have a cost figure and a value figure and they can be different from the perspective of each stakeholder. This would enable the decision makers to evaluate the solutions and their positions on them in a two dimensional space, defined by cost and value.

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