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RESEARCH NOTE

Investigating the value of information sharing in multi-echelon supply chains

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Abstract Under the structure of multiple business entities, supply chain management (SCM) offers the external and internal integration of business processes in enterprises. The most important objective of SCM is to enhance the supply chain performance such as reinforcing the service level and increasing profit as well as reducing order cycle time and inventory. In recent years, due to the advancement of information technology, enterprises can manage the product flow and the information flow via economical and efficient mechanisms. The well-organized information sharing can enhance the supply chain performance and allow enterprises to refine their strategies of supply chain in order to maximize their profits. The previous studies pointed out the positive effect of information sharing on the efficiency of supply chain. However, relatively little literature focuses on the performance analysis for multi-echelon supply chain with various information sharing scenarios. By using the simulation technique, this paper models different scenarios of information sharing, and further analyzes the impacts of information quality on multi-echelon supply chain performance. In addition, this paper employs Data Envelopment Analysis (DEA) to integrate multiple performance measures to ensure the information sharing scenarios with enhanced performance.

Keywords Supply chain management · Multi-echelon · Information sharing · Simulation · Data envelopment analysis

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1 Introduction

Since the 1990s, Supply Chain Management (SCM) has been a relatively significant issue for global enterprises. After proceeding with international management, enterprises have to face the challenge with regard to SCM mainly because of rapid change of business environment, severe competition in dynamic market and customers' diverse demands. Therefore, how to operate information technology to upgrade the efficiency of supply chain has currently become one of the important issues for enterprises (Simchi-Levi et al. 2003). To keep the competitive advantage, enterprises have to integrate the supply chain for efficiently responding to dynamic market and customers' diverse demands.

Stroeken (2000) analyzed the link among information technology, innovation and supply chain. The role of information technology in innovation processes involves not only the logistics innovation, but also the total innovation of the supply chain (Coleman et al. 2004). Additionally, supply chain synchronization and incurred business benefits can be achieved through information transparency. Information technologies have the capability to facilitate collaboration, but they cannot alone guarantee information sharing among organizations (Barua et al. 1997). Barua et al. applied a game theory based approach to show how elements of organizational culture such as trust, teamwork and reward system can assist to achieve the willing of information exchange.

Enterprises require efficient information exchange to bring together costly information gaps between numerous decision makers or organizations, which manage isolated databases. From the survey in Sahin and Robinson (2002), the effectiveness of information sharing can affect the efficiency of supply chain. However, the cooperative relationship among enterprises may tend to be full of suspicions. Enterprises may not comprehensively share information with each other since they do not have enough mutual trust.

Traditionally, each business entity tends to merely purse partially local optimization and neglects global optimization in supply chains. It has been claimed that he global optimization can generate the maximum benefit of supply chain (Simchi-Levi et al. 2003). A better understanding of the advantages resulted from supply chain partnership can promote the information sharing among involved partners. Based upon the well-known bullwhip effect (Forrester 1958), due to the incapable or incomplete delivery of information sharing at downstream of supply chain, the actual demands may be distorted and demand variations may be amplified which further force the upstream members to keep more inventory for responding to demand uncertainty. Such situation results in excess rise of inventory level and cost.

The ever-increasing complexity of organizations and the scale of information activities require corporation and collaboration between enterprises (Widén-Wulff and Ginman 2004). The investment in social values based on mutuality, trust and respect can result in long-term benefits of business. Effective information sharing can bring along various benefits to supply chain partners. For example, it can reduce lead time and rapidly respond to customers' orders. Thus, information sharing can further reduce the unnecessary stock, enhance the customer service level, reinforce the coordination and collaboration among partners, etc. (Simchi-Levi et al. 2003). If the involved members of supply chain can share the information immediately and efficiently, the performance of supply chain can certainly be upgraded. However, many enterprises are still not willing to share information with their partners since they are afraid of damaging their own benefits. Therefore, in order to encourage the enterprises to share information, the benefits generated by information sharing need be comprehensively recognized and evaluated.

Supply chain partners with high corporate performance have a high level of information sharing (Rassameethes et al. 2000). Most previous studies focused on the performance analysis of two-echelon supply chain, but relatively little literature on the multi-echelon supply chain with various information sharing scenarios. This paper explores the effect of information visibility on the performance of multi-echelon supply chains. By using simulation, the effects of different levels of information sharing on supply chain performance are analyzed to allow the development of maximum value of supply chain information sharing. The supply chain performance is generally measured in terms of multiple criteria, and it is difficult to determine which information sharing scenario is better due to the various performance measures. Therefore, it is necessary to integrate multiple measures to distinguish the superiority of various information sharing scenarios in supply chains.

This paper aims at using a non-parametric approach, Data Envelopment Analysis (DEA), to estimate the efficiency of information sharing scenarios in supply chain with multiple criteria. Establishing an integrated measure by DEA allows managers to analyze and compare the performances of different supply chain scenarios. The remainder of this paper is organized as follows. Section 2 reviews the previous studies of information sharing in supply chain. Section 3 introduces the simulation modeling of various information scenarios. Section 4 presents the simulation results and the analysis with DEA. Finally, conclusions are made in Section 5.

2 Information sharing in supply chain

SCM employs a series of efficient means to integrate suppliers, manufacturers, distributors and retail outlets in order to rapidly respond the customers' diverse needs. SCM integrates and controls materials, funds, and related information in the supply chain process from the acquisition of raw materials to the delivery of finished goods to the end customers (Coyle et al. 2003). SCM is also an integrated business process, which incorporates and manages the business entities in supply chain and their activities to allow them to work as a virtual entity (Handfield and Nichols 2002). With the partners' cooperation, integrated enterprise procedure and intense information sharing, SCM offers the competitive advantage to enterprises.

The primary objective of SCM is to minimize the total cost of a supply chain with the service level satisfying the end customers. The SCM system is developed to collect information, to support information visibility, and to provide a single point of contact for all involved business entities. Based on the shared information, involved partners can forecast demands and plan activities to collaborate with each other (Simchi-Levi et al. 2003). If an important piece of information cannot be delivered to each partner in order to respond to the immediate state of activities, the value of information would be considerably reduced. In SCM, ensuring which information is the one to be shared is an important issue (Handfield and Nichols 2002). In an effective supply chain, partners share the information such as inventory level, order status, sales forecast, quality and production capacity. To improve the supply chain performance under the demand uncertainty, the involved members need share their information to coordinate the production, distribution and order fulfillment (Lee et al. 2000).

Information sharing is usually taken as a basic treatment for supply chain collaboration (Sahin and Robinson 2002; Simchi-Levi et al. 2003). In a supply chain, the more direct and immediate information involved, the higher accuracy of forecast can be obtained. The integration of information including the prices, quantities, discounts of products and seasonal factors can allow each partner to proceed with better demand and production forecasts. The joint forecasting system allows all involved members, which are geographically dispersed, to remain common consensus to forecasts, to coordinate their activities and to generate maximum benefits for the entire supply chain. The effective SCM is not achievable by any single enterprise, but instead requires a virtual entity by faithfully integrating all involved partners. They should come up with the insightful commitment of real-time information sharing and collaborative management (e.g., Vendor Management, VMI).

Under the situation with non-information sharing (Sahin and Robinson 2002), the demand information received by suppliers is not referred to the actual demand of end customers. The constantly distorted and amplified demand information can smash up the inventory control in the supply chain. The primary strategies in response to bullwhip effect refer to reducing the order lead time, sharing the retailers' information of point of sales (POS) to all of the involved members and collaborating on inventory control (Simchi-Levi et al. 2003). Through the efficient information sharing mechanism, we can considerably reduce the impact of bullwhip effect on supply chain. With the advancement of recent information technology, enterprises can obtain the information related to SCM with more inexpensive cost.

Information sharing is one of the important success factors to strategic alliance. Hammond (1990) analyzed the impacts of Quick Response (QR) on the short sales season environment in the apparel industry. Hammond concluded that QR mainly could reduce the retailer's surplus inventory and reinforce the service level for the customers because that the manufacturers' replenishment lead time is shorten by sharing the demand information. In the traditional Just In Time (JIT) production, the information sharing regarding JIT scheduling can efficiently reduce the suppliers' distribution uncertainty (Srinivasan et al. 1994). Information sharing can also upgrade the service level of suppliers and reduce the suppliers' holding cost, customers' demand variation and order cycle time (Bourland et al. 1996).

Lee et al. (2000) focused upon a two-echelon supply chain to quantify the value of information sharing. The findings of Lee et al. revealed that when the demand variation is large and lead time is lengthy at each tier, information sharing can reduce the suppliers' costs and inventories. Yu et al. (2002) quantified the benefits of information sharing in a two-echelon supply chain involving manufacturers and retailers. From their results, the increasing information sharing among the members can improve the performance of the entire supply chain. In particular, the manufacturer can significantly benefit from reductions in inventory levels and cost savings. Cheng and Wu (2005) further evaluated the impact of information sharing on inventory and expected cost in a two-echelon supply chain with multiple retailers. They showed that both the inventory level and expected cost of the manufacturer decrease with the increasing in information sharing level.

Strader et al. (1999) employed simulation analysis to study the performance of supply chain with information sharing. According to their simulation results, Strader et al. recognized that the order fulfill rate is prominently improved. Supply and demand information sharing enhances the persistent reduction of inventory cost. In addition, supply information sharing can also remain the persistent reduction of order cycle time. The degree of information sharing generates different levels of effect upon supply chain. Gavirneni et al. (1999) employed infinitesimal perturbation analysis to explore the value of information sharing in a two-echelon supply chain. Gavirneni et al. categorized the information sharing into three levels: non-information sharing (NIS), partial information sharing (PIS) and full information sharing (FIS). In the case of PIS, suppliers can recognize the retailers' inventory policies and demand information. In the case of FIS, suppliers can recognize the retailers' inventory level and demand information. Gavirneni et al. concluded that the alteration from NIS to PIS could allow suppliers to save about 50% cost. The alteration from PIS to FIS could save the suppliers' costs with about 35%.

Zhao et al. (2002) also investigated the impacts of various forecasting models on the value of information sharing by using simulation. In Zhao et al. information sharing was also categorized into different levels: non-information sharing (NIS), demand information sharing (DIS), and demand and order information sharing (OIS). In the case of NIS, suppliers can merely proceed with production according to the retailers' orders. In the case of DIS, retailers share demand forecast to suppliers. In the case of OIS, retailers share demand forecast and prospective order planning information to suppliers. The simulation results in Zhao et al. revealed that the selection of adequate forecasting model could apparently affect the performance of supply chain. In addition, retailers' various demand characteristics and suppliers' different capacity levels also influence the value of information sharing.

Thonemann (2002) proposed the Advance Demand Information (ADI) sharing regarding the supply chain of architecture industry. Thonemann divided ADI into two categories: aggregated ADI and detailed ADI. In the case of aggregated ADI, contractors can imply the manufacturers about the prospective orders for certain products next period; however, contractors cannot refer to the details about which products are ordered and which manufacturers receive the orders. In the case of detailed ADI, contractors can further provide the information for which products are ordered; however, as to which manufacturer will receive the orders, it is still uncertain. Thonemann pointed out that both of the above ADI scenarios could reduce the costs and lower the demand uncertainty. These two ADI scenarios can lead to more accurate forecasts. When the order probability is low and information quality is high, these two ADI scenarios reveal a maximum value of information. Furthermore, in the case of multi-product, the detailed ADI is more efficient than the aggregated ADI.

Simulation has been reported to be a powerful tool for evaluating complex systems. Simulation can be used to express the dynamic processes in the supply chain, which cannot be model mathematically (e.g., Strader et al. 1999; Zhao et al. 2002). Terzi and Cavalieri (2004) made a wide-ranging review for applying the simulation tool in decision-making processes of supply chain, and provided practical recommendations on the applicability of simulation. The uncertainty exists in customers' demands, reliability of external suppliers and lead time. Petrovic (2001) used a supply chain simulation tool, namely SCSIM, to explore the behavior and performance of supply chain under the high uncertain environment. Jansen et al. (2001) developed a simulation model in order to analyze the distribution system of multi-product supply chain. Jansen et al. analyzed the supply chain performance with regard to logistics and financial measures under different supply chain scenarios. Through the simulation analysis, they pointed out that the supply chain implementation could significantly save the total cost and improve the customers' satisfaction.

In recent years, the supply chain collaboration has become a certain tendency. In supply chain, information technology is considered as one of the strategic developments and success of collaboration strategies (Neubert et al. 2004). It is due to that information technology can collect and share information to optimize supply chain process. It is due to that information technology can collect and share information to optimize supply chain process. For the supply chain of retail industry, Waller et al. (1999) explored the potential benefits of Vendor Managed Inventory (VMI). In VMI, suppliers control the retailers' inventory level and replenishments. From Waller et al. suppliers could reduce the demand uncertainty by implementing VMI. Therefore, suppliers could maintain certain service level while reduce inventory level and production cost.

According to the above review, information sharing reveals positive effect on supply chain performance. This paper employs simulation and DEA to analyze the effects of different levels of information sharing upon the supply chain performance with several scenarios. Additionally, the collaboration scenario of VMI is also included in this paper.

3 Data envelopment analysis

In 1978, Data Envelopment Analysis (DEA) was initiated by Charnes, Cooper and Rhodes (CCR), and they demonstrated how to change a fractional linear measure of efficiency into a linear programming model (Charnes et al. 1978). Researchers have developed several DEA models by theoretically broadening the CCR model (e.g., Charnes et al. 1985; Cook and Kress 1990; Obata and Ishii 2003).

DEA was originally designed to mathematically measure decision making units (DMUs) with multiple inputs and outputs in terms of relative efficiency (i.e., the ratio of total weighted output to total weighted input). Cook and Kress (1990) introduced a theoretical extension of DEA to analyze ranked voting data. In the approach developed by Cook and Kress, preference scores are estimated without initially imposing any fixed weights. The score of each candidate (DMU score) is calculated based on its most favorable weights (Obata and Ishii 2003).

The preference score, Z_i, of candidate (DMU) i is the weighted sum of votes with certain weights. The mathematical model of the ranked voting system in DEA is formulated as follows (Cook and Kress 1990):

$$\text{Maximize} \sum_{j=1}^{k} w_j v_{oj} \tag{1}$$

Subject to:

$$\sum_{j=1}^{k} w_j v_{ij} \leqslant 1, i = 1, 2, \ldots, m; \tag{2}$$

$$w_j - w_{j+1} \geqslant d(j, \varepsilon), j = 1, 2, \ldots, k-1; \tag{3}$$

$$w_j \geqslant d(k, \varepsilon); \tag{4}$$

where w_j denotes the weight of the j-th place; v_{ij} represents the number of j-th place votes of candidate i ($i = 1, 2, \ldots, m, j = 1, 2, \ldots, k$); and $d(\bullet, \varepsilon)$, known as the discrimination intensity function, is non-negative and non-decreasing in ε and satisfies $d(\bullet, 0) = 0$. Parameter ε is non-negative.

The above mathematical model is resolved for each candidate o, $o = 1, 2, \ldots, m$. The resulting objective value is the preference score of candidate o. Constraints (2) ensure that the vote of the higher place may have a greater importance than that of the lower place. Several candidates may achieve a maximum preference score of 1 once the linear programs (1)–(3) are resolved for all candidates. Candidates with preference score 1.0 are called *efficient candidates*. Without setting the priorities of criteria, Constraints (2) are relaxed.

DEA frequently generates several efficient candidates (Obata and Ishii 2003). The set of efficient candidates is the top group of DMUs, but no efficient DMU can be distinguished as the winner among this group. It is necessary to further discriminate these efficient candidates. To discriminate efficient candidates, the discriminant method proposed by Obata and Ishii is adopted in this paper. The discriminant model for efficient candidates is formulated as follows (Obata and Ishii 2003):

$$\text{Minimize} \sum_{j=1}^{k} w_j \tag{5}$$

Subject to:

$$\sum_{j=1}^{k} w_j v_{oj} = 1; \tag{6}$$

$$\sum_{j=1}^{k} w_j v_{ij} \leqslant 1, \text{for all efficient} i \neq o; \tag{7}$$

$$w_j - w_{j+1} \geqslant d(j, \varepsilon), j = 1, 2, \ldots, k-1; \tag{8}$$

$$w_j \geqslant d(k, \varepsilon). \tag{9}$$

Obata and Ishii's model, (5)–(6), is also a linear program. The preference score of the second stage (Z_i') is obtained as a reciprocal of the optimal value, that is $Z_i' = 1 \Big/ \sum_{j=1}^{k} w_j$. This discriminant model does not employ any information about inefficient candidates, and thus the problem of varying the rank of efficient candidates does not occur (Obata and Ishii 2003). Similar to Cook and Kress's DEA model, (1)–(3), Constraints (5) are relaxed if the priorities of criteria are not specified. In this paper, an information sharing scenario is a DMU in DEA.

4 Development of simulation models for information sharing scenarios

There are various items of information which can be shared such as production capacity, demand, inventory level, etc. This paper mainly intends to explore the effect of degree of information sharing upon the multi-echelon supply chain performance. The supply chain structure in this paper is a four-echelon model (see Fig. 1), which includes suppliers, manufacturers, distributors and retailers. The previous studies focused on the impacts of demand information and inventory information on supply chain

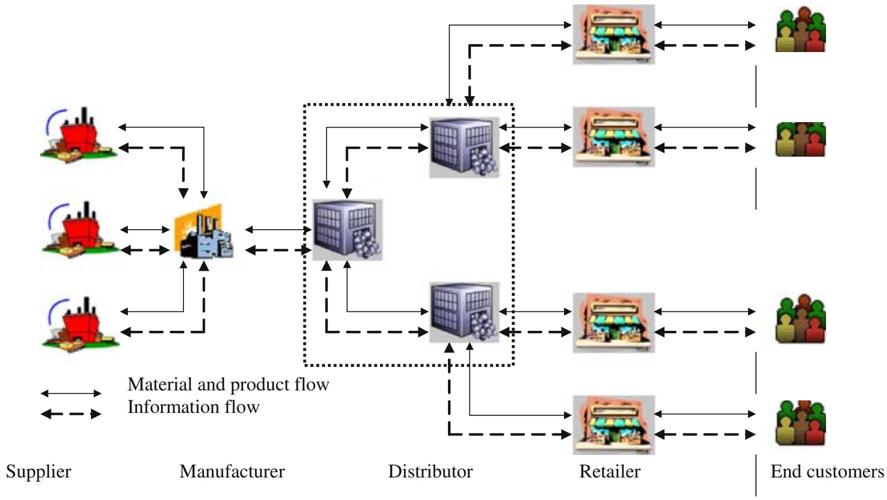

Fig. 1 The schematic architecture of supply chain

performance. In this paper, the shared information refers to inventory information, demand information and capacity information.

The different information sharing scenarios are compared by analyzing the resulting performance measures including total cost, order fulfill rate, customer service level and order cycle time. Finally, with the efficiency analysis of DEA, the enhanced scenario of information sharing in supply chain can thus be suggested.

4.1 Framework of multi-echelon supply chain

The following elaborates the basic activities with respect to supplier, manufacturer, distributor and retailer in the multi-echelon supply chain studied herein:

1. Retailer: Upon facing different customer demand rates, the retailer thus fills customer orders according to the order quantity. If the order quantity is more than the current stock, the retailer offers all of the inventories to the customer. The insufficient part is regarded as the shortage order. After receiving the replenishment from the distributor, the retailer firstly fills the shortage orders. In addition, at the beginning of each period, the retailer proceeds with replenishment according to the established inventory policy.

2. Distributor: After receiving the retailer's orders, the distributor fills these orders according to its own inventory status and the order quantity of retailer. If the order quantity of retailer is more than the current stock, the distributor offers all of the inventories to the retailer. The insufficient part is regarded as the shortage order. After receiving the replenishment from the manufacturer, the distributor firstly fills the shortage orders. In addition, at the beginning of each period, the distributor proceeds with replenishment according to the established inventory policy.

3. Manufacturer: After receiving the distributor's orders, the manufacturer fills the orders according to its own inventory status and the order quantity of distributor. If the order quantity of distributor is more than the current stock, the manufacturer offers all of the inventories (finished products) to the distributor. The insufficient part is regarded as the shortage order. After receiving the replenishment of required materials from suppliers, the manufacturer starts to proceed with manufacturing according to the production plan.

4. Supplier: It is assumed that the supplier possesses an infinite capacity. After receiving the manufacturer's orders, the supplier offers the materials to the manufacturer according to the order quantity.

The parameters in the multi-echelon supply chain model is as follows:

1. Inventory level: The supplier is assumed to have an infinite capacity. Except for the supplier, other involved supply chain partners involving the manufacturer, distributor and retailer should establish their inventory policies. In this paper, these involved members proceed with (s, S) inventory policy, in which s represents the reorder point and S represents the order up-to-level. For calculating the total cost, we should establish unit shortage cost, unit inventory handling cost and unit order cost. In addition, the initial inventory levels for the manufacturer, distributor and retailer need be given.

2. Lead time: In the case of delivering materials and finished products to downstream members, there exists delivery lead time. In addition, for the manufacturer, the production lead time is set according to the batch size.

3. Customer demand rate: The arrival of customer orders and order quantities follow some empirical probability distributions.

4.2 Information sharing scenarios

According to the types of information mentioned above, the inventory information, demand information and capacity information are used to design several scenarios of information sharing. These three types of information are described as follows:

1. Inventory information: The information regarding current inventory level and inventory policy is shared among involved members in the supply chain.

2. Demand information: Without sharing demand information, the members of each tier proceed with their demand forecasts according to the orders from the downstream members. With sharing demand information, the members of supply chain of each tier can obtain the demand information of end customers to establish the inventory policies.

3. Capacity information: Without sharing capacity information, the manufacturer can only fulfill the distributor's orders with its own production capacity. In the case of sharing capacity information, the manufacturer can have the additional capacity by using outsourcing strategy.

To investigate the effect of information sharing upon supply chain performance, eight scenarios are designed with respect to the three types of information mentioned above. They are as follows:

1. Non-information sharing: In Scenario 1, the involved members do not share any type of information.
2. Partial information sharing: In this paper, the partial information sharing refers to one or two types of information are shared among members. Therefore, there are six scenarios for partial information sharing, and they are as follows:
   a. capacity information sharing (Scenario 2);
   b. demand information sharing (Scenario 3);
   c. inventory information sharing (Scenario 4);

   d. capacity and demand information sharing (Scenario 5);
   e. demand and inventory information sharing (Scenario 6);
   f. capacity and inventory information sharing (Scenario 7).
3. Full information sharing: In Scenario 8, the demand information, inventory information and capacity information are shared among supply chain members.

4.3 Performance measures

Simulation models are constructed and executed to collect the performance measures for the above eight scenarios. The performance measures are as follows:

1. Total supply chain cost: It is the summation of average costs of manufactures, distributors and retailers. Suppliers are not included for computing performance measures because they are assumed to have an infinite capacity to supply raw materials. The cost items consist of inventory holding cost, shortage cost and order cost.

2. Supply chain fulfill rate: The supply chain fulfill rate represents the average order fulfill rates of manufactures, distributors and retailers.

3. Supply chain service level: The supply chain service level represents the average service levels of manufactures, distributors and retailers.

4. Supply chain order cycle time: This measure represents the average order cycle time of manufactures, distributors and retailers.

After collecting all of the performance measures by running simulation models, The DEA method presented in Sect. 3 is then applied to perform the efficiency analysis of these scenarios.

5 Simulation results and analysis

5.1 Simulation parameter setups

The multi-echelon supply chain is used to explore the effect of degree of information sharing upon supply chain performance. In this simulation study, there are three retailers, one distributor, one manufacturer, which can have additional capacity by outsourcing, and one supplier in the supply chain. The parameter settings of the above eight information sharing scenarios are listed Table 1. The performance measures of various information sharing scenarios are obtained by running the simulation models. The simulation results are presented in the following.

5.2 Simulation results

5.2.1 Non-information sharing

The performance measures derived from simulation results are summarized in Table 2. In the non-information sharing scenario, the measures of total cost and order cycle time remain in a reasonable scale provided that they are compared with those of other scenarios. However, service level and fulfill rate merely reached 61.83% and 65.22%, respectively. In the non-information sharing scenario, there exists a considerable room to improve the service level and cycle time in the supply chain.

Table 1 Simulation parameter setups

Parameters	Values
Simulation replications	30
Simulation length	120 periods
Order interval	Exponential distribution with mean 30
Order size (X)	$P(X) = \begin{cases} 0.167, & \text{if } X = 1 \\ 0.333, & \text{if } X = 2 \\ 0.333, & \text{if } X = 3 \\ 0.167, & \text{if } X = 4 \end{cases}$
Transportation lead time	1 period
Production lead time	Normal distribution with mean 0.1 and standard deviation 0.02
Unit holding cost	1
Unit shortage cost)	5
Ordering cost	10 for retailer; 50 for distributor and manufacturer

Table 2 Performance measures of information sharing scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Total cost	452.84	539.78	392.8	429.77	607.34	446.17	646.94	684.68
Service level (%)	61.83	72.62	77.44	68.84	77.26	74.66	76.42	81.3
Fulfill rate (%)	65.22	75.25	79.26	72.16	79.13	77.04	72.36	79.35
Cycle time	1.3593	1.1205	1.0568	1.1961	1.0475	1.0943	1.1762	1.0451

5.2.2 Partial information sharing

1. Capacity information sharing In the scenario of capacity information sharing, while the distributor encounters shortage, they can order at an alternative manufacturer. Compared with the scenario of non-information sharing, there is cost reduction in distributor. Additionally, the performance of retailers is improved since the manufacturer can have the additional capacity by using outsourcing strategy. However, the inventory holding cost of manufacturer increases since there exist a contracted manufacturer for moderating capacity. From Table 2, the total supply chain cost of this scenario is thus higher than that of non-information sharing scenario. The service level, fulfill rate and cycle time in this scenario are better than that of non-information sharing scenario.

2. Demand information sharing In the scenario of demand information sharing, all of the involved members, except for the supplier, in the supply chain implement the (s, S) inventory policy according to the demand information from the end customers. Compared with the performance measures of the non-information sharing scenario, the demand information sharing scenario performs better. From Table 2, sharing demand information indeed reveals significant improvement with respect to the performance measures.

3. Inventory information sharing With inventory information sharing, the upstream members can recognize the inventory levels and inventory policies of downstream ones. Therefore, the upstream members can respond quicker to their own inventory levels. Compared with non-information sharing, the inventory information sharing results in reduction in total cost. The service level, fulfill rate and cycle time in the inventory information sharing scenario also reveal better performance. From Table 2, sharing inventory information can actually enhance the improvement of supply chain performance.

4. Capacity and demand information sharing Compared with the capacity information sharing scenario and the demand information sharing scenario, the capacity and demand information sharing scenario reveals better performance measures except for the total cost.

5. Demand and inventory information sharing The performance of demand and inventory information sharing scenario is better than that of demand information sharing scenario and inventory information sharing scenario.

6. Capacity and inventory information sharing Except for the total supply chain cost, the performance of capacity and inventory information sharing scenario is better than that of capacity information sharing scenario and inventory information sharing scenario. From the results of partial information sharing scenarios, the more information is shared, the more positive effects on the supply chain performance may reveal.

5.2.3 Full information sharing

The performance measures of full information sharing scenario are also summarized in Table 2. In this scenario, the distributor and manufacturers prepare more inventories in response to shortage. Thus, the inventory holding cost in the supply chain significantly increases. Compared to other scenarios, the full information sharing scenario generates the highest total cost. However, this scenario performs better regarding to the other three performance measures.

From the performance measures of each scenario illustrated in Table 2 and Fig. 2, we cannot easily determine the most appropriate scenario with respect to the performance data of these eight information sharing scenarios. Thus, the DEA method described in Section 3 is adopted to ensure the most efficient information sharing scenario.

5.3 Scenario analysis by DEA

By using DEA, the efficiency analysis for the above eight scenarios is conducted to further rank them. Note that the measures of supply chain fulfill rate and supply chain service level are positively related to the supply chain performance. On the other hand, the total supply chain cost and supply chain order cycle time are negatively related, and these two measures are input to the DEA models in reciprocal values.

Table 3 indicates the efficiency of each scenario by using Cook and Kress's model. The demand information sharing and full information sharing scenarios are identified as the efficient DMUs (information sharing scenarios) in the first stage. These two scenarios are further discriminated by Obata and Ishii's model in the second stage. In this stage, the efficiency values of demand information sharing scenario and full information sharing scenario are respectively 0.434 and 0.957. From this two-stage

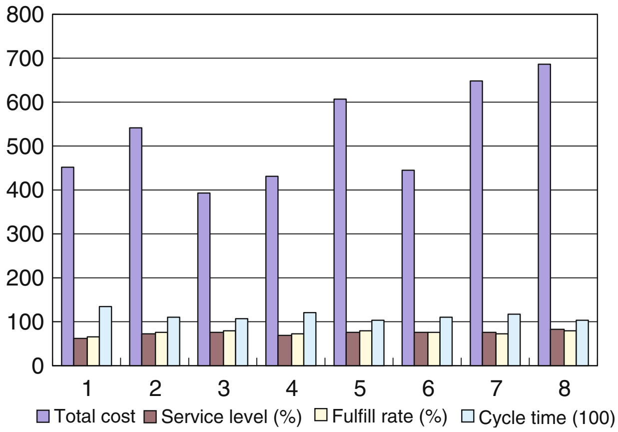

Fig. 2 Performance comparison of eight information sharing scenarios

Table 3 Efficiency values of information sharing scenarios by Cook and Kress's DEA model

Scenarios	1	2	3	4
Efficiency	0.867	0.949	1.000	0.914
Scenarios	5	6	7	8
Efficiency	0.999	0.972	0.947	1.000

DEA analysis, the full information sharing scenario is determined as the most efficient information sharing alternative in multi-echelon supply chains.

5.4 Vendor managed inventory scenario

Beside the information sharing among the involved members, the collaboration on supply chain members is also considerably important in SCM (Waller et al. 1999). Vendor Managed Inventory (VMI) is a popular strategic alliance in supply chain. This paper further constructs a VMI simulation model to investigate the performance of VMI. In VMI, the full information sharing is adopted as well as the upstream members of supply chain are in charge of the inventory control of the downstream ones. The upstream members determine the time for replenishment as well as the quantities of replenishment. In this paper, the manufacturer controls the inventory for the distributor, and the distributor manages the inventory for the retailer. Table 4 summarizes the performance measures of VMI.

In the scenario of VMI, each performance measure is relatively prominent. By additionally considering the VMI scenario, we can recognize that the most efficient

Table 4 The performance measures of VMI scenario

Measures	Results
Total cost	241.08
Service level (%)	98.09%
Fulfill rate (%)	98.5%
Cycle time	1.0021

scenario is VMI without the DEA analysis since all of the performance measures of VMI are better than that of other scenarios. From the above analysis, it indicates that the full information sharing can upgrade the efficiency of supply chain. In addition, the business collaboration can considerably improve the performance of supply chain.

6 Conclusions

In order to face the challenge of global business competition, SCM has become a certain tendency. SCM can reduce uncertainty and thus improve the supply chain performance. Therefore, how to upgrade the performance and how to assist all of the involved members to obtain the utmost benefit are essential issues in SCM. This paper explores the effect and inspiration derived from information sharing with regard to the performance of multi-echelon supply chain. As to the aspect of information sharing, this paper respectively explores the effects of various scenarios of information sharing and non-information sharing on supply chain performance. In addition, this paper also accesses to the effect of supply chain collaboration (VMI). This paper provides efficient integration and exploration with respect to the concept of information sharing and functions as the reference for industries in introducing SCM.

Through the simulation experiments and the DEA analysis, the conclusions of this paper are drawn as follows:

1. Information sharing can enhance the performance of supply chain. After sharing the demand, inventory and/or capacity information, the involved members of supply chain can recognize the inventory levels, inventory policies, capacity information and customers' actual demand information. Therefore, the partners along the supply chain can establish the more real-time and effective decisions. Additionally, the performance measures such as service level, fulfill rate and order cycle time can be prominently improved.
2. In addition, collaboration is also an important mechanism in supply chain to improve performance. Collaboration can reduce the influence of bullwhip effect and improve efficiency.
3. In the previous literature related to the supply chain performance analysis, researchers merely judged the individual superior and inferior aspects of performance measures under different scenarios. Since the performance measures generally reveal both superior and inferior aspects, it is difficult to determine which scenario is better. This paper employs Data Envelopment Analysis to determine the efficiency values of each scenario. Thus, the we can determine the appropriate supply chain information sharing model, which can be the reference for the industry circle's execution of supply chain information sharing.

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