The Impact of Information Sharing in a Two-Level Supply Chain

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Abstract

Information sharing in the supply chain brings a great advance in business connections to integrate individual activities, thereby reshaping the inter-organizational dynamics and resulting in a more efficient system. In this study, we investigate the impacts of information sharing strategies for a two-stage supply chain consisting of a single manufacturer and multiple retailers. Demand at the retailers is random, but stationary. Each retailer places the orders to the manufacturer according to the continuous review \((Q, R)\) policy. Using a computer simulation model, this paper examines the scenario where the retailer shares the real time demand information to the manufacturer. We investigate how the manufacturer can implement this shared information to its own inventory system to determine the production policy. Analysis of the simulation output demonstrates the impacts of the new policy. Numerical examples indicate that substantial cost savings can be achieved through information sharing.

Keywords
Supply Chain Management, Information Sharing, Simulation

1. Introduction

The information technology has achieved great power of influence to the entire industry. The explosion of information availability provides lots of possibilities and opportunities for the improvements in the supply chain efficiency. In particular, information technology has changed the way companies interact with suppliers and customers. For example, in quick response, suppliers receive Point-of-Sales (POS) data from retailers and use this information to improve their forecast and better manage production and inventory activities [26].

Even though the supply chain can be studied as a logistic network, supply chain management concentrates on the overall benefits of all the members of the supply chain through cooperation and information sharing. The performance of a supply chain depends critically on how its members coordinate their decisions. Sharing information is the most basic form of the coordination in supply chains. Accordingly, the effectiveness of supply chain management tightly depends on the information technology. Nowadays, more and more companies have realized this and enhanced the coordination and collaboration to share their information among supply chain partners. Retailers and manufacturers have shown increasing interests in cooperating to improve the performance of the supply chain and increase their gains [13].

Let us consider a traditional supply chain system which involves activities, information and resources in moving a product or service from supplier to customer. These activities and operations transform the natural resources, raw materials and components into a finished product and deliver to the end customer. Usually a typical supply chain consists of raw material suppliers, assembly manufacturers, distributors and retailers. For each component, based on the information received from its immediate suppliers and customers, every stage manages its operations to control cost and maximize profit, which also impacts on other stages in the supply chain. Thus, each stage makes locally optimal decisions based on the orders placed by its customers, and the replenishment lead time provided by its suppliers. However, this information and control system confronts crucial challenges. The main challenge in a supply chain is the uncertainties, which is usually caused by machine breakdowns, delayed deliveries, order fluctuation, etc.

Uncertainties through the supply chain result in excess safety stock, increased inventory costs and inefficient use of resources. To achieve an effective supply chain system, uncertainties in the system need to be studied. An important
discovery in supply chain practices is that moving up in the supply chain from end-consumer to raw materials supplier, each supply chain participant has a greater observed variation in demand. This phenomenon is known as Bullwhip effect [16]. The main causes of the bullwhip effect have been defined as demand forecasting, order batching, price fluctuation and rationing game [19]. During the last two decades, it has become a major concern for many supply chain systems. For instance in a manufacturing system, this phenomenon can be described as the variance of production exceeding the variance of sales even though the manufacturer can backorder excess demand [14]. To mitigate this effect, information sharing between supply chain partners is therefore adopted to reduce the uncertainty through the supply chain. Several researchers have applied information sharing as the main strategy to counteract the Bullwhip effect (see, e.g., [6, 12]).

Sharing information has emerged as one of the most significant practices in improving the performance of supply chains. There are a number of new emerging technologies available to connect the members of a supply chain to support information sharing. Development over the last several decades in corporate information technology, such as Enterprise Resource Planning (ERP) systems, Vendor Managed Inventory (VMI), Electrical Data Interchange (EDI) and Collaborative Planning, Forecasting and Replenishment (CPFR) allow information to be shared closely and seamlessly between members of a supply chain. However, sharing information also faces significant challenges. The challenges include: incentive issues, confidentiality of the information shared, anti-trust regulations, reliability and cost of information technology, the timeliness and accuracy of the shared information, and finally the development of capabilities that allow companies to utilize the shared information in an effective way [18].

In this paper, we study the impacts of demand information sharing strategies through a simulation model. We want to investigate a two-stage supply chain consisting of one manufacturer and \( N \) identical retailers. We consider the scenario where the downstream retailer shares the real time demand information to the manufacturer, and investigate how to modify the production policy upon this information sharing. Although there are plenty of research which studied the downstream demand information sharing, most of them considered sharing demand patterns or sharing future forecast demand values. Only very limited articles have tackled the problem which takes into account of the real time demand information.

The rest of this paper is organized as follows. In the next Section, we review the related literature in supply chain information sharing. A detailed problem statement and model assumptions are described in Section 3. We also describe the simulation model in this section. In Section 4 some numerical analysis and results are demonstrated. Finally, we made some conclusions and recommendations for future research.

2. Literature Review

Information sharing is a vital aspect of coordination among parties in a supply chain, which provides great of possibilities and opportunities for the improvements in the supply chain efficiency. However, from analytical research perspective, the benefits of sharing information among supply chain members are not always the same. They depend on the supply chain structure (e.g., serial distribution systems), the operational characteristics (e.g., demand patterns and costs involved), and the shared information type (e.g., order information and planning information). Various studies have examined their model based on different structures, operational characteristics, and information types. This section mainly discusses the impacts of information sharing in supply chains according to the literature review.

Academic researchers have addressed strong interests in the information sharing aspect of supply chains. Some review works about information sharing in the supply chain have been done by [11][21]. These reviews are very extensive and have broad scopes in terms of supply chain models, methodologies, and types of information being shared. For example, Huang et al. [11] summarized types of information being shared into six categories: product, process, inventory, resource, order, and planning (see table 1 for details). In our proposed model, we are more interested in considering the inventory, capacity, and demand information. Thus, we mainly review the articles which have considered these types of information.

In the literature, the suppliers in the top of supply chain are usually called the upstream members, while the retailers (or buyers) are called the downstream members. Information sharing can occur between both of the upstream and downstream sources. For example, the upstream supplier may provide detailed information about how much of order is being shipped and when the order will arrive at the downstream. This is called upstream advanced shipping information sharing, which could be particularly important when the upstream supply chain member has processes with yield losses or output uncertainty. An example of sharing downstream information can be found in Vendor Managed Inventory (VMI) platforms where downstream retailers share end customer point of sale (POS) demand data with their upstream
suppliers.

When conducting a thorough literature review for supply chain information sharing, several fundamental questions should be considered: which information should be shared? With whom should it be shared? How it should be shared? And what is the value of such information sharing? In this section, we focus on the articles which have implemented the mathematical models for the information sharing. And we divide the reviews into two categories: downstream information sharing and upstream information sharing.

There are plenty of researches which have considered the downstream inventory and demand information sharing during the last two decades. Researches mainly implemented either the simulation modeling or the analytical model to tackle such problems. First of all, we review several articles which conducted simulation models. Zhao et al. [25] conducted a simulation model to consider one supplier and multiple retailers. The study examined the value of shared forecasting requirements and planned orders from the downstream retailers under different demand patterns. Then Lau et al. [15] extended this research and built similar models to consider different inventory policies. In [24], the authors considered a serial supply chain to build a demand information sharing strategy and use such information to forecast the future demand. A discrete simulation model was designed to examine the impact of demand parameters and lead time on supply chains with and without information sharing. Yu et al. [23] designed production capacity, customer demand and inventory information-sharing scenarios to analyze the supply chain performance through a simulation model. The results demonstrated that the scenario of demand information sharing is the most efficient one.

Researches have considered different supply chain structures, demand patterns and inventory policies to build the analytical models. Gavirneni et al. [8] studied information flow between a supplier and a retailer in a two-echelon model where the supplier knew the retailer ordering policy and day to day inventory level. The paper conducted an estimated model to compute the saving at the supplier due to this information sharing. Cachon and Fisher [3] discussed how sharing demand and inventory information influence the value of supply chain. The model was extended to consider one supplier and N identical retailers under stationary stochastic consumer demand. Through the numerical study, they found that the supply chain costs are lower on average when the information is shared. Later, Lee et al. [17] studied a two-level supply chain with nonstationary end demands, but restricted the demand to be auto-correlated over time. The authors, identified the benefits of downstream information sharing and showed the manufacturer can obtain inventory reduction and cost reduction by sharing the downstream demand pattern. In [20], a one supplier and multiple retailers supply chain inventory model was studied and the (Q, R) replenishment policy was assumed at retailers. The information of the demand and inventory activities at each retailer was shared to the supplier. The paper provided an exact analysis of the analytical model for such information sharing. Recently, Wu and Cheng [22] extended the model to consider a three-echelon supply chain with AR(1) demand. Not only the demand pattern but also the real time inventory information was shared from the downstream to the upstream. The inventory and expected cost in the supply chain was reduced based on the analytical results. There are a number of other papers, which analyze the value of downstream information sharing in supply chains with various different structures, such as [2, 4, 8–10, 16].
While most of the research work has focused on the value of the downstream information sharing, upstream information has received limited attentions in the literature. We could find several articles which are related to our work. Chen and Yu [7] considered the value of lead time information in a single location inventory model with a markovian lead time process where a retailer buys a product from an outside supplier and sells it to her customers. Based on their work, the retailer’s total long-run average costs were calculated when the lead time information was shared by the supplier. In paper [13], a two stage supply chain with reverse information exchange was proposed, where the manufacturer allows the retailer to access to its own inventory status. An exact method was provided for computing performance of the upstream information sharing and a procedure was developed for evaluating optimal policy. More recently, Chen [5] studied the value of revealing suppliers’ production cost information to the buyer when there are multiple suppliers bidding for a buyer’s business. The last paper we found in upstream information sharing is [1], the author considered a single stage, single item inventory system with stochastic capacity. By sharing the dynamic forecasts of the future capacity availability information, the author showed the state-dependent base-stock policy is optimal, and proposed a heuristic policies to compute the value of information sharing.

3. Methodology

3.1 Problem Definition and Assumptions

We consider a traditional two-echelon "manufacturer - retailer" supply chain. As illustrated in figure 1, the manufacturer schedules the production and delivers finish product to the retailer upon its order. Nowadays, in this kind of multi-echelon supply chain, the traditional "push" strategy, represented by "make-to-stock" (MTS) in which the production is not based on actual demand, is shifting to the "pull" strategy, represented by "make-to-order" (MTO) in which the production is based on actual demand, thanks to the advances of information technology. Nevertheless, this promotion is far away sufficient. The reason is that each of supply chain members is primarily concerned with optimizing its locally objectives and such individual serving focus often results in poor performance. For example, the manufacturer may be concerned with the cost of inventory as well as manufacturing fees, while the retailer pays more attention to reduce its order fees and storage cost. In fact, since each echelon makes decisions solely, it is imperative to make coordinated decisions to achieve a system-level optimization.

![Figure 1: Illustration of a two-echelon supply chain](image)

In this work, we study a two-stage supply chain that consists of one manufacturer and \( N \) identical retailers with the following assumptions:

- Demand at the retailer is assumed to follow a Poisson process with rate \( \lambda \).
- The retailer holds stock and satisfies its demand through its on hand inventory, and we assume the excess demand at the retailer is lost.
- The retailer adopts the continuous review \((Q, R)\) replenishment policy to place orders from the manufacturer.
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- Orders placed by the retailer are shipped immediately if the manufacturer has stock; otherwise, the orders are delayed and served in a first-come-first-serve order.
- The manufacturer manages its finished goods inventory using a base-stock production policy.
- We model the manufacturer production system as a single server queue with exponentially distributed processing time with a mean of $1/\mu$.
- The replenishment lead time from the manufacturer to the retailer is a random variable $L$ with known distributions.

We now introduce the information sharing scenarios discussed in this paper, as illustrated in figure 2. In the first scenario, no information will be shared between the members of the supply chain. We call it the "As-Is" model in this paper. The inventories at different member of the supply chain are controlled independently. The manufacturer manages its own inventory based on the arriving demands where retailers make replenishments. In the second scenario, we study the instance where the information of the initial demand at the retailer is shared to the manufacturer so that the manufacturer has the direct knowledge of the incoming demands. We name this scenario as the "DIS" model.

In the "As-Is" model, when the customer demand occurs at the retailer, it is satisfied from the retailer’s available stock. Otherwise, the demand is lost. Under this policy, the inventory position is checked continuously, when it declines to the reorder point $R$, a batch size $Q$ is ordered at the manufacturer. The inventory position is defined as the on-hand inventory plus stock on order minus the number of outstanding backorders. After an order is placed with the manufacturer, an effective lead time takes place between placing the order and receiving it. For the manufacturer, the retailer replenishment orders are satisfied if the on-hand inventory at the manufacturer is greater than or equal to the retailer’s order size. That is, a partial replenishment of an order at the manufacturer is not allowed. For each order it receives from any retailer, the manufacturer updates its inventory position. When it reduces to the base stock level, the single-machine production is triggered.

For the "DIS" scenario, retailers adopt the same replenishment inventory policy. However, when the customer demand arrives, the retailer sends the demand information to the manufacturer at the same moment. To take advantage of this information, the manufacturer then updates its inventory position upon the customer demand arrives at the retailer, instead of the replenishment order from the retailers. Under this policy, the manufacturer manages its finish goods when the inventory position reaches the base stock level. Thus, by using the shared downstream information, the manufacturer could better manage its inventory by utilizing the upcoming demands from the customers so that the cost can be reduced. We implement this strategy in the simulation model. In what follows, we elaborate the simulation model constructed for the information sharing scenarios.

3.2 Simulation Models
The simulation model imitates, manipulates and records time-persistent net inventory level in each member of the supply chain. In this system, we define two types of inventory variables, i.e., net inventory and inventory position.
Recall that in inventory systems, the net inventory is the on-hand inventory minus backorder level, and the inventory position is the net inventory plus replenishment orders. Both are continuously monitored in the system. Figure 3 generally illustrates the technological process of the proposed simulation model. In this figure, the plain text describes the note for "As-Is" scenario, while the blue note is for the "DIS" scenario.

![Simulation Process Diagram]

Figure 3: Illustration of the simulation process of the two-level supply chain

The simulation begins with a randomly-defined inventory position and net inventory level, of the same initial value. When a demand request arrives in the retailer, the corresponding inventory level and inventory position drop. If the stock is not available to fulfill the demand, the lost sale cost will be updated. Then it is required to check the inventory position value. This procedure continuously occurs during each arriving of the new request until the inventory position reaches the reorder point, a replenishment request of batch size \(Q\) is submitted to the manufacturer. Following this, the system checks the manufacturer inventory level to make sure whether an immediate replenishment can happen. If such stock is not available, the request will be ranked in a queue to be released according to a first-in-first-out (FIFO) policy.
Upon each replenishment taking place, the replenishment lead time is enforced on the system and the inventory level is only updated at the end of this period. For the manufacturer, an entity was triggered to enter into the model upon the replenishment request is ordered from the retailer. Then the inventory position of the manufacturer is updated. If the machine is idle and needs to start production, the set up cost of the manufacturer is updated.

The model we build above is the basic "As-Is" scenario for a two stage supply chain system. Then we want to present how the information sharing model works. In the simulation model setting, each time when a demand arrives at the retailer, the inventory position of the manufacturer updates accordingly. In addition, when we run the simulation model, we find sometimes the inventory position at the manufacturer reaches a very small number, which makes the policy not effective. To avoid this, we introduce another variable $e$ as the threshold level. When the inventory position becomes even smaller than this threshold level, we reset the inventory position to be 0. Such setting works as a heuristic to avoid unnecessary values for the inventory position.

4. Numerical Examples
In this section, we simulate the information sharing scenarios according to the model described in Section 3. The model is built by the simulation software package Anylogic 6.8.1. The main purpose for the experiments in this section is to show the effectiveness of the information sharing model.

We consider $N=3$ retailers, each with $\lambda = 0.33$ as the demand arrival rate. The manufacturer’s production rate $\mu$ is 1. The unit holding cost per unit time $h$ is set to be 1, the unit lost sale cost $b$ is set to be 3. We also set the retailer's fixed ordering cost $k$ to be 150, and the manufacturer’s set up cost $s$ to be 100. Besides, the replenishment lead time $L$ from the manufacturer to the retailer is set to be uniform distributed with boundaries 1.5 and 5.5. All the parameters are summarized in Table 2. We then calculate the unit time average total holding, lost sale, and fixed ordering cost for the retailer, and the unit time average holding and set up cost for the manufacturer.

Table 2: Parameter values assigned in the experiment

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N</th>
<th>$\lambda$</th>
<th>$\mu$</th>
<th>$h$</th>
<th>$b$</th>
<th>$k$</th>
<th>$s$</th>
<th>$L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>3</td>
<td>0.33</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>150</td>
<td>100</td>
<td>$U(1.5, 5.5)$</td>
</tr>
</tbody>
</table>

In the simulation model, the initial inventory level and inventory position are arbitrarily set to be 50 for the retailers and the manufacturer. Such settings prevent the initial inventory status from being unrealistically empty and idle. We then warm up the simulation model to remove the influences from the initial condition. This warm up period for the simulation is determined by observing the moment when the average time-persistent inventory level begins to stabilize. In the experiments, the warm up period for the simulation is set to be 30 days in the system, while the model is run for 360 days. To obtain the time-persistent average total holding, lost sale, fix ordering and setup cost, the model is run with 20 replications.

To compare the difference of the total average cost between the "As-Is" model and "DIS" model, we run four scenarios. In each scenario, the retailer adopts the same replenishment policy, and the manufacturer maintains the same base stock level as well. This indicates that the same decision variables are assigned in each model, and the only difference is that for the "DIS" model, a threshold value is adopted to reset the manufacturer’s inventory position to avoid unnecessary values. When we run the simulation model in different scenarios, we find out the value -5 is a good value. To illustrate this here, we set the retailer replenishment ($Q, R$) policy to be (19, 13), the base stock level at the manufacturer to be 29. As illustrated in Figure 4. we conduct the sensitivity analysis for the threshold value $e$ from -50 to 20, based on the total manufacturer cost. The histogram displayed in this figure indicates that the value -5 results in the lower manufacturer cost overall. Thus, in this section, we set $e = -5$ for all the scenarios.

Table 3 displays all the decision variable settings for each scenario, and the comparison of the average total cost between each model. The values of decision variables are randomly selected. As demonstrated in this table, by implementing the demand information sharing, the manufacturer could save about 10% cost. The cost for the retailers is also reduced a little in the demand information sharing model.

To illustrate detailed cost saving through information sharing, Figure 5 and 6 display the cost structure and total cost for the manufacturer and retailers in each model in one run of scenario 1. Please note the values may not be necessarily
Table 3: Illustration of the average total cost: As-Is vs. DIS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>As-Is</th>
<th>DIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables ((Q, R))</td>
<td>10, 5</td>
<td>19, 13</td>
</tr>
<tr>
<td>Base stock level</td>
<td>20</td>
<td>29</td>
</tr>
<tr>
<td>Objectives Manufacturer</td>
<td>8.79</td>
<td>6.90</td>
</tr>
<tr>
<td>Retailers</td>
<td>15.29</td>
<td>15.10</td>
</tr>
</tbody>
</table>

The same as in Table 3, since the values in the table are the average values based on 20 replications. Compared between the two figures, the saving of the manufacturer cost in "DIS" model is mainly due to the holding cost.

5. Conclusions

This study illustrates the benefits of supply chain information sharing. Based on a two-stage decentralized supply chain comprising one manufacturer and \(N\) identical retailers, the simulation model and analysis have been performed to investigate how to utilize the information sharing to improve the inventory control policies through the supply chain. We examine the scenario where the retailer shares the real-time demand information to the manufacturer. To utilize such information sharing, we propose an updated policy for the manufacturer to determine its production decision. The numerical analysis from the simulation model demonstrates the impacts of the new policy. Specifically, the manufacturer can obtain substantial performance improvement in terms of inventory cost with demand information sharing.
There are several directions for the future work. First, as we mentioned, there are limited research for the upstream information sharing, future work is suggested to consider the upstream information sharing policy. Second, in this paper we assume the $(Q, R)$ continuous review policy. Future work may consider a periodic review system. Finally, our model can be extended to consider multiple products and joint replenishment costs.

References


