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Collaborative Vendor Managed Inventory Models for Managing 2-Echelon Supply Chains with the Consideration of Shortage in Demand

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재고부족을 고려한 2단계 공급 망을 위한 협업 VMI 모델

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Abstract One of the most important issues of managing a supply chain is to determine the inventory level whenever shortage is permitted and vendor is responsible for management of the both buyer and supplier's inventory. We present two vendor managed inventory models in the form of two-echelon supply chain models for: 1) one buyer-one supplier problem, and 2) two buyers- one supplier problem. We assume that shortage is permitted. The proposed methods of this paper provides a simple condition, which makes it easy to decide when and how vendor managed inventory model costs less than traditional one. The paper is supported with some numerical examples to show the implementation of the proposed methods.

Key Words : 벤더재고관리 (VMI), 공급망관리 (SCM), 2단계 공급망, 협업관리, 재고부족.

요 약 공급 망 관리의 주요 이슈중의 하나는 재고부족(Shortage)이 허용되고 벤더가 공급자와 구매자 모두의 재고관리를 책임지는 상황 하에서, 재고수준을 결정하는 것이다. 본 연구에서는 두 개의 벤더재고관리 (Vendor managed inventory, 이하 VMI) 모델을 제시하고 각각의 해법을 개발한다. 두 모델 중 하나는 단일 구매자 및 단일 공급자 문제이고, 다른 하나는 두 구매자 및 단일 공급자 문제이다. 본 연구가 제안하는 방법론은 VMI모델이 전통적인 모델과 비교해서 어떠한 상황에서 적은 비용으로 운영될 수 있는지 결정하는 조건들을 유도해 낸다. 또한 수치예제를 통해서 제안된 방법론들의 타당성을 입증해 보인다.

1. Introduction

During the past decade, there have been some evidences indicating that Vendor Managed Inventory (VMI) could improve the performance of supply chain by decreasing inventory levels and increasing fill rates [4]. Retailers and manufacturers have recognized that their profitability and revenue growth is directly linked to supply chain efficiency due to a highly competitive and volatile market [8, 9]. As a result, many consumer goods manufacturers and retailers have looked to collaborative partnerships as an avenue to supply chain optimization. VMI is believed to be one of the most successful types of these collaborative partnerships. Using the idea of VMI, retailers can shift the responsibility for planning and replenishment activities to the manufacturers.

VMI presents major benefits for manufacturers as well since they can respond more quickly to unexpected changes in consumer demand, increase customer service levels and product turns,decrease stock-outs and returns and gain "preferred vendor"status with key retailers. VMI is a process where the supplier generates orders for the customer based on demand information sent by the

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customer. Based on the procedure of VMI, the supplier is guided by mutually agreed to objectives for inventory levels, fill rates and transaction costs. VMI is only one term for inventory management systems where the supplier manages the day-to-day inventory activity. The process is also known as Supplier ManagedInventory, Consignment Inventory, Consignment Stores, Breadman and VMI. VMI can provide big business benefits, including: Increased sales (100% or more in certain categories), a 50% reduction in lead-time, 20% –70% reduction in inventory, and in-stock improvements of 1% - 2%. But there are benefits beyond the tangible as well: successful VMI implementations have helped suppliers get closer to their key trading partners. And you can't put a value on that. The VMI module enables suppliers to utilize information provided by the customer to monitor and replenish inventory levels at customer facilities. VMI provides complete functionality to support all aspects of supplier managed inventory programs for both managed and/or consigned inventory scenarios. VMI is not only a perfect method for managing and optimizing inventory at stores but also it combines sophisticated replenishment techniques, superior inventory transaction management, flexible billing options, with excellent business intelligence and host integration to provide a complete solution to satisfy even the most demanding customer compliance needs.VMI is an operating model in which the supplier takes responsibility for the inventory of its customer [10]. In a VMI-partnership the supplier makes the maininventory replenishment decisions for the customer. The supplier, which may be a manufacturer, reseller or a distributor, monitors the buyer's inventory levels and makes supply decisions regarding order quantities, shipping and timing.

Fry et. al. [5] consider the (z, Z)-type VMI contract in a one supplier, one retailer supply chain: The retailer sets a minimum inventory level z and a maximum inventory level Z, and the supplier is agreed to pay a penalty to the retailer for every unit of retailer's inventory that is outside this band after customer demand. Both parties know the retailer's demand distribution. The supplier produces every T periods with no capacity limit. It also has the option of outsourcing in order to maintaiwn the desired retailer's inventory level. The supplier's decisions are thus how much to produce in each production cycle, how much to outsource and how much to send to the retailer in each period. With the outsourcing option (so that the supplier can always supply what is needed at the retailer), the retailer's problem becomes a single-location inventory problem, whose backorder costs influence the supplier's costs. Recall that model treats a two-location inventory problem. In their paper, there is also no capacity issue. As indicated by these authors, in all of the VMI agreements they observed in practice, "the penalties are not incurred immediately (i.e., on a daily basis), but are based on long-term (approximately yearly) performance, often as part of "balanced scorecard" evaluation".

Cachon [2] studies how to achieve channel coordination in a one-supplier, multi-retailer competitive supply chain using VMI. Both the supplier and the retailers incur inventory and backorder costs. Cachon shows that VMI is not guaranteed to coordinate the chain unless all members are willing to accept or pay fixed transfer payments. A numerical study shows that VMI provides no improvement in supply chain costs when fixed transfer payments are forbidden. Narayanan and Raman [7] examine a retailer and a supplier under a newsvendor setting. The retailer carries a private label product that is a substitute to the product he carries from the supplier. Thus, the cost associated with a stockout is different for the supplier and the retailer, and consequently their target fill rates are different. They derive conditions under which stocking decisions should be transferred from retailer to supplier (VMI). Clark and Hammond [6] and Cachon and Fisher [3] study the issue of whether VMI coupled with information sharing provides greater benefits than information sharing alone. Bernstein and Federgruen [1] analyze the constant-demand-rate case and consider a model of VMI where the replenishment decision is transferred to the supplier, but the retailer is able to make his own pricing decisions. Other papers on VMI study logistics issues; Fry et. al. [5] provide an excellent review. Our study here has a different focus from these works. In this paper we first study a special case of VMI where a supplier provides goods for onebuyer when shortage is allowed. Yao et. al. [11] study a simpler model where there are one buyer and one supplier without considering any shortage in demand. We then study a case of two buyers- one supplier while shortage is allowed. For each problem, we first present the necessary notations and assumptions, and the problem formulation along with some numerical examples is given in the next section. Finally, conclusion remarks are given at the end of the paper to summarize the contribution of the paper.

General assumptions

The following assumptions hold in throughout this paper:

- Demand is constant.
- The order is delivered at once.
- Transportation time is negligible.
- Shortage is allowable.
- The Setup, holding and shortage costs in VMI model are paid by supplier.
- The cost of each good is constant.

2. One buyer – one supplier problem

We use the following notations for this problem:

- K_0, K_1: the costs of inventory of supply chain which includes the costs of supplier and buyer in traditional and VMI models, respectively.
- K_0^*, K_1^*: the optimal values for K_0, K_1.
- KS_0, KS_1: the cost of inventory for the supplier in traditional and VMI models
- KB_0, KB_1: the cost of inventory for the buyer in traditional and VMI models.
- Q: the size of each order.
- Q_0^*, Q_1^*: The optimal value for Q in traditional and VMI models.
- B: the amount of shortage in each period.
- B_0^*, B_1^*: the optimal value for B in traditional and VMI models.
- b: the cost of each unit of shortage.
- A_S: the cost of each order for the supplier.
- A: the cost of each order for the buyer.
- R: demand for buyer in each period.
- H: the cost of inventory for each unit of product in the stock in each period.

In a traditional inventory model with shortage, the cost of inventory is as follows,

$$K_0 = KS_0 + KB_0 \tag{1}$$

Where $KS_0 = \frac{A_S * R}{Q}$ and

$$KB_0 = \frac{A*R}{Q} + \frac{H}{2} * \frac{(Q-B)^2}{Q} + \frac{bB^2}{2Q}$$

In a traditional system we have,

$$Q_0^* = \sqrt{\frac{2RA}{H}}\sqrt{\frac{H+b}{b}}$$

and

$$B_0^* = \frac{HQ}{H-b} = \sqrt{\frac{2RA}{b}}\sqrt{\frac{H}{H-b}} \tag{2}$$

Using (1) and (2), the optimal value of K_0 is calculated as follows,

$$K_0^* = \frac{R(2A+A_S)\sqrt{Hb}}{\sqrt{2RA(H+b)}} \tag{3}$$

The total cost of inventory with shortage in VMI model is calculated as follows,

where

$$K_1 = \frac{A_S * R}{Q} + \frac{A*R}{Q} + \frac{H}{2} * \frac{(Q-B)^2}{Q} + \frac{bB^2}{2Q} \tag{4}$$

In order to find the optimal value of K_1, we need to take the derivative of K_1 respect to Q and B, i.e. $\frac{\partial K_1}{\partial Q} = 0$ and $\frac{\partial K_1}{\partial B} = 0$, which yields the following results,

$$Q_1^* = \sqrt{\frac{2R(A_S + A)}{H}}\sqrt{\frac{H+b}{b}} \tag{5}$$

and $B_1^* = \frac{HQ}{H-b} = \sqrt{\frac{2R(A_S + A)}{b}}\sqrt{\frac{H}{H-b}}$

Using (4) and (5), the optimal value of K_1 is calculated as follows,

$$K_1^* = \frac{2R(A_S + A)\sqrt{Hb}}{\sqrt{2R(A_S + A)(H+b)}} \tag{6}$$

In order to prefer VMI to traditional model we must have,

$$K_1^* : K_0^* \tag{7}$$

$$\frac{2R(A_S + A)\sqrt{Hb}}{\sqrt{2R(A_S + A)(H+b)}} \le \frac{R(2A + A_S)\sqrt{Hb}}{\sqrt{2RA(H+b)}}$$

$\frac{2(A_S + A)}{\sqrt{(A_S + A)}} \le \frac{(2A + A_S)^2}{\sqrt{A}}$ and this can be transformed into,

$$4(A_S + A) \le \frac{(2A + A_S)^2}{A}$$

A_S, A >0 Which yields, $X^2 \ge 0$, where

$$\frac{A_S}{A} = X \tag{8}$$

Relation (8) shows that VMI always costs less than traditional method. It is an important result.

■ **Numerical example**

Consider the following data,

A =10, A_S =100, R =100, H =5, b =2

The optimal values of K_0 and K_1 are calculated as K_0^* = 320.76 and K_1^* = 177.295. As we can observe in this example, $K_1^* : K_0^*$. Now suppose the ratio of $\frac{A_s}{A}$ is changed to 20. Therefore, the optimal values of K_0 and K_1 are K_0^* = 587.66 and K_1^* = 244.78, respectively. In this situation, we can also see, $K_1^* : K_0^*$ therefore the VMI model is always better than the traditional model.

3. Two buyers – one supplier problem

Two different models are studied in this section. Following notations are used for all three models:

- K_0, K_1: the costs of inventory of supply chain which includes the costs of supplier and buyers in traditional and VMI models, respectively.
- K_0^*, K_1^*: The optimal value for K_0, K_1.
- Q_1, Q_2 : The size of orders for buyers 1 and 2 in traditional model.
- Q_1^*, Q_2^*: The optimal values of Q_1, Q_2 in traditional model.
- B_1, B_2 : The amount of shortage in each period for buyer 1 and 2 in traditional model.
- B : the amount of shortage in each period for supplier in VMI model.
- B_1^*, B_2^*: The optimal value for B_1, B_2 in traditional model.
- B^* : The optimal value for B in VMI model (We assume that $B_1 = B_2 = B$ in VMI model).
- b : the cost of each unit of shortage for supplier in VMI model.
- b_1, b_2 : The cost of each unit of shortage for buyer 1 and 2 in traditional model.
- A_S : the cost of each order for the supplier.
- A_1, A_2 : The cost of each order for buyer 1 and 2.
- R_1, R_2 : Demand for buyer 1 and 2 in each period.
- H_1, H_2 : The cost of inventory for each unit of product in the stock in each period for buyer 1 and 2.
- T : the duration of each period in VMI model.
- T^* : The optimal value for T in VMI model

We assume that there is a total shortage (B) in VMI model so that $b >= \max(b_1, b_2)$.

3.1 Model 1

In this model shortage is permitted only in traditional model and no shortage is allowed in VMI model. In a traditional inventory model, for the twodiscussed models, the cost of inventory for buyer 1 and 2 is calculated as follows,

$$K_0=\frac{A_SR_1}{Q_1}+\frac{A_SR_2}{Q_2}+\frac{A_1R_1}{Q_1}+\frac{A_2R_2}{Q_2}+\frac{(Q_1-B_1)^2H_1}{2Q_1}+\frac{b_1B_1^2}{2Q_1}+\frac{(Q_2-B_2)^2H_2}{2Q_2}+\frac{b_2B_2^2}{2Q_2} \quad (9)$$

In a traditional system we have,

$$Q_{1,2}^*=\sqrt{\frac{2R_iA_i}{H_i}}\sqrt{\frac{(H_i+b_i)}{b_i}},$$

$$B_{1,2}^*=\sqrt{\frac{2R_iA_i}{b_i}}\sqrt{\frac{H_i}{(H_i+b_i)}}, \quad (10)$$

Using (9) and (10), the optimal value of K_0 is calculated as follows,

$$K_0^*=\frac{R_1(2A_1+A_S)\sqrt{H_1b_1}}{\sqrt{2R_1A_1(H_1+b_1)}}+\frac{R_2(2A_2+A_S)\sqrt{H_2b_2}}{\sqrt{2R_2A_2(H_2+b_2)}}=\sum_{i=1}^{2}\frac{R_i(2A_i+A_S)\sqrt{H_ib_i}}{\sqrt{2R_iA_i(H_i+b_i)}}. \quad (11)$$

The total cost of inventory without shortage in VMI model is calculated as follows,

$$K_1=\frac{(A_1-A_2-A_S)}{T}+\frac{1}{2}R_1TH_1+\frac{1}{2}R_2TH_2, \quad (12)$$

Problem (12) is a pseudo-convex function. In order to find the optimal value of K_1, we need to take the derivative of K_1 respect to T, i.e. $\frac{\partial K_1}{\partial T}=0$, which yields the following result,

$$T^2=\frac{2(A_1+A_2+A_S)}{(R_1H_1+R_2H_2)}, \quad (13)$$

Using (12) and (13), the optimal value of K_1 is calculated as follows,

$$K_1^*=\sqrt{2(A_1+A_2+A_S)(R_1H_1+R_2H_2)}, \quad (14)$$

In order to prefer VMI to traditional model we must have,

$$K_1^* : K_0^*,$$

$$\sqrt{2(A_1+A_2+A_S)(R_1H_1+R_2H_2)}<\frac{R_1(2A_1+A_S)\sqrt{H_1b_1}}{\sqrt{2R_1A_1(H_1+b_1)}}+\frac{R_2(2A_2+A_S)\sqrt{H_2b_2}}{\sqrt{2R_2A_2(H_2+b_2)}}, \quad (15)$$

Using a simple modification in (15) yields the following quadratic function,

$$(R_1\sqrt{H1b_1G}+R_2\sqrt{H_2b_2F})^2A_S^2+4[R_1R_2(A_1+A_2)\sqrt{H_1b_1GH_2b_2F}-R_1^2H_1^2A_1G-R_2^2H_2^2A_2F]A_S+(2R_1A_1\sqrt{H_1b_1G}+2R_2A_2\sqrt{H_2b_2F})^2-2(A_1+A_2)(R_1H_1+R_2H_2)FG>0, \quad (16)$$

Where,

$$F=2R_1A_1(H_1-b_1)$$
$$G=2R_2A_2(H_2+b_2)$$

So we have:

$$\alpha.A_s^2-\beta.A_s-\gamma>0$$

Where,

$$\alpha=(R_1\sqrt{H1b_1G}+R_2\sqrt{H_2b_2F})^2$$
$$\beta=4[R_1R_2(A_1+A_2)\sqrt{H_1b_1GH_2b_2F}-R_1^2H_1^2A_1G-R_2^2H_2^2A_2F]$$
$$\gamma=(2R_1A_1\sqrt{H_1b_1G}+2R_2A_2\sqrt{H_2b_2F})^2-2(A_1-A_2)(R_1H_1-R_2H_2)FG$$

The resulted quadratic function has two real roots: $x_1=\frac{-\beta+\sqrt{\Delta}}{2\alpha}$ and $x_2=\frac{-\beta-\sqrt{\Delta}}{2\alpha}$ with $\Delta=\beta^2-4\alpha\gamma$. This could help us determine when VMI costs less than the traditional method. When $X_2<A_s<X_1$ is hold, the traditional model costs less than VMI ($K_0-K_1<0$). However, whenever ($A_s>X_1$ or $A_s<X_2$) and $A_s>0$ VMI would be less costly than the traditional model ($K_0-K_1>0$). We now demonstrate the implementation of the proposed method.

■ Numerical example

Consider the following data,

$A_1=10$, $A_2=8$, $R_1=100$, $R_2=200$, $H_1=5$, $H_2=3$, $b_1=6$, $b_2=4$.

Provided that $X_1=14.21$, $X_2=-17.998$ and $A_s=10$, using (11) and (14), the optimal values of K_0 and K_1 are calculated as $K_0^*=231.14$ and $K_1^*=248.19$. As we can observe in this example, $K_1^*\geq K_0^*$, therefore the traditional model works better than VMI. Now let's suppose A_s is changed to 20. In this case, as the same manner as the above, using (11) and (14), we can get the optimal values of K_0 and K_1 as following; K_0^*= 314.36 and K_1^* = 289.14, respectively. We can see, K_1^* : K_0^* therefore, the VMI model costs than the traditional model.

3.2 Model 2

In this model, the shortage is permitted in both the traditional model and the VMI model and in VMI model supplier has two shortages for buyer 1 and buyer 2 which are B1 and B2, respectively. The total costof inventory with shortage in VMI model is calculated as follows,

$$K_1 = \frac{A_1 + A_2 + A_S}{T} + \frac{(R_1 T - B_1)^2 H_1 + b_1 B_1^2}{2R_1 T} + \frac{(R_2 T - B_2)^2 H_2 + b_2 B_2^2}{2R_2 T}, \quad (16)$$

Problem (16) is a pseudo-convex function. In order to find the optimal value of K_1, we need to take the derivative of K_1 respect to T, B_1 and B_2, i.e. $\frac{\partial K_1}{\partial T}=0$, $\frac{\partial K_1}{\partial B_1}=0$ and $\frac{\partial K_1}{\partial B_2}=0$, which yields the following results,

$$B_1^* = \frac{H_1 R_1 T}{H_1 + b_1}, \quad B_2^* = \frac{H_2 R_2 T}{H_2 + b_2} \quad (17)$$

$$T^{2*} = \frac{2(A_1 + A_2 + A_S)(H_1 + b_1)(H_2 + b_2)}{R_1 H_1 b_1 (H_2 + b_2) + R_2 H_2 b_2 (H_1 + b_1)}$$

Using (16) and (17), the optimal value of K_1 is calculated as following (18),

$$K_1^* = \frac{\sqrt{2(A_1 + A_2 + A_S)(R_1 H_1 b_1 (H_2 + b_2) + R_2 H_2 b_2 (H_1 + b_1))}}{\sqrt{(H_1 + b_1)(H_2 + b_2)}}$$

In order to prefer VMI to traditional model we must have,

$$K_1^* \le K_0^*, \text{ or:} \quad (19)$$

$$\frac{\sqrt{2(A_1 + A_2 + A_S)R_1 H_1 b_1 (H_2 + b_2) + 2(A_1 + A_2 + A_S)R_2 H_2 b_2 (H_1 + b_1)}}{\sqrt{(H_1 + b_1)(H_2 + b_2)}} \le \frac{R_1(2A_1 + A_S)\sqrt{H_1 b_1}}{\sqrt{2R_1 A_1 (H_1 + b_1)}} + \frac{R_2(2A_2 + A_S)\sqrt{H_2 b_2}}{\sqrt{2R_2 A_2 (H_2 + b_2)}}$$

Using a simple modification in (19) yields the following quadratic function,

$$(R_1\sqrt{H1b_1G} + R_2\sqrt{H_2b_2F})^2 A_S^2 + [4R_1R_2(A_1 + A_2)\sqrt{H_1b_1GH_2b_2F} + 4R_1^2 H_1 A_1 b_1 G + 4R_2^2 H_2 A_2 b_2 F - 8R_1R_2A_1A_2(M+N)]A_S + (2R_1A_1\sqrt{H_1b_1G} + 2R_2A_2\sqrt{H_2b_2F})^2 - 8R_1A_1R_2A_2(A_1 + A_2)(M+N) > 0 \quad (20)$$

Where,

$$F = 2R_1A_1(H_1 + b_1)$$
$$G = 2R_2A_2(H_2 + b_2)$$
$$M = 2R_1H_1b_1(H_2 + b_2)$$
$$N = 2R_2H_2b_2(H_1 + b_1)$$
$$\alpha = (R_1\sqrt{H1b_1G} + R_2\sqrt{H_2b_2F})^2$$
$$\beta = 4[R_1R_2(A_1 + A_2)\sqrt{H_1b_1GH_2b_2F} - R_1^2H_1^2A_1G - R_2^2H_2^2A_2F]$$
$$\gamma = (2R_1A_1\sqrt{H_1b_1G} + 2R_2A_2\sqrt{H_2b_2F})^2 - 2(A_1 + A_2)(R_1H_1 + R_2H_2)FG$$

The resulted quadratic function (20) has two real roots as $x_1 = \frac{-\beta + \sqrt{\Delta}}{2\alpha}$ and $x_2 = \frac{-\beta - \sqrt{\Delta}}{2\alpha}$ with $\Delta = \beta^2 - 4\alpha\gamma$. This could help us determine when VMI costs less than traditional method. We can conclude that when $X_2 < A_s < X_1$ traditional model costs less than VMI ($K_0 - K_1$ <0). However, whenever ($A_s > X_1$ or $A_s < X_2$) and $A_s > 0$ VMI would be less costly than the traditional model ($K_0 - K_1$ >0).

■ Numerical example

Consider the following data,

A_1=10, A_2=15, R_1=1000, R_2=300, H_1=7, H_2=4, b_1= 10, b_2 = 6.

Provided that X_1=5.83, X_2= -24.8 and A_s= 4, using (11) and (18), the optimal values of K_0 and K_1 are calculated as K_0^*= 510.93 and K_1^* = 529.7, respectively. As we can observe in this example, $K_1^* \ge K_0^*$ so the traditional model works better than VMI. Now suppose A_s is changed to 15. In this case, using (11) and (18), we also can get the optimal values of K_0 and K_1 as following; $K_0^* = 722.65$ and $K_1^* = 622.1$, respectively.

Since $K_1^* \le K_0^*$, we can obtain the results that the VMI model is better than the traditional model.

4. Conclusions

Vendor Managed Inventory has become as one of the most popular methods among practitioners and the implementation of the VMI models has been successfully adopted among many corporations. In this paper, we have presented a VMI model for one buyer-one supplier problem and two models for two buyers-one supplier problem. In our one buyer-one supplier model, we assume that shortage is allowed and show that the VMI could perform better than traditional system under different conditions. In two buyers-one supplier problem, the concept of VMI has been studied when shortage is permitted for either buyers or supplier or both. The implementation of the proposed methods of this paper has been demonstrated using simple numerical examples. This paper could be extended for the problems considering more than one supplier or two buyers.

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