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Vendor-Managed Inventory in Three Stage Supply Chain

Chungsuk Ryu*

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Abstract

Purpose - Many researchers analyze VMI as a supply chain collaboration program to reveal its true value. Most of them focus on the dyadic relationship in two stage supply chain systems. This study examines the effect of VMI when it is applied to the different parts of three stage supply chain systems.

Research design, data, and methodology – Based on three stage supply chain, this study compares three different systems including full VMI, partial VMI, and non-VMI by using mathematical models. The performances of three systems are compared with the numerical examples of the proposed supply chain models.

Results - The numerical examples reveal that full VMI where the manufacturer controls inventories at all stages outperforms any other systems in terms of the system profit and enables all individual members to gain greater profits than non-VMI. Meanwhile, under partial VMI where VMI is implemented between the wholesaler and retailer, only these two members improve their performances and the manufacturer who does not belong to VMI makes less profit than even under non-VMI. This study also examines the impact of market size and profit margin on the system performance.

Conclusions - The result of this study supports the common belief that VMI secures the best result when it is applied to the entire supply chain system. The additional findings from the numerical analysis are discussed.

Keywords: Supply Chain Management, Vendor-Managed Inventory (VMI), Supply Chain Collaboration, Optimization Problem.

JEL Classifications: M11, M19, M21, M29.

1. Introduction

Supply chain collaboration, which aligns all decisions and operations at every stage of the supply chain system to accomplish the global system goal, has been the main research topic in the region of supply chain management, because of its prospective consequence that could be the ultimate goal of managing the supply chain operations. Among several supply chain collaboration programs, Vendor-Managed Inventory (VMI) is the most popular and has been already applied to various industries (Bookbinder et al., 2010; Tyan & Wee, 2003). Obviously, many studies already conduct researches on VMI and most of them are successful in supporting its strong advantage over any other programs either theoretically or empirically (Claassen et al., 2008; Rad et al., 2014; Stalhane et al., 2014). Meanwhile, the most previous studies focus on only the dyadic relationship between two stages and make their conclusions on the performance of VMI once it is applied to only the partial supply chain system. Their efforts may not be sufficient to reveal the real value of VMI according to the true meaning of supply chain collaboration that is supposed to occur at every stage of the supply chain system.

This study has a purpose of evaluating the performance of VMI when it is applied to different stages of the supply chain system. In this study, the case that VMI is used in the entire system is compared with the case that VMI is implemented to a part of the system, and any difference in the system performance is observed. Three stage supply chain system with a single member at each stage are formulated as the mathematical model and three forms of VMI are different in terms of who controls inventories, pays the relevant costs, and shares demand information at each stage. In the numerical examples, the performances of three systems are compared to make a conclusion about how VMI should be implemented to obtain its full benefit. This study also examines the impacts of market size and profit margin on the system performance and gains additional managerial implications that support the proper application of VMI in practice.

* Associate Professor, College of Business Administration, Kookmin University, Korea. Tel: +82-2-910-4543,
E-mail: ryubear@kookmin.ac.kr

The numerical analysis on the proposed model indicates that the supply chain system achieves better performance when VMI is applied to the whole system than when only the part of the supply chain is involved in VMI. Furthermore, every individual supply chain member obtains greater profit when the manufacturer controls inventories at all the stages than when VMI is not used at all. Even when the VMI contract is made only between the wholesaler and retailer, the supply chain system as a whole still gain greater profit than the traditional non-VMI case. In the case that VMI is applied to the part of the supply chain, however, the benefit from VMI goes to only those participants and the manufacturer who does not belong to VMI makes poor performance than the case without VMI. The additional analysis on the effect of market size indicates that the increase market demand enlarges the benefit from VMI. On the other hand, the extremely high demand increases the manufacturer's cost of ordering and inventory holding in the case that VMI is applied to the whole supply chain system, and consequently, the manufacturer may make less profit than the case without VMI. The supplementary investigation on the profit margin reveals that both manufacturer and wholesale need to set the sufficient level of their profit margins to receive the benefit from VMI.

The key contributions that this study makes are twofold. First, this study improves theoretical research on VMI by considering more realistic condition of the supply chain system. Although there have been already many studies that examine how VMI affects the supply chain performance, most of them focus on only the dyad between two stages of the supply chain system. Meanwhile, this study expands the area of VMI application into three stage supply chain system in the theoretical models and successfully figures out the true value of VMI by comparing the case that VMI is used in the entire system with the case that it is applied to the partial system.

Second, this study gives a practical help to any supply chain member who should decide whether to participate in VMI once it is already used at different stages of the supply chain system. The case that one member does not belong to VMI is tested and the impact of VMI on his performance is evaluated in this study. This result provides the valuable managerial implication that assists any supply chain member to make a right decision on whether he should participate in VMI in practice.

2. Research Background

Supply chain collaboration is defined to be the supply chain system where its every member makes decisions and takes operational actions in a way to maximize the supply chain profit. According to the supply chain collaboration, Vendor-Managed Inventory (VMI) is one of the programs that are designed to bring the improvement of the supply chain performance. Compared with other programs such as Quick Response (QR) and Efficient Consumer Response (ECR), VMI is known as more advanced collaboration initiative that enables supply chain members to actively collaborate on the operations for their mutual benefit.

According to the VMI contract, the vendor has a full authority to determine the amount of inventories at the buyer's level. VMI is commonly considered to be a business contract made between a vendor and a buyer, and the most studies on VMI evaluate its effect in two stage supply chain system. Those studies compare VMI with various programs such as traditional non-VMI (De Toni & Zamolo, 2005; Egri & Vancza, 2013; ElHafsi et al., 2010; Govindan, 2015; Mateen & Chatterjee, 2015), information sharing (Fry et al., 2001; Salzarulo & Jacobs, 2014; Yao & Dresner, 2008), Continuous Replenishment Policy (Tyan & Wee, 2003; Yao & Dresner, 2008), and consignment (Chen et al., 2010; Gumus et al., 2008; Savasaneril & Erkip, 2010). Many studies on VMI commonly support its superiority to the other programs by measuring its performances including the cost (Darwish & Odah, 2010; Govindan, 2015; Mateen & Chatterjee, 2015; Tat et al., 2015), profit (Almehdawe & Mantin, 2010; Chakraborty et al., 2015; Dong & Xu, 2002; Stalhane et al., 2014), inventory level (Choudhary & Shankar, 2015a; Waller et al., 1999; Yao & Dresner, 2008), customer service level (Bichescu & Fry, 2009; Sari, 2008a; Webster & Weng, 2008), and bullwhip effect (Disney et al., 2004; Disney & Towill, 2002; Kristianto et al., 2012).

The past studies focus on the key collaborative features of VMI, which are information sharing and integrated decision making, and they rely on these two special functions to explain the reason that VMI improves the supply chain performance. Information sharing, as the first collaborative feature of VMI, represents that the vendor receives the information of market demand and inventory amount directly from the buyer. While many studies examine the effect of information sharing combined with integrated decision making (Chen, 2013; Kannan et al., 2013; Mishra & Raghunathan, 2004b; Rad et al., 2014; Sari, 2008b), a group of researchers still address information sharing as the main research topic in their studies on VMI. Angulo et al. (2004) examine how the inaccuracy and delay of information transferred from the buyer to the vendor affect the performance of VMI. In Kulp's study (2002), the precision and reliability are the key qualities of shard information and they determine whether VMI outperforms non-VMI. On the other hand, Yang et al. (2003), in their study on several determinants of success in VMI application, find out that the effect of information sharing is minimal under VMI.

Since the vendor controls buyer's inventory under VMI, the vender is able to make the integrated decisions on replenishment of buyer's inventory accordant with his own inventory control and production scheduling. A group of studies consider the integrated decision making to be the key feature that enables VMI to improve the system performance by directly comparing with the system with only information sharing (Choudhary & Shankar, 2015a, b; Savasaneril & Erkip, 2010; Yao & Dresner, 2008), and they generally support that VMI makes more value beyond information sharing. Several studies compare VMI with the centralized decision making system and reveal that VMI still requires a further improvement to make the same performance as the centralized system (Ben-Daya et al., 2013; Bookbinder et al., 2010; Chen & Wei, 2012; Dong & Xu, 2002; Song & Dinwoodie, 2008).

Meanwhile, some researchers point out that it is necessary to look over VMI beyond the simple dyadic contract made between two supply chain members. Danese (2004, 2006) compares the integrated VMI system with the traditional dyadic VMI in his case study, and finds out that VMI is successful when its application extends to the entire supply chain system. In his study, the traditional VMI is described as the customer-and-supplier dyadic program that manages the supply chain operations happening only between customers and their immediate suppliers. He claims that the supply chain members can achieve the best performance from VMI by managing the supply chain system as a whole object rather than as a series of customer and supplier dyads.

VMI is a program for realizing coordination among supply chain members. It is commonly accepted that the supply chain system achieves a full benefit from coordination only when the entire network is coordinated and it is not sufficient to coordinate only between two stages (Chopra & Meindl, 2010). By implication, VMI is appreciated at its true value only when it is used in the whole supply chain system beyond the dyad between two stages. Furthermore, in real cases, most supply chain systems have the complicated structure with more than two stages (Kalpakam et al., 2014; Sabitha et al., 2016). Accordingly, to make the realistic conclusion about VMI, it is necessary to examine VMI in multiple stage supply chain system with more than two echelons.

In the research area of supply chain management, there have been many studies about how to manage inventories at the supply chain with more than two stages (Kim & Glock, 2013; Lee, 2005; Simpson, 2007). Only a few studies, however, examine VMI in more than two stage supply chain system. Angulo et al. (2004) evaluate the performance of VMI by simulating the supply chain system with four echelons. Meanwhile, their study emphasizes only the information sharing activity in the VMI system and examines the impact of delay and accuracy of shared information on the system performance. Sabitha et al.'s work (2016) is another study that focuses on the benefit of information sharing under the VMI system with multiple stages rather than the effect of VMI.

Sari (2007) designs the simulation model that represents a four stage supply chain system and evaluates the impact of VMI application on the system performance by comparing with the traditional non-VMI system. His proposed VMI system includes the aspects of centralized decision making process as well as information sharing. In his model, however, VMI is assumes to occur only between the distributor and the retailer. Yu and Huang (2010) consider the VMI system having three stages with multiple suppliers, one manufacturer, and multiple retailers. However, their study also assumes that VMI is applied to only lower level of the supply chain system and focuses on developing the optimal solution algorithm rather than evaluating the performance of VMI. Sohrabi et al. (2016) compare VMI with

<Table 1> Summary of Selected Studies on VMI

Authors (Year)	Research Issue	Supply Chain Structure (Number of Stages)	Performance Measurement
Fry et al. (2001)	New replenishment contract for VMI	A supplier and a retailer (2 stages)	Supply chain cost
Angulo et al. (2004)	Influence of information accuracy and delay	A plant, a vendor DC, a retailer DC, and a retailer store (4 stages)	Inventory level, fill rate, costs
Mishra & Raghunathan (2004)	VMI under brand competition	Two manufacturers and a retailer (2 stages)	Profits
Sari (2007)	Performance of VMI under different operational conditions	A plant, a warehouse, a distributor, and a retailer (4 stages)	Cycle service level, system cost, inventory level
Bichescu & Fry (2009)	Effect of channel power	A supplier and a retailer (2 stages)	System cost, customer service
Almehdawe & Mantin (2010)	Retailer versus manufacturer led VMI	A manufacturer and three retailers (2 stages)	Profits
Chen et al. (2010)	Revenue sharing contract with side payment	A wholesaler and multiple retailers (2 stages)	Profits
Darwish & Odah (2010)	Solution algorithm for optimal replenishment	A vendor and multiple retailers (2 stages)	System cost
Govindan (2015)	Performance of VMI and solution algorithm	A vendor and multiple retailers (2 stages)	System cost
Sabitha et al. (2016)	Value of information sharing	More than two echelons (N stages)	Demand variance
Sohrabi et al. (2016)	Impact of VMI on the supplier selection decision	Multiple suppliers, a single distributor, and multiple retailer (3 stages)	System profit

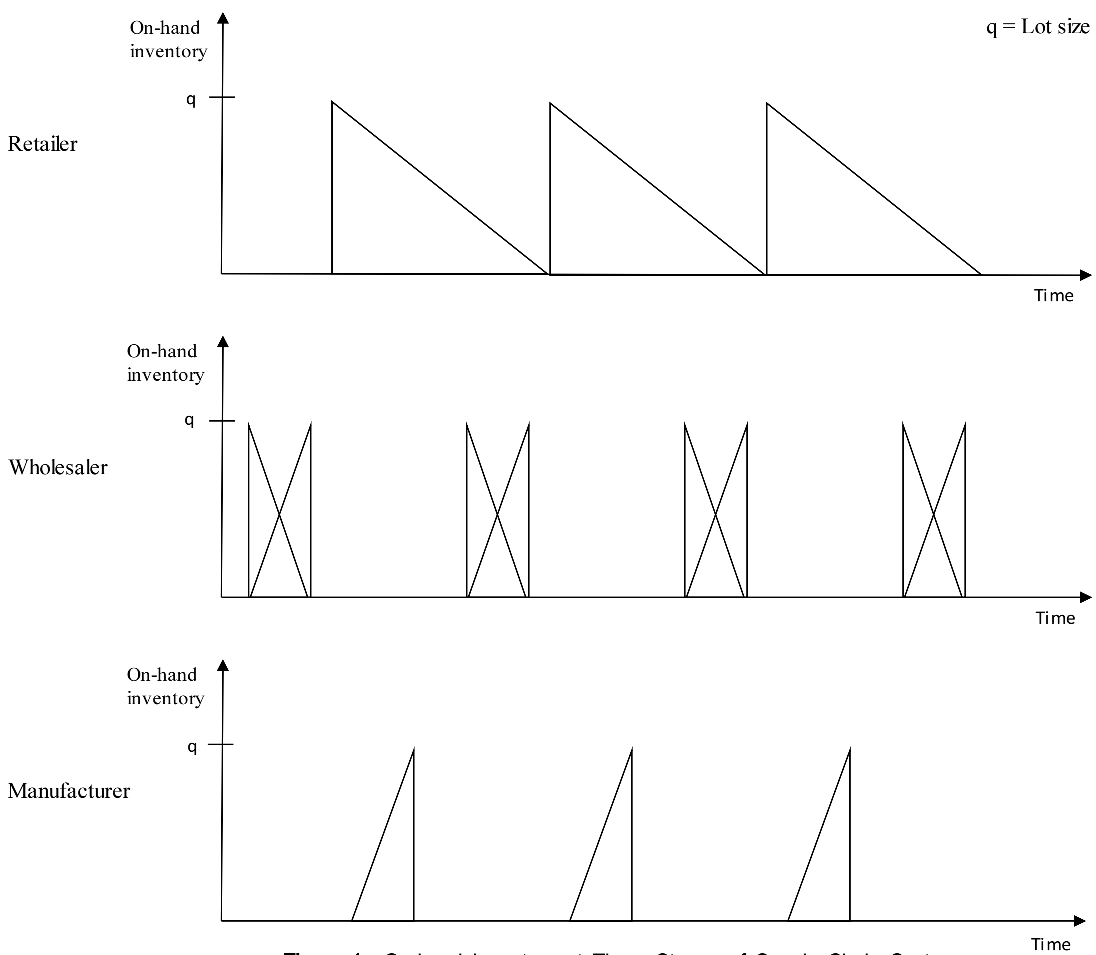
non-VMI in three stage supply chain system with multiple suppliers, a single distributor, and multiple retailer. In their VMI model, however, the suppliers are responsible for ordering and pay cost for only the distributor and their study attends to mainly the impact of VMI on the supplier selection decision.

This study evaluates the performance of VMI in three stage supply chain system, while most past studies focus on the dyadic contract made between two stages. Furthermore, by examining the distinct cases that VMI is applied to different stages, this study figures out whether VMI should be implemented at the whole supply chain system to achieve its full benefit or it is sufficient to apply VMI to a part of the system. The selected studies that conduct research on VMI are summarized in <Table 1> and they can be easily compared in terms of the key issue, supply chain structure, and performance measurement that they use.

3. Three Supply Chain Models

This study examines the effect of VMI at different stages of the supply chain system by using the mathematical model. The proposed model represents the supply chain system that has three stages with one manufacturer, one wholesaler, and one retailer, and only a single product type is handled in the entire system. The manufacturer takes orders from the wholesaler and determines the production amount and the product price at which he sells to the wholesaler. The wholesaler places orders to the manufacturer and makes decisions on the price of his product and the amount of products to be processed into the products that are sold to the retailer. The retailer’s decisions are ordering to the wholesaler and pricing the products that are sold to the retail market.

This study develops the inventory control system by using the joint economic lot size model (Banerjee, 1986). <Figure 1> shows how the inventory level changes over time at each stage of the supply chain system.



<Figure 1> On-hand Inventory at Three Stages of Supply Chain System

The supply chain model represents the decision making process conducted by three individual supply chain members. <Table 2> explains the notations used in the proposed model.

<Table 2> Notations Used in Mathematical Models

Manufacturer's		**Wholesaler's**		**Retailer's**	
π_M	Profit	π_W	Profit	π_R	Profit
p_M	Unit price	p_W	Unit price	p_R	Unit price
x_M	Production rate	x_W	Processing rate	q_R	Order quantity
S_M	Setup cost per wholesaler's order	q_W	Oder quantity	O_R	Ordering cost
α_M	Unit inventory cost per price	S_W	Setup cost per retailer's order	α_R	Unit inventory holding cost per price
v_M	Unit production cost	α_W	Unit inventory holding cost per price	D_R	Retail market demand
τ_M	Unit transportation cost per price	O_W	Ordering cost	k_R	Potential market size
ω_M	Profit margin	ω_W	Profit margin	d_R	Price sensitivity parameter
		v_W	Unit processing cost		
		τ_W	Unit transportation cost per price		

The proposed supply chain model is composed of three member's problems and each problem indicates that the individual member makes any decisions in a way to maximize his own profit. In addition, this study assumes that the cost to hold the inventory with higher value is more expensive. The cost to transport the product is also proportional to its price in the proposed model. The following models show the traditional non-VMI system as the basis of supply chain models.

Manufacturer's problem:

$$\max_{p_M, x_M} \pi_M = x_W \cdot p_M - \frac{S_M \cdot x_W}{q_W} - \frac{\alpha_M \cdot p_M \cdot q_W \cdot x_W}{2x_M} - V_M \cdot x_M - \tau_M \cdot p_M \cdot x_W \quad (1)$$

subject to

$$x_M \geq x_W \quad (2)$$

$$p_M, x_M \geq 0 \quad (3)$$

Wholesaler's problem:

$$\max_{p_M, x_M, q_W} \pi_M = D_R \cdot p_W - x_W \cdot p_M - \frac{o_W \cdot x_W}{q_W} - \frac{\alpha_W \cdot p_W \cdot q_W}{2} - \frac{S_W \cdot D_R}{q_R} - \frac{\alpha_W \cdot p_W \cdot q_R \cdot D_R}{2 \cdot x_W} - v_W \cdot x_W - \tau_W \cdot p_W \cdot D_r \quad (4)$$

subject to

$$x_W \geq D_R \quad (5)$$

$$p_W, x_W, q_W \geq 0 \quad (6)$$

Retailer's problem:

$$\max_{p_R, q_R} \pi_R = D_R \cdot (p_R - p_W) - \frac{O_R \cdot D_R}{q_R} - \frac{\alpha_R \cdot p_W \cdot q_R}{2} \quad (7)$$

subject to

$$p_R, q_R \geq 0 \quad (8)$$

Equation (1) indicates that the manufacturer determines his product price and production rate in a way to maximize his profit. The manufacturer's profit is composed of the sale revenue from the wholesaler, setup cost, inventory holding cost, and manufacturing cost, and transportation cost. Constraint (2) specifies that the manufacturer should produce at least the amount of products that the wholesaler processes. The manufacturer should decide his product price and production amount to be non-negative values in Constraint (3).

Wholesaler's decision process is formulated into the optimization model in Equation (4) and it indicates that he determines his product price, the amount of orders to the manufacturer, and the amount of products to be processed for sales to the retailer. He also intends to maximize his profit that includes the sales revenue, purchasing cost, ordering cost, cost for holding inventories that come from the manufacturer, setup cost, cost for holding inventories that are processed by the wholesaler, processing cost, and transportation cost. The wholesaler should process a sufficient amount of products to satisfy the retail market demand as shown in Constraint (5). Equation (6) indicates the non-negativity constraints for the wholesaler's price, processing amount, and order quantity.

Equation (7) represents that the retailer determines the price at which he sells to the retail market and the amount of order to the wholesaler. His profit is comprised of the revenue from sales to the retail market, purchasing cost, ordering cost, and inventory holding cost. Non-negativity constraints for the retailer's price and order quantity are shown in Equation (8).

The retail market demand is assumed to be sensitive to the retail price and it is represented as the linear function in Equation (9).

$$D_R = k_R - d_R \cdot p_R \quad (9)$$

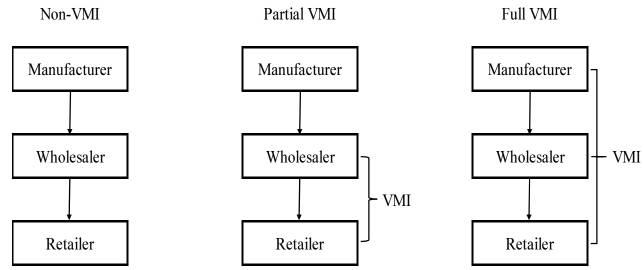
With VMI, the wholesaler obtains the detailed information of the retail market and estimates the demand based on his profit margin as Equation (10) shows. The manufacturer also assesses the market demand based on his own profit margin under VMI.

$$D_W = k_R - d_R \cdot \omega_W \cdot p_W \tag{10}$$

This study examines the effect of VMI when it is applied to the different stages of the system and compares three different supply chain systems that are non-VMI, partial VMI, and full VMI. Non-VMI does not have VMI at all, and all three supply chain members behave in the traditional way. In the non-VMI system, each member controls only his own inventories independently and pays only the cost for ordering and holding his own inventories. Information sharing is quite limited in this system, and only the order is known to the right next upstream member. Since only the retailer knows about the retail market demand, both manufacturer and wholesaler determine their own prices and production/ processing rates based on the estimated demand.

In the partial VMI system, VMI occurs only between the wholesaler and retailer as shown in <Figure 2>. Since the manufacturer does not belong to VMI, he controls only his inventories and pays for them. In this system, the manufacturer does not receive any information about the retail market demand, he decides his price and production rate based on his own estimated demand. The wholesaler is responsible for retailer's inventories as well as his own inventories and pays the consequent costs for retailer's ordering and inventory holding. With the information of retail market demand, the wholesaler determines his price and retailer's order.

As <Figure 2> shows, full VMI indicates the supply chain system where VMI is applied to all the stages. In this system, all three members participate in the single VMI program, and the manufacturer controls everyone's inventories. The manufacturer determines the lot size for both wholesaler's and retailer's inventories. Since all three members are under the same VMI contract, the manufacturer decides everyone's order, his price, and production rate with knowledge of the retail market demand directly received from the retailer. The costs for setup, ordering, and inventory holding at all three stages are paid by the manufacturer.



<Figure 2> Three forms of VMI

4. Numerical Analysis

In this study, three different systems including non-VMI, partial VMI, and full VMI are considered and their performances are evaluated by using the numerical examples of the proposed supply chain models. <Table 3> illustrates the specific parameters used in the base case and they are arbitrarily determined.

<Table 3> Basic Parameter Setting

S_M = 70	S_W= 50	O_W = 70	O_R= 90
α_M = 0.02	α_W= 0.03	α_R= 0.04	
v_M = 20	v_W = 10	τ_M = 0.05	τ_W = 0.08
k_R = 1,800	d_R = 6	ω_M = 1.50	ω_W = 1.50

In the numerical examples, various cases are considered with different values of the model parameters. Four parameters including the market demand size, setup cost, ordering cost, inventory holding cost are adjusted to be seven different levels, and accordingly, total number of cases for each supply chain system is 2,401.

4.1. Overall performances of three forms of VMI

Each detailed measurement of supply chain performance is averaged over all the cases and presented in <Table 4>.

<Table 4> Supply Chain Performances

	Non-VMI	Partial VMI	Full VMI
Market demand	342.73	400.27	361.43
Manufacturer			
Price	110.56	110.56	111.82
Production Rate	894.44	894.44	361.43
Setup Cost	275.34	304.17	203.23
Inventory Holding Cost	55.23	45.2	137.7
Production Cost	17,888.81	17,888.81	7,228.58
Transportation Cost	2,360.14	2,237.89	2,044.63
Total Cost	20,579.53	20,476.07	11,211.52
Revenue	47,202.81	44,757.90	40,892.62
Profit	26,623.29	24,281.83	29,681.10

	Non-VMI	Partial VMI	Full VMI
Wholesaler			
Price	184.77	166.58	179.52
Order Quantity	107.21	91.73	-
Processing Rate	421.84	400.27	361.43
Purchasing Cost	47,202.81	44,757.90	40,892.62
Ordering Cost	275.34	304.16	203.77
Inventory Holding Cost (Before Processing)	176.51	151.88	207.25
Setup Cost	187.65	216.97	144.85
Inventory Holding Cost (After Processing)	205.69	228.92	332.86
Processing Cost	4,218.36	4,002.74	3,614.29
Transportation Cost	5,132.42	5,400.72	5,256.90
Total Cost	57,398.78	55,762.88	49,763.81
Revenue	64,155.26	67,508.99	65,711.25
Profit	6,756.48	11,746.11	15,947.44
Retailer	5,132.42	5,400.72	5,256.90
Price	242.88	233.29	239.76
Order Quantity	91.12	-	-
Purchasing Cost	64,155.26	67,508.99	65,711.25
Ordering Cost	337.53	393.99	264.12
Inventory Holding Cost	337.53	305.60	444.54
Total Cost	64,830.32	67,508.99	65,711.25
Revenue	84,426.96	94,637.88	87,826.38
Profit	19,596.64	27,128.89	22,115.13
Supply Chain System			
Cost	142,808.62	143,747.95	126,686.58
Revenue	195,785.03	206,904.77	194,430.25
Profit	52,976.40	63,156.83	67,743.67

The outcomes from the numerical analysis show that full VMI outperforms partial VMI as well as traditional non-VMI in terms of total supply chain profit. Furthermore, each supply chain member obtains greater profit when they are in the full VMI system than under partial VMI and non-VMI. Only one exception is that partial VMI results in greater retailer's profit than full VMI. This result implies that VMI results in the best overall system performance when it is applied to the entire supply chain system. Even the individual supply chain member receives the benefit from the VMI program when all of them involve in it. In details, the manufacturer improves his performance under full VMI mainly because he controls the size of production rate properly based on the information of actual retail market demands. The wholesaler also adjust his processing rate to the retail market demand without considering orders to the manufacturer and receives benefits from full VMI. Since the manufacturer is responsible for all the costs regarding inventories under full VMI, both wholesaler and retailer save the ordering, setup, and inventory holding costs.

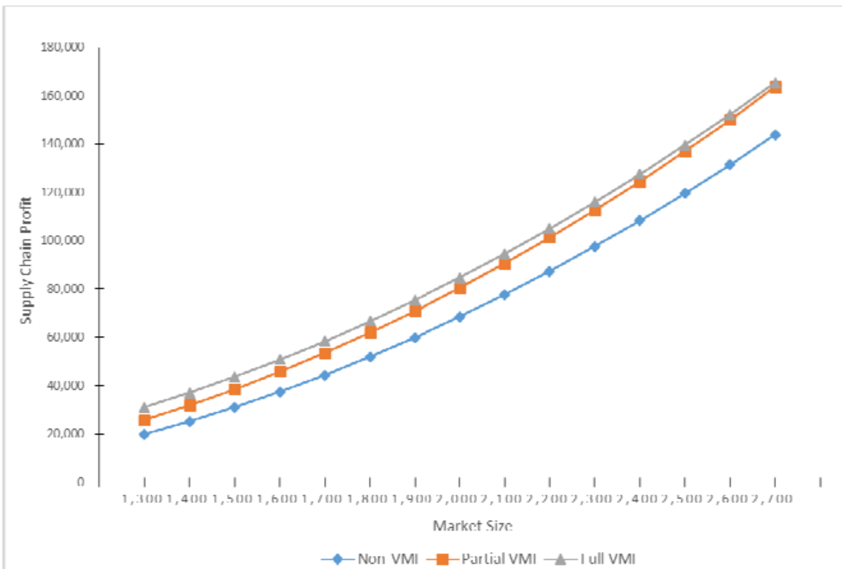
The partial VMI system also results in higher supply chain profit than the non-VMI system. Meanwhile, not every supply chain enjoys the benefit from VMI in this case, and only the wholesaler and retailer increase their profits compared with non-VMI. In fact, the manufacturer who does not belong to VMI obtains less profit under partial VMI than he does in non-VMI. This result indicates that any supply chain member takes a risk of poor performance when he is one of the members who do not participate in the VMI program. The outcomes of partial VMI in <Table 4> show that the wholesaler receives the benefit of VMI by saving the processing cost with knowledge of the retail market demand. The retailer also saves both ordering and inventory holding costs, which are paid by the wholesaler. The manufacturer who does not belong to VMI, however, does not know the retail market demand and still pays huge production cost under partial VMI.

4.2. Impact of Market Size on Supply Chain Profit

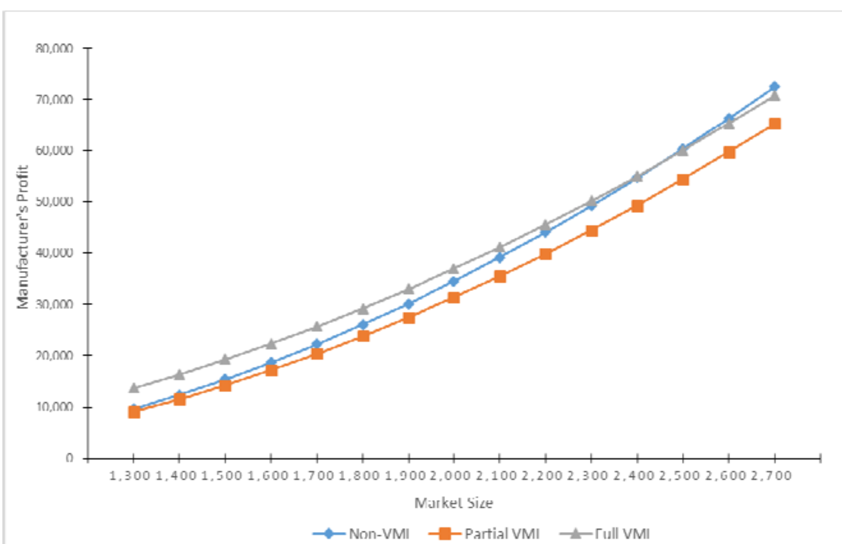
The additional analyses are conducted with the numerical examples and this study examines the impact of the market size on the supply chain profit. <Figure 3> shows how the system profit changes with different market sizes. As the entire demand size increases, the difference in system profit between full VMI and non-VMI increases. The similar pattern is noticed in comparison between partial VMI and non-VMI. Meanwhile, full VMI achieves greater profit than partial profit as it noticed in the previous analysis, but the difference becomes smaller as the market demand increases.

The further analyses on the individual supply chain member's profit reveal the reason that this outcome happens. When the market demand is small, the manufacturer obtains greater profit under full VMI than he does under non-VMI as it appears in <Figure 4>. As the demand size increases, however, the manufacturer under full VMI has to pay much greater cost of ordering and inventory holding for all three stages. After all, his cost burden overcomes the benefit from VMI and his profit under full VMI becomes even less than under non-VMI. Meanwhile, partial VMI keeps a certain amount of difference in manufacturer's profit from full VMI as the market demand increases, because the manufacturer does not belong to VMI and cannot receive any benefit from it.

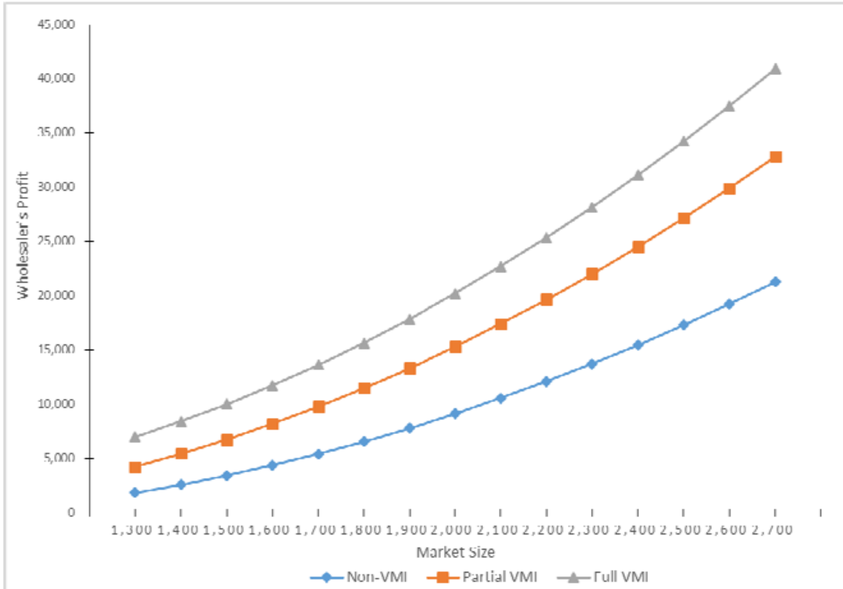
<Figure 5> shows the change of wholesaler's profit with different market sizes. As the market demand increases, the differences in the profit among three supply chain systems consistently increase. This result implies that the wholesaler reliably receives greater benefits from additional VMI application to the supply chain system with larger size of market demand.



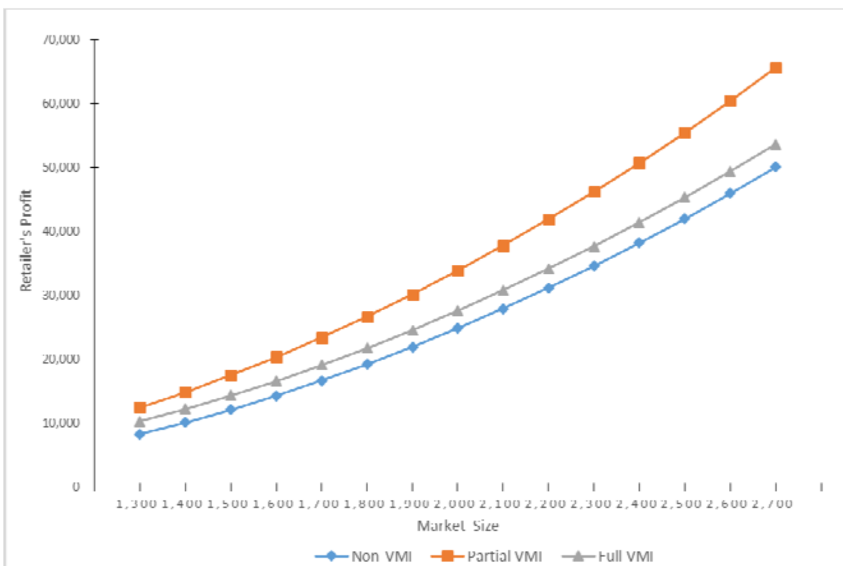
<Figure 3> Impact of Market Size on Supply Chain Profit



<Figure 4> Impact of Market Size on Manufacturer's Profit



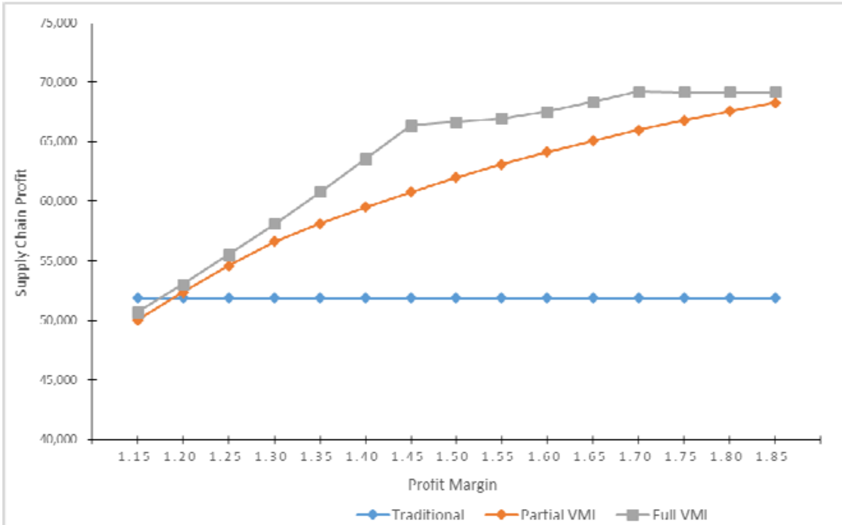
<Figure 5> Impact of Market Size on Wholesaler's Profit



<Figure 6> Impact of Market Size on Retailer's Profit

The retailer obtains greater profit under partial VMI than any other systems as <Figure 6> shows. Full VMI results in less profit for the retailer than partial VMI, because the manufacturer has to set the high price to cover his cost of ordering and inventory holding for all three stages and it reduces the market demand after all. The difference in retailer's profit between partial VMI and non-VMI increases as the market size becomes larger. Meanwhile, full VMI keeps the relatively constant difference from non-VMI.

The outcomes from analysis on the market size indicates that VMI with larger market demand results in greater supply chain profit. Meanwhile, the impact of increased market demand on each individual supply chain member's profit is different depending on how VMI is applied to the supply chain system. Under full VMI, larger market demand leads to greater profits for the wholesaler and retailer compared with partial VMI and non-VMI. Meanwhile, when the market demand is really high, the manufacturer under full VMI obtains less profit than he does under non-VMI, because his cost of ordering and inventory holding increases due to the large demand. By implication, when the market demand is really high, full VMI is beneficial to only the wholesaler and retailer, and a certain incentive scheme should be prepared to keep the manufacturer in the VMI program by compensating for his loss.



<Figure 7> Impact of Profit Margin on Supply Chain Profit

4.3. Impact of Profit Margin on Supply Chain Profit

This study considers manufacturer's and wholesaler's profit margins to be additional factors affecting the supply chain performance and examines how the profit margins affect the system profit. When the wholesaler sets the low profit margin under partial VMI, the system performance becomes poorer than non-VMI. However, as the wholesaler's profit margin increases, the supply chain profit of partial VMI becomes higher as <Figure 7> shows. The same result is observed when both manufacturer and wholesaler set higher profit margins under full VMI. Meanwhile, the difference in the system profit between full VMI and partial VMI becomes larger as the profit margin increases at the beginning and then the difference gets smaller after all. The system profit under both partial VMI and full VMI increases at the decreasing rate as the profit margin increases.

5. Discussion and Managerial Implications

This study conducts theoretical analysis on VMI as a supply chain collaboration when it is applied to different stages of the supply chain systems. Most previous studies examine VMI in two stage supply chain, because VMI is commonly known as a dyadic contract made between a customers and his immediate supplier. In real cases, however, most supply chain network is comprised of more than two stages. Theoretically, the collaboration should be applied to the whole supply chain to get its optimal result. Accordingly, this study investigates the extensive application of VMI to three stage supply chain system and obtains new findings that are not feasible to the studies on two stage network.

Three different forms of VMI are considered in three stage supply chain system and their performances are evaluated with the proposed mathematical models. Based on the numerical examples, this study shares the common idea with many previous studies that support that VMI improves the supply chain performance in two stage network (Disney & Towill, 2003; Dong & Xu, 2002; Mishra & Raghunathan, 2004). In this study, however, the additional findings are obtained by considering the case that VMI is applied to the supply chain system with three echelons.

The numerical analysis reveal that full VMI, where VMI is applied to the entire system achieves greater supply chain profit than partial VMI, where only the wholesaler and retailer participate in VMI, as well as non-VMI. Furthermore, except for the retailer under partial VMI, every individual supply chain member achieves the greater profit under full VMI than he does in partial VMI and non-VMI. This result supports the idea of the past study and implies that VMI can lead to its best result when it is applied to the whole supply chain system. Even almost every individual supply chain member can secure the greatest achievement from VMI when they altogether participate at the VMI program. This outcome implies that VMI should be designed to attract every supply chain members and keep them stay in the single program to achieve the ideal performance.

Under partial VMI, the supply chain system achieves greater profit than under non-VMI, but not every individual member improves his performance. According to the numerical examples, only the wholesaler and retailer who participate in VMI under partial VMI obtain greater profits than under non-VMI. The manufacturer, who does not belong to VMI under partial VMI, achieves less profit than he does in the traditional system without VMI. By implication, any supply chain member takes a risk of poor performance once he fails to participate in the VMI program. These findings indicate that it is important not only for the whole supply chain system but also for its individual members to belong to the VMI program.

The additional analysis on the market size illustrates that full VMI results in much greater system profit than non-VMI as the demand size increases. However, the difference in the system profit between full VMI and partial VMI becomes smaller as the demand gets larger. In particular, when the demand size is quite large, the manufacturer under full VMI achieves poor performance than under non-VMI due to his heavy burden of ordering and inventory holding costs to pay for all three stages. By implication, when the throughput of the entire supply chain system is huge, it is necessary to prepare the proper incentive scheme that compensates for manufacturer’s loss under full VMI. This result points out that it is important to add the certain supplementary program to the original design of VMI to hold every supply chain members together under VMI.

According to the analysis on the profit margin, both full VMI and partial VMI obtain greater system profit when the manufacturer and wholesaler set higher profit margins. However, the amount of increase in the system profit becomes smaller as the profit margin increases. Since both full VMI and partial VMI make poorer performance than non-VMI when the profit margins are quite low, the manufacturer and wholesaler need to determine the sufficient level of their profit margin to get the benefit from VMI. The agreement on the profit margins for upstream stages can be the additional critical element of VMI contract required for the successful VMI application.

6. Conclusion

VMI as a supply chain collaboration program has been used in diverse industries, and both business practitioners and academic researchers have recognized its practical value that leads to the significant improvement of the supply chain performance. Meanwhile, VMI is considered to be a certain contract made by two supply chain members who have a direct business relationship in most past studies. The question is raised about whether VMI needs to be implemented in the whole supply chain system or it is sufficient to have just a dyadic VMI contract made between two members. This study examines how VMI affects the supply chain performance when it is applied to different stages of the supply chain system.

This study considers three stage supply chain system where one manufacturer, one wholesaler, and one retailer handle a single product type. Three different forms of VMI including non-VMI, partial VMI, and full VMI are formulated into mathematical models and their performances are evaluated in the numerical examples. Outcomes of the numerical analysis indicate that full VMI where the manufacturer controls the inventories at all the stages outperforms partial VMI, where only the wholesaler and retailer belong to VMI, as well as non-VMI. Furthermore, every individual supply chain member obtains greater profit under full VMI than under non-VMI. While partial VMI results in higher supply chain profit than non-VMI, only the wholesaler and retailer receive the benefit from VMI. In fact, under partial VMI, the manufacturer who does not belong to VMI makes worse performance than he does under non-VMI. The additional analysis is conducted on the market size and profit margin to get more ideas about how to properly operate VMI in practice.

The overall outcome from numerical analysis supports that VMI has to be applied to the whole supply chain system to realize its true value. This result supports the theoretical reasoning that the supply chain collaboration achieves its optimal performance only when the entire supply chain network is coordinated. Moreover, this study provides some practical managerial implications for anyone who implements VMI in real businesses. Once VMI is implemented in the supply chain system, any supply chain member has to take a risk of poor performance when he fails to participate in the VMI program. Since the manufacturer under full VMI is expected to make poorer performance than under non-VMI when the demand size is quite large, it is necessary to prepare a certain incentive scheme that compensate for his loss. The outcome from the numerical analysis also implies that both manufacturer and wholesaler should set the appropriate levels of their profit margins to get the benefit from VMI.

Some points can be found to be certain limitations in this study and they become potential research issues for future studies. First, the numerical examples used in this study use the arbitrarily determined parameters, and they may fail to present the definite situation that happens in the real businesses. By using the real data from the case study or the specific values of parameters from the empirical study on the real industry, future studies can obtain more realistic analytic results that are useful for the practitioners.

Second, the supply chain system designed by this study contains a very simplified retail market model that may not apprehend various market situations. In the proposed supply chain model, this study assumes the market demand is solely dependent on the retail price. Future researchers can conduct sophisticated analyses on the effect of VMI under diversified market conditions by employing the other significant elements that possibly affect the market demand such as competition and demand uncertainty (Dong et al., 2007; Mishra & Raghunathan, 2004).

Third, this study relies on a very conventional supply chain structure and ignores the special features of the emerging online supply chain system. Since the business trade over the websites is quite widespread over almost every industry in these days, it is necessary to examine the performance of VMI in the online supply chain system by addressing its unique characteristics that are quite different from the common offline supply chain (Disney et al., 2004).

Finally, this study intentionally emphasizes the vendor's work on managing inventories under VMI and overlooks the retailer's activities in supply chain operations. In the retail industry, in particular, the retailer plays a critical role in assessing demand information and providing services directly for the retail market, and VMI should find its way to be compatible with the retailer-led supply chain system (Wang & Liu, 2007). This research issue is passed to future studies.

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