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Supply-side collaboration and its value in supply chains

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Abstract

Collaboration has been recognized as a significant process that holds the value creation opportunity in supply chain management. Evaluating the value of collaboration is thus necessary for developing the effective collaboration mechanisms. This paper presents the evaluation approach specifically focusing on the supply-side collaboration on inventory decisions between a supplier and a distributor in a two-echelon supply chain. Two scenarios are compared. In the traditional scenario, the distributor is unaware of the supplier's inventory decisions and merely makes its own inventory decisions according to the available information. In the second scenario with supply-side collaboration, the distributor considers the supplier's inventory policy (r, Q) and the planned service level as provided by the supplier. The numerical experiments show that the supply-side collaboration has the ability to improve the supply chain performance in terms of better stabilizing effect and service level.

Keywords: Supply chain management; Supply-side collaboration; Inventory; Performance evaluation

1. Introduction

A traditional supply chain is a sequence of weakly connected activities and decisions both within and outside of the organization. This lack of cohesion destroys value in the supply chain. Collaboration is thus recognized as a significant process that holds the value creation opportunity which can drive effective supply chain management (Bauknight, 2000; Anderson and Lee, 1999). However, due to the complexity of supply chains, the modes and levels of collaboration are numerous. The typical collaboration modes in supply chains involve demand-side collaboration, supply-side collaboration and overall synchronization. The levels of collaboration in each mode vary from the basic execution through operational planning to cooperative optimization of supply chains (Roche, 1999). Thus, the collaboration mechanisms might be very different and complicated. In order to develop effective collaboration mechanisms, collaboration needs to be evaluated to both estimate its value and identify the factors that influence the decisions in supply chains.

In literature reviewed, most of the researchers evaluate the value of collaboration at demand side in terms of demand information sharing,

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collaborative forecasting and joint inventory replenishment etc. For example, Chen (1998) assesses the value of centralized/shared demand information by addressing two variations of the reorder point/order quantity policy. Gavirneni et al. (1999) evaluate the value of information in capacitated supply chains. They consider three situations to estimate the savings at the supplier. Kaipia and Holmstrom (2000) present a method for measuring and demonstrating the benefits of open information sharing in a supply chain with demand-side collaboration. Cachon and Fisher (2000) study the value of sharing demand and inventory data. They compare a traditional information policy that does not use shared information with a full information policy that does exploit shared information. Lee et al. (2000) analyze the benefit of demand-side information sharing to a two-stage supply chain that consists of a retailer and a manufacturer. Their analyses suggest that this kind of information sharing alone could provide significant inventory reduction and costing savings to the manufacturer.

While the demand-side collaboration has been proven to be significant for supply chain management, the associated information flow and the resulting benefits are often asymmetrical. To leverage on the impacts and align the incentives, supply-side collaboration is considered as a complementary approach towards the overall synchronization of supply chains. In this respect, Swaminathan (1996) analyzes the impact of supplier available-to-promise information on the performance of different entities in an inter-organizational supply chain. Zipkin (2000) also points out that incorporating the supplier's planning information such as the stock-out waiting time into the customer's decision-making process is important. Nevertheless, although the benefits of supply-side collaboration are intuitively clear, the literature is scant on the quantification of the benefits. Thus, evaluating the value of supply-side collaboration is valuable and imperative for developing the effective collaboration mechanism.

This paper differs from the previous researches by focusing on the evaluation of supply-side collaboration. We incorporate information flow and collaborative inventory decisions between a supplier and a distributor in a two-echelon supply chain. Different from the work as addressed in Gavirneni et al. (1999) and Lee et al. (2000) etc., the supply-side collaboration model in this research is built and evaluated from the distributor's point of view. The major difference between the demand-side collaboration model and supply-side collaboration model is that the latter considers the potential stock-out waiting time information at the upstream sites which would increase the replenishment lead time for the downstream sites. For the sake of comparison, two scenarios are considered. In a traditional scenario (Fig. 1), the distributor is unaware of the supplier's inventory decisions and merely makes its own inventory decisions according to the available nominal information. In the second scenario (Fig. 2), the distributor considers the supplier's inventory policy (r, Q) and the planned service level as provided by the supplier. The inventory decisions made by the distributor will consider the supplier's inventory decisions and potential stock-out information. In both scenarios, the distributor and the supplier share the demand information from the downstream sites. The numerical experiments show that the distributor with supply-side collaboration exhibits better performance in terms of improved service level and stabilizing effect (or bullwhip effect).

The rest of paper is organized as follows. Section 2 presents the mathematical models for evaluating the value of supply-side collaboration. In Section 3, we address the performance indices used in this research. Section 4 contains the numerical

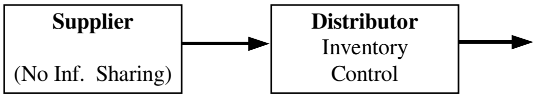

Fig. 1. The traditional supply chain.

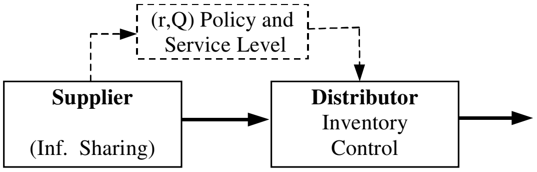

Fig. 2. Supply chain with supply-side collaboration.

experiments and their results as well as some insights. We conclude the paper in Section 5 by summarizing our finds and discussing future work of research.

2. Models for evaluating supply-side collaboration

In this paper, the models assume that both the distributor and the supplier follow the single product, service constrained continuous-review (r, Q) inventory policy. Under this policy, a fixed quantity Q is ordered whenever the inventory position drops to the reorder point r or lower. Note that the distributor and the supplier share the demand information from the downstream sites. The transit time between them is constant. Before continuing with the models, the notations used in this paper are listed as follows:

i	a subscript used in the following notations to represent different supply chain partners. When $i = d$, it refers to the distributor. When $i = s$, it refers to the supplier
f_i	planned service level by partner i (a type II service level measured by fill rate)
r_i	reorder point determined by partner i, in units
Q_i	order quantity set by partner i, in units
$\mu_i(R)$	mean replenishment lead time of partner i, in days
$v_i(R)$	variance of replenishment lead time of partner i, in days^2
$\mu_s(W)$	mean waiting time to demand at the supplier, given that the product is backordered, in days
$v_s(W)$	variance of waiting time to demand at the supplier, given that the product is backordered, in days^2
μ_T	mean transit time between the supplier and the distributor, in days
v_T	variance of transit time between the supplier and the distributor, in days^2
D	average annual demand, in units
μ	mean demand per unit time, in units
v	variance of demand per unit time, in units^2
μ_R	mean demand during replenishment lead time, in units
v_R	variance of demand during replenishment lead time, in units^2
k_i	ordering cost per replenishment cycle at partner i, in dollars
h_i	unit holding cost at partner i, in dollars
SS_i	safety stock set by partner i, in units
SC_i	expected shortage per replenishment cycle at partner i, in units

2.1. Scenario one: traditional supply chain without collaboration

In the traditional supply chain without collaboration, we assume that the inventory decision-making processes at the distributor and the supplier are identical. We thus drop the subscription i $(i = \mathrm{d}, \mathrm{s})$ from the notation to simplify the description of inventory decisions faced by both the distributor and the supplier. Note that all the decision-making processes addressed here are commonly used in practice or research. Considering a service constrained (r, Q) system, the decision on r and Q is critical. For the sake of simplification, we set the order quantity Q through EOQ process as

$$Q = \sqrt{\frac{2Dk}{h}} \tag{1}$$

Thus, reorder point can be obtained through the following equations:

$$\mu_R = \mu\mu(R) \tag{2}$$

$$v_R = \mu(R)v + \mu^2 v(R) \tag{3}$$

$$SC = Q(1 - f) \tag{4}$$

$$SC = -SS\left\{1 - F_s\left(\frac{SS}{\sqrt{v_R}}\right)\right\} + \sqrt{v_R}\, f_s\left(\frac{SS}{\sqrt{v_R}}\right) \tag{5}$$

$$r = \mu_R + SS \tag{6}$$

where we assume that the demand during replenishment lead time is normally distributed. For development of Eq. (5), refer to Chropra and Meindl (2001).

Herein, the supplier is supposed to know the distribution of its own replenishment lead time. However, the distributor is unaware of the supplier's inventory decisions in this scenario as aforementioned. Thus, the distributor merely calculates its replenishment lead time based on the nominal information of transit time from the supplier to the distributor. Therefore, there are

$$\mu_{\mathrm{d}}(R) = \mu_{\mathrm{T}} \tag{7}$$

$$v_{\mathrm{d}}(R) = v_{\mathrm{T}} \tag{8}$$

To further simplify the decision, we assume $v_{\mathrm{T}} = 0$ and thus the replenishment lead time of the distributor is a constant in this scenario.

2.2. *Scenario two: supply chain with supply-side collaboration*

In the scenario with supply-side collaboration, the distributor knows the supplier's inventory policy (r, Q) and the planned service level set by the supplier. Since the supplier's service level (fill rate) is usually less than 100%, there is some waiting time incurred when the distributor's order is backordered. As a result, the replenishment lead time of the distributor, which is not a constant any more, consists of the waiting time when backordered and the transit time from the supplier to the distributor. The distributor will make its inventory decisions by considering the supplier's inventory decisions to estimate the waiting time when backordered. On the other hand, we assume the decision-making processes at the supplier are same as the previous scenario, since we mainly evaluate the supply-side collaboration from the distributor's point of view. Thus, the key point in this scenario is the calculation of the distributor's replenishment lead time which is affected by the waiting time when backordered at the supplier site. The rest of this subsection addresses the issues.

As shown in Fig. 3, in a (r, Q) inventory system, the probability that the waiting time of a customer order from the distributor to supplier is greater than x unit times equals the probability that the demand in $\mathrm{LT} - x$ is greater than or equal to supplier's reorder point r_{s}. That is,

$$P(\mathrm{WT} > x) = P(\mathrm{DLT}x \geqslant r_{\mathrm{s}}) \tag{9}$$

where, WT is the waiting time random in a period, DLTx, demand random in period $\mathrm{LT} - x$.

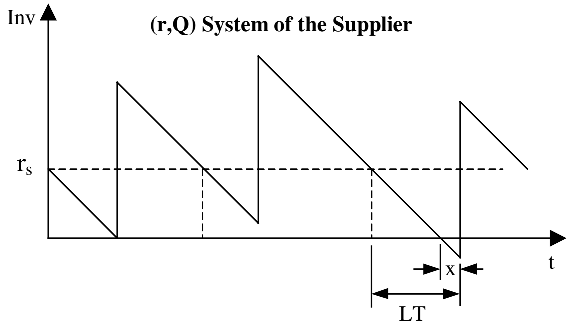

Fig. 3. (r, Q) inventory control.

Note that x is a non-negative integer. We can now deduce the expected waiting time and the variance of waiting time when backordered as follows:

$$\mu_{\mathrm{s}}(W) = \frac{\sum_{x=0}^{N} [1 - F(z_x)]}{1 - F(z_0)} \tag{10}$$

$$v_{\mathrm{s}}(W) = \frac{\sum_{x=0}^{N} (2x+1)[1 - F(z_x)]}{1 - F(z_0)} - \left[\frac{\sum_{x=0}^{N} [1 - F(z_x)]}{1 - F(z_0)}\right]^2 \tag{11}$$

where $F(z_x)$ is the cumulative function of normal distribution and $z_x = (r_{\mathrm{s}} - \mu_{\mathrm{DLT}x})/v_{\mathrm{DLT}x}$. For details, refer to Appendix A in this paper.

Based on the values of $\mu_{\mathrm{s}}(W)$ and $v_{\mathrm{s}}(W)$, we thus obtain the mean and variance of replenishment lead time of the distributor as follows:

$$\mu_{\mathrm{d}}(R) = \mu_{\mathrm{T}} + (1 - f_{\mathrm{s}})\mu_{\mathrm{s}}(W) \tag{12}$$

$$v_{\mathrm{d}}(R) = v_{\mathrm{T}} + (1 - f_{\mathrm{s}})^2 v_{\mathrm{s}}(W) \tag{13}$$

Finally, the decisions on reorder point and order quantity of the distributor can be carried out according to the equations from (1)–(6) as in scenario one.

3. Performance indices

The distributor's performance is measured in this paper to evaluate the value of supply-side collaboration. The performance indices of interest are percent error of service level and dynamics effect. The percent error of service level is defined as

$$\frac{|\text{actual service level} - \text{planned service level}|}{\text{planned service level}} \times 100\% \tag{14}$$

It is used to compare the accuracy of the decision-making under the aforementioned two supply chain scenarios. The smaller the percent error of service level, the better the performance.

The second performance index, dynamics effect (de), is related to the ratio of the coefficient of variation of demand generated by the distributor ($\mathrm{cv_{out}}$) to the coefficient of variation of demand received by the distributor ($\mathrm{cv_{in}}$). Note that dynamics effect may have two meanings depending on its value:

$$\begin{cases} \text{when}\,\frac{\mathrm{cv_{out}}}{\mathrm{cv_{in}}} \geqslant 1, & \text{it is known as bullwhip effect} \\ \text{when}\,\frac{\mathrm{cv_{out}}}{\mathrm{cv_{in}}} < 1, & \text{it is known as stabilizing effect} \end{cases} \tag{15}$$

Bullwhip effect describes the increase of demand volatility as it passes up through the supply chain (Fransoo and Wouters, 2000). Stabilizing effect describes the decrease of demand volatility on the other hand, as it passes up through the supply chain (Baganha and Cohen, 1998). Bullwhip effect harms the supply chain while stabilizing effect benefits the supply chain. In order to make sense, in this research we define the bullwhip effect (be) and the stabilizing effect (se) as follows:

$$\begin{cases} \mathrm{be} = \frac{\mathrm{cv_{out}}}{\mathrm{cv_{in}}} & \text{when } \frac{\mathrm{cv_{out}}}{\mathrm{cv_{in}}} \geqslant 1 \\ \mathrm{se} = 1 - \frac{\mathrm{cv_{out}}}{\mathrm{cv_{in}}} & \text{when } \frac{\mathrm{cv_{out}}}{\mathrm{cv_{in}}} < 1 \end{cases} \tag{16}$$

The smaller the bullwhip effect or the larger the stabilizing effect, the better the supply chain performance. Thus, we would like to decrease the $\mathrm{cv_{out}}$ in both situations.

4. Experiment and analysis

A simulation is described in this section based on the models of Section 2. The aforementioned performance indices are used to evaluate the results of experiments.

4.1. Numerical experiment

Simulation model of the supply chain is constructed using EXTEND®, which is a widely used simulation platform (Imagine That Inc., 1997). The inputs to the simulation are the demand distribution shared by the distributor and the supplier, the transit time between the distributor and the supplier, and the replenishment lead time distribution of the supplier. The order quantities and reorder points at the distributor and the supplier are determined through the analytical models presented in Section 2. The parameters and their settings are shown in Table 1.

Note that we do a series of experiments by varying the planned service level (from 95% to 98%) at the distributor and the variance-to-mean (VTM) ratio of demand (0.9, 1.6 and 2.5). The simulation is run for 5 years. The simulation results are listed in Table 2.

4.2. Result analysis

The value of collaboration is measured by the performance indices: percent error of service level and stabilizing effect. Based on the data in Table 2, we find that the average error of service level is about 5% in the traditional model (without collaboration). However, in the model with supply-side collaboration, the average error of service level has been greatly improved to less than 1%. The percent error of service level versus planned service level for various VTM ratio of demand is shown in Fig. 4. In general, we observe that the less the VTM ratio and the lower the planned service level, the

Table 1
Input parameters for evaluation

D	μ	v	f_d	k_d	h_d	μ_T	f_s	k_s	h_s	$\mu_\mathrm{s}(R)$	$v_\mathrm{s}(R)$
3600	10	9, 16, 25	95–98%	40	10	7	97%	160	10	7	4

Table 2
Simulated results given various settings

Planned service level (%)	VTM ratio of demand	Actual service level		cv_{out}/cv_{in}	
		Non-collaboration (%)	Collaboration (%)	Non-collaboration	Collaboration
95	0.9	88.15	94.91	0.8147	0.5163
	1.6	89.01	95.06	0.6753	0.4745
	2.5	91.51	95.26	0.6008	0.4812
96	0.9	90.54	96.00	0.7337	0.4860
	1.6	90.90	96.39	0.6005	0.4213
	2.5	92.45	96.44	0.5772	0.4596
97	0.9	91.87	97.51	0.7043	0.4563
	1.6	92.29	97.20	0.5963	0.4220
	2.5	93.33	97.72	0.5734	0.4046
98	0.9	92.86	98.07	0.6280	0.4180
	1.6	93.26	97.93	0.5808	0.3868
	2.5	94.27	98.21	0.5674	0.4066

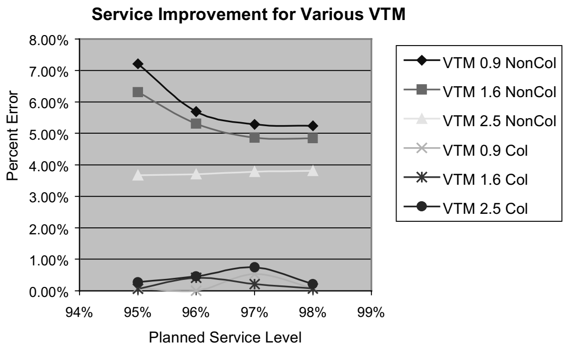

Fig. 4. Comparison of percent error versus planned service level.

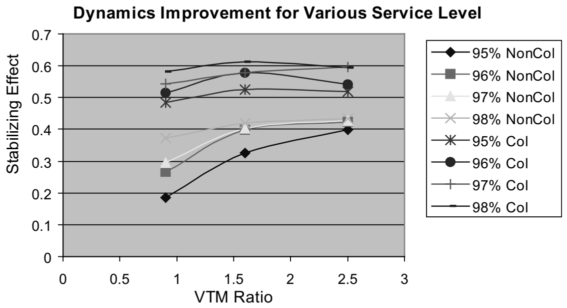

Fig. 5. Comparison of stabilizing effect versus VTM ratio.

more significant the service improvement by applying the supply-side collaboration.

In addition, Table 2 shows that $cv_{out}/cv_{in} < 1$ in both scenarios. Fig. 5 shows the stabilizing effect versus VTM ratio for various planned service levels. The average value of stabilizing effect has been increased from about 0.35 to about 0.55 after applying the supply-side collaboration. It means that supply-side collaboration can perform a stabilizing role by smoothing the flow of demands.

5. Conclusions

This paper addresses the approach to evaluate the supply-side collaboration by focusing on inventory decisions between a supplier and a distributor in a two-echelon supply chain. We have concerned two scenarios for comparison. One has no collaboration with respect to the processes of inventory decision making. The other involves the simple supply-side collaboration in which the distributor is aware of the supplier's inventory policy (r, Q) and its planned service level. Simulations are carried out to measure the distributor's performance before and after applying the supply-side collaboration. The numerical experiments indicate that supply-side collaboration can improve the distributor's performance in terms of more accurate service level realization and better stabilizing effect. However, degree of improvement depends on the planned service level and VTM ratio of demand.

Future work can address the following issues. First, the performance evaluated in the paper only focuses on the distributor. Further evaluation should be extended to measure the performance of the supplier and the whole supply chain. Second, effective collaboration mechanisms need to be developed for supply chain management based on the evaluation. In this evaluation, we noticed that the total inventory cost for supply chain with collaboration might be higher than that without collaboration. The reason might be its higher service level realized. Thus, the optimization based collaboration mechanism is needed to minimize the supply chain's inventory cost subject to the service level requirements. For details on the optimization based collaboration mechanism, readers can further refer to Fu and Piplani (2002).

Appendix A

As shown in Fig. 3, for the random variable DLTx, there exist:

$$\mu_{\mathrm{DLT}x} = [\mu(R) - x]\mu \tag{A.1}$$

$$v_{\mathrm{DLT}x} = [\mu(R) - x]v + \mu^2 v(R) \tag{A.2}$$

Thus, given integer $N = [v_{\mathrm{R}}/v]$, let $x = 0, 1, 2, \ldots, N$ and define $z_x = (r_{\mathrm{s}} - \mu_{\mathrm{DLT}x})/v_{\mathrm{DLT}x}$. From Eq. (9), We can get

$$\begin{cases} P(\mathrm{WT} = 0) = F(z_0) \\ P(\mathrm{WT} = x) = F(z_x) - F(z_{x-1}) \quad x = 1, 2, \ldots, N \\ P(\mathrm{WT} = N+1) = 1 - F(z_N) \end{cases} \tag{A.3}$$

Note that $F(z_x)$ is the cumulative function of normal distribution.

However, we care more about the conditional distribution of waiting time when backordered. As we know,

$$P(\mathrm{WT} = x|\mathrm{Backordered}) = \frac{P(\mathrm{WT} = x)}{P(\mathrm{Backordered})} \tag{A.4}$$

And,

$$P(\mathrm{Backordered}) = P(\mathrm{DLT} \geqslant r) \tag{A.5}$$

where DLT is a random variable of demand during replenishment lead time. It is easy to verify that

$$P(\mathrm{Backordered}) = 1 - F(z_0) \tag{A.6}$$

Therefore, the probability of waiting time when backordered is

$$\begin{cases} P(\mathrm{WT} = x|\mathrm{Backordered}) = \frac{F(z_x) - F(z_{x-1})}{1 - F(z_0)} \\ \qquad x = 1, 2, \ldots, N \\ P(\mathrm{WT} = N+1|\mathrm{Backordered}) = \frac{1 - F(z_N)}{1 - F(z_0)} \end{cases} \tag{A.7}$$

In succession, we can deduce the following equations:

$$\begin{aligned} E(\mathrm{WT}|\mathrm{Backordered}) &= \sum_{x=1}^{N+1} xP(\mathrm{WT} = x|\mathrm{Backordered}) \\ &= \frac{\sum_{x=0}^{N} [1 - F(z_x)]}{1 - F(z_0)} \end{aligned} \tag{A.8}$$

$$\begin{aligned} E(\mathrm{WT}^2|\mathrm{Backordered}) &= \sum_{x=1}^{N+1} x^2 P(\mathrm{WT} = x|\mathrm{Backordered}) \\ &= \frac{\sum_{x=0}^{N} (2x+1)[1 - F(z_x)]}{1 - F(z_0)} \end{aligned} \tag{A.9}$$

As a result, the expected waiting time and the variance of waiting time when backordered as shown in Eqs. (10) and (11) can be calculated respectively from the following:

$$\mu_{\mathrm{s}}(W) = E(\mathrm{WT}|\mathrm{Backordered}) \tag{A.10}$$

$$\begin{aligned} v_{\mathrm{s}}(W) &= \mathrm{Var}(\mathrm{WT}|\mathrm{Backordered}) \\ &= E(\mathrm{WT}^2|\mathrm{Backordered}) \\ &\quad - [E(\mathrm{WT}|\mathrm{Backordered})]^2 \end{aligned} \tag{A.11}$$

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