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How VMI and Consignment Jointly Affect Supply Chain Performance

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Abstract

Purpose – Due to its potential to improve supply chain operations, supply chain collaboration has attracted significant attention from both academics and practitioners. This study focuses on VMI, in collaboration with consignment, and examines its impact on supply chain performance.

Research design, data, and methodology – This study employs the analysis of mathematical models, formulated based on the proposed supply chain framework. Using numerical examples, it evaluates the performance of three supply chain systems: one including VMI and consignment, a consignment-only system, and a traditional system.

Results – The combination of VMI and consignment produces greater supply chain benefits than the consignment-only and traditional systems. Whereas only the performance of the buyer improves with the consignment-only system, the system with VMI and consignment is beneficial to both the buyer and supplier.

Conclusions – The results of this study reveal that the inclusion of the additional collaborative function of VMI makes consignment a better supply chain collaboration program. Future studies should examine issues regarding the testing of diverse collaboration programs and the building of a firm theoretical background.

Keywords: Supply Chain Management, Consignment, Vendor Managed Inventory, VMI with Consignment, Supply Chain Collaboration.

JEL Classifications: M11, M19, M21.

1. Introduction

Supply chain collaboration has been one of the important research issues in the area of supply chain management, due to its potential to improve the supply chain operations. Since every operation is orchestrated in accordance with the single goal of maximizing the supply chain profit, the supply chain collaboration is expected to bring the significantly improved performance, which any conventional management methods do not possibly achieve. Starting from the early forms including Quick Response (QR) and Efficient Customer Response (ECR), a series of collaboration programs such as Vendor-Managed Inventory (VMI) and Collaborative Planning, Forecasting, and Replenishment (CPFR) were already developed and have been successfully used in the diverse areas of business practices. Development of new collaboration programs is still in progress and VMI with consignment is one of them. In particular, VMI with consignment is the combination of two already existing collaboration programs and equips two collaborative functions from VMI and consignment.

The main goal of this study is to find out how VMI with consignment affects the supply chain performance. By directly comparing this new program with the consignment only system, this study finds out whether the combination of multiple collaboration programs performs better than the original one. Based on the proposed framework to characterize any supply chain collaboration programs, this study defines VMI with consignment as the combination of two collaborative features, which are cost payment and decision authority. With the series of profit maximization models that represent the operational processes, this study designs the numerical examples to evaluate the performance of three supply chain systems including VMI with consignment, consignment only system, and traditional system.

Outcomes from the numerical examples indicate that VMI with consignment obtains greater supply chain profit than the consignment only system as well as the traditional system. In addition, while only the buyer improves his performance in the consignment only system, VMI with consignment is beneficial to both buyer and supplier. These outcomes indicate that consignment can become a better supply chain collaboration program by having additional collaborative function of VMI. After all, the results of this study imply that there is a good opportunity to develop more advanced collaboration program by combining additional distinct collaborative features. Meanwhile, the analysis on the impact of consignment size on the supply chain performance reveals that the supply chain system can obtain the maximum profit only when the consignment size is carefully determined at the proper level between extremely high and low ones.

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2. Research Background

Consignment has a long history (Fenton & Sanborn, 1987), and it still has been used in diverse business areas including paper, steel, and commodity distribution industries in these days (Gerber, 1987). According to the consignment contract, the supplier keeps his own inventories on the buyer's premises until the buyer withdraws and uses them (Harding, 1999). Since the supplier still owns the inventories, the buyer does not pay for the inventories until the withdrawal (Gerber, 1991).

Many studies conduct research on the consignment as the collaboration program and illustrate that the consignment policy can improve the supply chain performance and resolve the problems that any traditional system possesses (Battini et al., 2010; Braglia & Zavanella, 2003; Chen & Liu, 2007; Corbett, 2001; Valentini & Zavanella, 2003). In their studies, consignment is considered to be a collaboration program that brings the significant benefits to the supply chain system, such as reduction of buyer's inventory cost (Sjoerdsma, 1991; Valentini & Zavanella, 2003; Williams, 2000), fewer stock out and emergency delivery (Ballard, 1991), saving of intermediate warehousing expenses (Gerber, 1987), and more accurate demand forecast (Gerber, 1987).

Vendor Managed Inventory (VMI) was developed as the buyer-supplier partnership that is designed to improve the performance of the whole supply chain system (Simchi-Levi et al., 2000). VMI has its unique feature that makes it different from the traditional system and consignment. While the buyer controls the inventories at his warehouse in the traditional system, the supplier has a full responsibility to manage buyer's inventories under VMI. In the consignment system, however, the buyer makes decisions on his inventories, even though he does not receive the ownership of them from the supplier yet.

Vendor Managed Inventory (VMI) is considered to be the advanced form of the buyer-supplier partnership that let the supplier control buyer's inventories by determining the appropriate levels of orders and inventories based on Point-Of-Sales (POS) data received from the buyer. Thus, the VMI program allows the buyer to remove the burden of ordering and inventory management. Since the supplier has a full authority on buyer's inventories, he can efficiently synchronize inventory holding, replenishment, shipment, and production activities with buyers' actual sales and systematically save the total costs associated with those activities.

Previous studies address various issues about VMI including the game relationship between the vendor and buyers (Yu et al., 2009a; Yu et al., 2009b; Yugang et al., 2006; Zheng et al., 2009), information sharing (Kim et al., 2001; Vigtil, 2007), contract schemes (Guan & Zhao, 2010; Wong et al., 2009), and algorithms for solving the optimal inventory and distribution management (Al-Ameri et al., 2008; Archetti et al., 2007; Darwish & Odah, 2010; Hemmelmayr et al., 2010; Nachiappan & Jawahar, 2007; Paik & Kim, 2000; Park & Park, 2008). In addition, some studies on VMI evaluate its performance compared with the other systems including the non-VMI system (Kiesmuller & Broekmeulen, 2010; Lee & Chu, 2005; Wang, 2009), Point-Of-Sales (POS) system (Kim et al., 2011), and Collaborative Planning, Forecasting, and Replenishment (CPFR) system (Sari, 2008a, b).

There have been several studies that examine VMI with consignment along with the other types of collaboration programs (Bernstein et al., 2006; Chen et al., 2010; Gumus et al., 2008; Nagarajan & Rajagopalan, 2008; Ru & Wang, 2010; Savasaneril & Erkip, 2010). The most of them, however, use analysis of simple mathematical models or measure only costs to evaluate the performance of VMI with consignment, and they do not provide the reason of its superiority. Meanwhile, this study evaluates the performance of VMI with consignment by comparing with the consignment only system and traditional system in terms of profit, and it is able to identify the specific features that enable this new collaboration program to outperform the others.

This study originates from the doctoral dissertation (Ryu, 2006a) and the series of relevant studies continue research on consignment and VMI as the supply chain collaboration programs. The early studies identify superiority of consignment and VMI over the non-collaborated traditional supply chain system (Ryu, 2006b, 2007a). The following studies conduct further investigation on the nature of these collaboration programs by evaluating their performances under various conditions (Ryu, 2013a) and directly comparing different types of collaboration programs (Ryu, 2012, 2013b). As an extension of the previous relevant studies, this study shares the basic supply chain models and the concept of the supply chain collaboration with them. While the previous studies consider the original forms of consignment and VMI, this study focuses on their combination and examines its potential to be an advanced collaboration program.

3. Three Supply Chain Systems

There have been many studies that conduct research on various supply chain collaboration programs and they contribute to reveal the nature of supply chain collaboration as the ultimate way to bring the significant improvement in supply chain operations. Meanwhile, the most of those studies rely on their own definitions to conceptualize the specific collaboration programs, and consequently, lack of common definitions of the collaboration programs prevents any researchers from making certain consensus on the superiority of any particular collaboration programs over the others.

This study defines three types of supply chain systems by applying the proposed framework for characterizing any collaboration programs, and develops the supply chain models. According to the propose framework (Ryu, 2007b), any supply chain collaboration programs can be analyzed by using three dimensions – information sharing, cost payment, and decision authority. Information sharing indicates that different supply chain members actively share their information and apply it to their operations. Supply chain collaboration also occurs through modification of the conventional cost payment method. The supply chain system realizes collaboration by modifying costing methods (for example, price discount) or changing the member who is responsible for the specific cost items (for example, consignment). Decision authority is another essential element of supply chain collaboration, and it specifies the supply chain member who makes decisions on the particular operations. In general, supply chain collaboration happens when the decision authority is monopolized to a single member or operational decisions are jointly made by different members.

The basic idea of the proposed framework is that any collaboration program equips more collaborative features performs better. According to this proposition, VMI with consignment, which has two collaborative features of cost payment and decision authority, is expected to outperform than the consignment only system, which has one feature of cost payment.

The supply chain system that is considered in this study is a simple two-stage system that is comprised of one buyer and one supplier. The supplier manufactures a single product item and sells it to the buyer. The buyer stores the products at his warehouse before he sells them to the retail market. The supplier has the inventories at his warehouse and delivers them to the buyer once the order is placed. The joint economic-lot-size model (Banerjee, 1986) is applied to the mathematical models for the inventory control policy, and basic Economic Order Quantity (EOQ) principles are used for basic assumptions and cost calculation.

The traditional supply chain system represents the fundamental case where collaboration does not occur at all. No particular information except the orders is shared between the buyer and supplier. Cost payment and decision authority follows the conventional rule, which indicates that the one decides and pays for what the one owns. The buyer determines the retail price and order quantity with information about the retail market demand. The supplier decides the price on products sold to the buyer and the amount of products to be produced after knowing the orders placed by the buyer. The supplier pays production cost, delivery cost, setup cost, and inventory holding cost for products stored at his warehouse. The buyer pays ordering cost and prices for the products that he buys from the supplier. The buyer also pays for holding inventories at his warehouse.

The consignment system has only one difference from the traditional supply chain system, and it is that the buyer pays only the stocking cost rather than the whole cost to hold inventories at his warehouse. The buyer's annual inventory holding cost is divided into two items- stocking cost and financing cost (Valentini & Zavanella, 2003). The stocking cost refers the costs for storing and moving inventories and it also contains the insurance cost. The financing cost represents the opportunity cost paid by the buyer once he invests financial resources in purchasing a product. Based on the consignment contract, the buyer is responsible for paying only the stocking cost for his inventories and the supplier should pay the cost for financing any inventories at buyer's warehouse.

Under the VMI system, the supplier has a full authority on managing buyer's inventories. Instead of receiving the orders from the buyer, the supplier makes decisions on orders with information about market demands directly received from the retail market. Meanwhile, the VMI system follows the same rules of cost payment as the traditional system.

VMI with consignment is the combination of two different collaboration programs. This system utilizes the consignment feature and the supplier is responsible for paying the financing cost for buyer's inventories. In addition, VMI with consignment gives the full authority on buyer's inventories to the supplier.

4. Mathematical Models for Three Supply Chain Systems

The proposed supply chain model contains the fundamental operations including purchasing, inventory control, manufacturing, and transportation. In the basic supply chain model, both buyer and supplier make operational decisions in a way to maximize their profits. The buyer's profit is composed of the revenue due to the market sales and various cost items as follows:

Buyer's total profit = Sales to market - Ordering cost - Inventory holding cost - Payment to supplier

The supplier's profit includes the cost items and the revenue due to sales to the buyer.

Supplier's total profit = Sales to buyer - Setup cost - Inventory holding cost - Production cost - Transportation cost

<Table 1> Notation Used in Mathematical Models

Supplier side		Buyer side	
π_S	Total profit	π_B	Total profit
π_S'	Estimated total profit	D	Annual market demand
X	Annual production rate	D'	Estimated annual market demand
I	Planned annual production rate	Q	Order quantity
P	Transfer price paid by buyer	E	Estimated order quantity
v	Unit production cost	R	Sales price to the market
t	Unit transportation cost	w	Profit margin
h_s	Annual inventory holding cost	h_B	Annual inventory holding cost
o_S	Setup cost per buyer's order	h_B^S	Annual stocking cost for inventory
l	Maximum estimated demand	h_B^F	Annual financing cost for inventory
m	Price sensitivity to estimated demand	o_B	Ordering cost per order
β	Transportation cost per price	k	Maximum demand
		d	Price sensitivity to demand
		α	Inventory holding cost per price

Table 1 describes the notations used in the mathematical model that represents the supply chain system. The proposed supply chain models are developed based on the following assumptions.

Assumption 1. The market demand is a linear function of buyer's sales price. As the price increases, the demand decreases ($d > 0$).

$$D = k - d \cdot R \tag{1}$$

Assumption 2. When the supplier does not know the exact market demand, he determines the production rate based on the estimated market demand (D'). Since the retail price (R) is unknown to the supplier, the estimated market demand is assumed to be a linearly decreasing function of the transfer price (P) ($m > 0$).

$$D' = l - m \cdot P \tag{2}$$

Assumption 3. The buyer determines the retail price (R) by setting the profit margin (w) on the transfer price (P). The profit margin is described as the ratio of the retail price over the transfer price. In general, the profit margin has a value that guarantees a certain amount of buyer's profit ($w > 1$).

$$R = w \cdot P \tag{3}$$

Assumption 4. Buyer's annual inventory holding cost is a function of the transfer price (P). As the transfer price increases, the annual inventory holding cost also increases ($\alpha > 0$).

$$h_B = \alpha \cdot P \tag{4}$$

Assumption 5. Supplier's annual transportation cost is a linear function of the price paid to the seller (P). As the transfer price increases, the annual transportation cost also increases ($\beta > 0$).

$$t = \beta \cdot P \tag{5}$$

Assumption 6. In the consignment system, the buyer's annual inventory holding cost is divided into stocking cost and financing cost as Equation (6) shows (Valentini & Zavanella, 2003).

$$h_B = h_B^S + h_B^F \tag{6}$$

Corresponding to Assumption 4, both stocking cost (h_B^S) and financing cost (h_B^F) for buyer's inventories are also defined to be functions of the transfer price (P), as they appear in Equations (7) and (8).

$$h_B^S = \alpha_S \cdot P \tag{7}$$

$$h_B^F = \alpha_F \cdot P \tag{8}$$

4.1. Traditional supply chain system

In the traditional supply chain system, the buyer and supplier independently make their own decisions on operations and possess exclusive information that may not be shared with another member. The buyer determines the retail price (R) and order quantity (Q) with knowledge of the market demand (D) and cost items (o_B and h_B). On the supplier side, the transfer price (P) and the production rate (X) are determined based on the information of buyer's order quantity (Q), estimated market demand (D'), and detailed cost items (o_S and h_s). In the traditional supply chain system, the buyer and the supplier go through the following decision procedures.

Step 1. The supplier determines the optimal price paid to him (P), estimated optimal order quantity (E), and production quantity (I) based on the estimated retail demand (D') as Equation (9) shows. The constraints (10) and (11) indicate that the planned production quantity should be large enough to cover the estimated demand and all decision variables should be non-negative values.

$$\underset{P,E,I}{Maximize}\ \pi_S' = P \cdot (l - m \cdot P) - \frac{o_S \cdot (l - m \cdot P)}{E} - \frac{h_S \cdot E \cdot (l - m \cdot P)}{2 \cdot I} - v \cdot I - \beta \cdot P \cdot (l - m \cdot P) \tag{9}$$

$$subject\ to \quad I \ge D' \tag{10}$$

$$P, E, I \ge 0 \tag{11}$$

Step 2. With the information of transfer price (P) determined by the supplier, the buyer decides the retail price (R) and order quantity (Q) to maximize his profit as Equation (12) describes. In Equation (13), the optimization problem has the constraints representing non-negative decision variables.

$$\underset{R,Q}{Maximize}\ \pi_B = R \cdot D - \frac{o_B \cdot (k - d \cdot R)}{Q} - \frac{h_B \cdot Q}{2} - P \cdot (k - d \cdot R) \tag{12}$$

$$subject\ to\ R, Q \ge 0 \tag{13}$$

Step 3. Based on the information of transfer price (P) and order quantity (Q), the supplier makes the optimal decision on production quantity (X) to maximize his profit as Equation (14) shows. The constraints of the optimization problem in Equations (15) and (16) indicate that the production quantity is more than the estimated demand and that the decision variable is non-negative.

$$\underset{X}{Maximize}\ \pi_S' = P \cdot (l - m \cdot P) - \frac{o_S \cdot (l - m \cdot P)}{Q} - \frac{h_S \cdot Q \cdot (l - m \cdot P)}{2 \cdot X} - v \cdot X - \beta \cdot P \cdot (l - m \cdot P) \tag{14}$$

$$subject\ to \quad X \ge D' \tag{15}$$

$$X \ge 0 \tag{16}$$

Step 4. Total profits of supplier and buyer are calculated according to Equations (17) and (18).

$$\pi_S = P \cdot D - \frac{o_S \cdot D}{Q} - \frac{h_S \cdot Q \cdot D}{2 \cdot X} - v \cdot X - t \cdot D \tag{17}$$

$$\pi_B = R \cdot D - \frac{o_B \cdot D}{Q} - \frac{h_B \cdot Q}{2} - P \cdot D \tag{18}$$

4.2. Consignment system

In the consignment system, the only difference from the traditional supply chain system is that the supplier pays the financing cost for the inventories at buyer's warehouse. Otherwise, the decision authority and available information are identical to the traditional system

Step 1. The supplier decides the transfer price (P), estimated order quantity (D'), and planned production quantity in a way to maximize the profit as Equation (19) shows. In Equations (20) and (21), the optimization problem contains the constraint indicating that the planned production quantity should be greater than the estimated demand and the decision variables are non-negative.

$$\underset{P,E,I}{Maximize}\ \pi_S' = P\cdot(l-m\cdot P)-\frac{o_S\cdot(l-m\cdot P)}{E}-\frac{h_S\cdot E\cdot(l-m\cdot P)}{2\cdot I}-v\cdot I-\beta\cdot P\cdot(l-m\cdot P)-\frac{\alpha_F\cdot P\cdot E}{2} \quad (19)$$

$$\text{subject to} \quad I\geq D' \quad (20)$$

$$P,E,I\geq 0 \quad (21)$$

Step 2. The buyer determines the optimal order quantity (Q) and retail price (R) with the knowledge of the transfer price (P), as Equation (22) describes. In Equation (23), every decision variable is non-negative.

$$\underset{R,Q}{Maximize}\ \pi_B = R\cdot(k-d\cdot R)-\frac{o_B\cdot(k-d\cdot R)}{Q}-\frac{h_B^S\cdot Q}{2}-P\cdot(k-d\cdot R) \quad (22)$$

$$\text{subject to} \quad R,Q\geq 0 \quad (23)$$

Step 3. The supplier determines the production quantity (X) with the knowledge of the order quantity (Q), as Equation (24) shows. In Equations (25) and (26), the constraints indicate that the production quantity should be greater than the estimated demand and non-negative.

$$\underset{X}{Maximize}\ \pi_S = P\cdot(l-m\cdot P)-\frac{o_S\cdot(l-m\cdot P)}{Q}-\frac{h_S\cdot Q\cdot(l-m\cdot P)}{2\cdot X}-v\cdot X-\beta\cdot P\cdot(l-m\cdot P)-\frac{h_B^F\cdot Q}{2} \quad (24)$$

$$\text{subject to} \quad X\geq D' \quad (25)$$

$$X\geq 0 \quad (26)$$

Step 4. Total profits of supplier and buyer are computed according to Equations (27) and (28).

$$\pi_S = P\cdot D-\frac{o_S\cdot D}{Q}-\frac{h_S\cdot Q\cdot D}{2\cdot X}-v\cdot X-t\cdot D-\frac{h_B^F\cdot Q}{2} \quad (27)$$

$$\pi_B = R\cdot D-\frac{o_B\cdot D}{Q}-\frac{h_B^S\cdot Q}{2}-P\cdot D \quad (28)$$

4.3. VMI with Consignment

In VMI with consignment, the supplier has an authority over decisions on the inventory management at the buyer's warehouse, and he is responsible for paying the financing cost for buyer's inventories. The buyer still pays the stocking cost for his inventories. Under VMI with consignment, the buyer and supplier go through the following operational decision procedures.

Step 1. The buyer determines the profit margin (w) over the price paid to the supplier (P).

Step 2. With the knowledge of the actual retail demand (D), the supplier determines the order quantity (Q), production quantity (X), and price paid to the supplier (P) to maximize his profit, as Equation (29) describes. Equation (30) and (31) indicate that the production quantity should be greater than the market demand and that the decision variables are non-negative.

$$\underset{P,X,Q}{Maximize}\ \pi_S = P\cdot(k-d\cdot w\cdot p)-\frac{o_S\cdot(k-d\cdot w\cdot p)}{Q}-\frac{h_S\cdot Q\cdot(k-d\cdot w\cdot p)}{2\cdot X}-v\cdot X-\beta\cdot P\cdot(k-d\cdot w\cdot p)-\frac{\alpha_F\cdot P\cdot Q}{2} \quad (29)$$

$$\text{subject to} \quad X\geq D \quad (30)$$

$$P,X,Q\geq 0 \quad (31)$$

Step 3. The buyer determines the optimal retail price (R) with the knowledge of the actual retail demand (D), as described in Equation (32). Equation (33) represents the non-negativity constraint for the decision variable.

$$\underset{R}{Maximize}\ \pi_B = R\cdot(k-d\cdot R)-\frac{o_B\cdot(k-d\cdot R)}{Q}-\frac{h_B^S\cdot Q}{2}-P\cdot(k-d\cdot R) \quad (32)$$

$$\text{subject to} \quad R\geq 0 \quad (33)$$

Step 4. Total profits of supplier and buyer are calculated according to Equations (34) and (35).

$$\pi_S = P\cdot D-\frac{o_S\cdot D}{Q}-\frac{h_S\cdot Q\cdot D}{2\cdot X}-v\cdot X-t\cdot D-\frac{h_B^F\cdot Q}{2} \quad (34)$$

$$\pi_B = R\cdot D-\frac{o_B\cdot D}{Q}-\frac{h_B^S\cdot Q}{2}-P\cdot D \quad (35)$$

5. Analyses on Supply Chain Performances in Numerical Examples

Based on the proposed profit optimization models, this study examines three different supply chain systems in numerical examples. The key objective of numerical examples is to evaluate the performances of VMI with consignment and find out whether the combination of these two programs result in better economic performances than the system with only consignment. Direct comparison between distinct supply chain systems is conducted in terms of their profits and costs, and the analysis reveals that a particular supply chain system is superior to the other systems for whole supply chain system, supplier, and buyer.

The numerical examples are designed to consider nine factors (l, d, k, w, h_S, o_B, o_S, α, and β) that represent the internal and external conditions of the supply chain system. Fifteen different values are considered for each factor, and total 135 cases (9×15) for each supply chain system are included in the numerical examples. For comparisons between different cases, the base case is fixed with arbitrarily chosen parameters as described in Table 2.

<Table 2> Parameters Used in the Base Case.

l = 2,000	m = 15	w = 1.2
k = 1,800	d = 13	v = 30
α = 0.05	α_F = 0.03	α_S = 0.02
o_S = 500	h_S = 1	β = 0.02
o_B = 550		

5.1. Comparison of total supply chain system profits

Table 3 indicates how three supply chain systems perform in the numerical examples. The outcome indicates that the VMI with consignment results in greater supply chain profit than the consignment only system as well as traditional system. The consignment only system obtains higher supply chain profit than the traditional system. Since the consignment contract reduces buyer's cost burden on his inventories, he intends to increase the market demand by decreasing the retail price. The increased market demand raises both buyer's and supplier's profits. After all, the consignment system outperforms the traditional system due to the expanded throughput in the entire supply chain system. However, the consignment only system increases the supply chain profit by much smaller amount than VMI with consignment does. Since the buyer and supplier make decisions on their own operations, the consignment system is still limited to increase the market demand.

Under VMI with consignment, the supplier is allowed to decide his price before the retail price is determined. By decreasing the transfer price by a quite large amount, the supplier tends to increase the market demand significantly. After all, the substantially increased throughput leads to much greater revenues for both supplier and buyer in VMI with consignment than in the consignment only system.

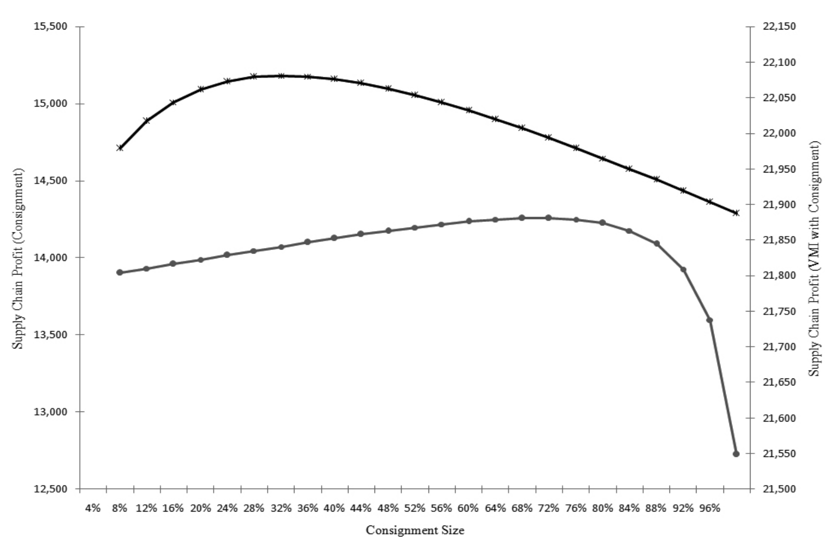
When the outcomes from the numerical examples are analyzed in terms of buyer's and supplier's profits separately, the consignment only system and VMI with consignment show different results. The buyer obtains higher profit in the consignment only system than the traditional system. On the other hand, the consignment results in less profit for the supplier, because he has to pay the financing cost for buyer's inventories. Meanwhile, both buyer and supplier achieve increased profits in VMI with consignment. The enlarged throughput in the entire supply chain system significantly increases both buyer's and supplier's revenue. In addition, the VMI function of VMI with consignment allows the supplier to determine the proper amounts of lot size and production rate at the same time, and it enables him to save the inventory holding and production costs.

<Table 3> Comparison of Performances from Numerical Examples

Averaged values	Traditional	Consignment	VMI w/ Consignment
Market demand (D)	353.93	358.21	415.38
Transfer price (P)	82.26	82.28	73.43
Retail price (R)	111.33	111.00	106.61
Order quantity (Q)	308.10	490.45	452.84
Production quantity (X)	766.05	765.85	656.28
Supplier's revenue	28,962.67	29,321.09	30,534.38
Buyer's revenue	39,433.33	39,793.28	44,360.58
Supplier's cost	24,206.11	24,646.01	21,397.45
Buyer's cost	30,222.08	30,122.40	31,371.66
Supply chain cost	54,428.18	54,768.41	52,769.11
Supplier's profit	4,756.56	4,675.08	9,136.93
Buyer's profit	9,211.25	9,670.88	12,988.92
Supply chain profit	13,967.81	14,345.96	22,125.85

5.2. Impact of Consignment Size on Profit

The additional analysis on the numerical examples are conducted to find out how the consignment size affects the performances of the consignment only system and VMI with consignment. In the numerical examples, the consignment size is defined as the percentage of financing cost over total cost for holding buyer's inventories. In the base case, the consignment size is 60% $\left(\frac{0.03}{0.05}\right)$.



<Figure 1> Impact of Consignment Size on Supply Chain Profit

Figure 1 shows the changes of supply chain profit with different consignment size under the consignment only system and VMI with consignment. In both systems, as the consignment size increases, the supply chain profit increase up to some point early and decreases later. The consignment only system obtains the greatest profit with 68% of consignment size. Under VMI with consignment, the supply chain profit is highest when the consignment size is 28%. In general, the large consignment size has a negative impact on supplier's profit, because the supplier pays the financing cost in both systems. The buyer gets the benefit from the large amount of consignment sizedue to cost saving on inventory holding. This result implies that the supply chain profit is maximized under both the consignment only system and VMI with consignment when the consignment size is set at the appropriate level, which is not extremely high or low.

6. Discussion and Managerial Implications

The main purpose of this study is to examine the impact of VMI with consignment on the supply chain performance. This study uses the proposed framework for characterizing any supply chain collaboration programs in terms of three collaborative features, and defines this program as the combination of two collaborative features, which are decision authority and cost payment. According to the proposition that the supply chain system performs better when it applies more collaborative features, VMI with consignment is expected to outperform the consignment only system. With the series of optimization models that represents the operational decision processes in the supply chain system, this study examines three systems including traditional system, consignment only system, and VMI with consignment and evaluates their performances in the numerical examples. The results of the numerical examples lead to the following results and managerial implications.

First, VMI with consignment achieve greater supply chain profit than the consignment only system as well as the traditional system. The consignment only system also outperforms the traditional systemin terms of supply chain profit, but the amount of improvement is relatively small compared with VMI with consignment. The consignment only system uses only cost payment as the collaborative feature and fails to achieve the performance as much as VMI with consignment that uses both cost payment and decision authority. This result implies that the supply chain collaboration program with more collaborative features achieves better supply chain performance.

Second, VMI with consignment is superior to the consignment only system even in terms of buyer's and supplier's profits. The consignment only system results in smaller amount of supplier's profit than the traditional system due to his additional burden of financing cost for holding buyer's inventories. Under VMI with consignment, however, the supplier holds the authority to make decisions on buyer's inventories, and he can save inventory holding and production costs by properly balancing the lot size and production rate. In addition, the enlarged market demand leads to the significantly increased revenues for both buyer and supplier. By implication, the supply chain system can overcome the weakness of consignment, which is beneficial to only the buyer, by having additional collaborative feature of VMI, and the combination of consignment and VMI leads to a mutual benefit of supplier and buyer.

Finally, this study examines the impact of consignment size on the supply chain profit in the numerical examples, and finds out that both consignment only system and VMI with consignment obtain the maximum profit when the consignment size is set at a certain level between extremely high and low values. This outcome implies that the buyer and supplier should carefully determine the consignment size to obtain the maximum supply chain profit when they use the consignment function.

7. Conclusion

This study focuses on VMI with consignment, which is one of the recent supply chain collaboration programs, and examines its impact on the supply chain performance. Based on the proposed framework for analyzing any supply chain collaborative systems with three collaborative features, VMI with consignment is characterized as the combination of cost payment and decision authority. The main goal of this study is to find whether the additional collaborative features improve the supply chain performance. With the series of optimization models that represent the operational procedures in the supply chain system, this study compares VMI with consignment with the consignment only system as well as the traditional system in the numerical examples. The analysis on outcomes from the numerical examples leads to the following results and managerial implications.

First, VMI with consignment outperforms the consignment only system as well as the traditional system in terms of the supply chain profit. This outcome from the numerical examples supports that the additional collaborative features lead to the improved supply chain performance. This result implies that the existing supply chain collaboration programs can become a more advanced system and achieve better performance by having additional collaborative features.

Second, both buyer and supplier have benefits of improved performances under VMI with consignment. On the other hand, the consignment only system has a weakness in that it is beneficial to only the buyer. By implication, VMI with consignment can be considered to be an alternative to the consignment program when the fair benefit of every participant is essential to apply the supply chain collaboration program.

Finally, the supply chain profit is maximized in VMI with consignment and the consignment only system, when the consignment size is a certain value between extremely high and low ones. This result implies that the buyer and supplier should carefully determine the consignment size to obtain the maximum level of performance, when they apply the consignment function in their supply chain collaboration program.

This study has some limitations and they can be addressed in future studies. First, three supply chain models proposed by this study does not have firm theoretical background. Due to the lack of commonly accepted formats of consignment and VMI, this study relies on its own definitions of detailed supply chain operations when it formulates three supply chain models. Since the supply chain models proposed by this study may not be acceptable by the others, the outcome from these models is not generalizable to every case. Future studies are expected to keep refining the proposed supply chain models and provide the strong theoretical background based on multiple case studies.

Second, this study focuses on only a few supply chain collaboration programs. Since this study considers only consignment and VMI, it cannot examine the effects from diverse collaborative functions. By considering other collaboration programs such as Co-Managed Inventory (CMI) (Peck, 1998) and Collaborative Planning, Forecasting, and Replenishment (CPFR) (Ryu, 2014), the study can obtain comprehensive implications on supply chain collaboration. This study renders this issue to future studies.

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