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An effective coordination strategy for performance improvement of vendor managed inventory

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Abstract: Aiming at solving the coordination strategy problems in a VMI supply chain with low total supply chain profit, unbalanced revenue distribution mechanism and unreasonable inventory replenishment quantities, an improved VMI model for a supply chain with one supplier and one retailer is presented. In the Improved VMI model, the influences of the inventory holding cost and the stock out cost and the promotion effort level of downstream entity under the stochastic demand are considered, which makes the model closer to the actual situation. By utilizing the distribution factor, the profits between the supplier and the retailer are redistributed, and the win-win outcome is ensured. In order to achieve the optimum of the overall profit of the channel-wide system, the starting point of negotiations with the supplier and the retailer is established and a Lagrange function is introduced. In addition, numerical simulation experiments are conducted to show the utility of the improved model proposed in this paper.

Keywords: Supply chain management, vendor managed inventory, coordination strategy, inventory management

1 Introduction

The efficient operations of a supply chain system require the very close collaboration of each member in the supply chain. Vendor managed inventory (VMI) is one of an effective supply chain collaboration technique that aims at reducing the total supply chain cost, and improving the supply chain flexibility, and enhancing the overall supply chain competitiveness [1,2,3]. In a VMI, the supplier undertakes the responsibility of inventory replenishment and simultaneously monitors the inventory levels of the purchaser, and ultimately ensures a certain level of inventory turnover and customer service. Many researches show that VMI plays an active role in promoting information sharing, reducing the bullwhip effect and improving the level of the supply chain collaboration [4,5,6] VMI is regarded as a novel inventory management mode in the integrated supply chain management ideology, and collaboration mechanism of VMI has been a popular research topic [7].

Designing the reasonable collaboration mechanism of VMI for profit sharing and risk sharing is the key factor of successfully implementing VMI. At present, the researches of collaboration mechanism of VMI mainly include buy-back mechanism, quantity discount mechanism, rebate mechanism, revenue share mechanism and price subsidy mechanism, et al [8,9,10]. Among these collaboration mechanisms of VMI, revenue share mechanism gets the researchers enough attention. However, the efficiency of the VMI supply chain can not be improved by revenue share mechanism used solely. In the revenue share mechanism, the management power of the inventory is transferred to the upstream entity, and the management costs of the inventory of the upstream entity are dramatically increased, and the distribution proportion between the upstream and downstream entity can not be well determined, and the total profit of the channel-wide system can not achieve the optimum [11,12]. Therefore, improving the collaboration mechanism of VMI has important significance.

To solve the problem mentioned above, we proposed an improved VMI coordination strategy. In the improved VMI coordination strategy, the revenue share mechanism based on the Stackelberg game was used to distribute the profits between the upstream and downstream entity. In this way, the downstream entity is regarded as the leader

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and the upstream entity is regarded as the follower, and the coordination power of upstream and downstream entity is increased, and the profit of each member is higher than that in the VMI used revenue share mechanism solely. Furthermore, in order to achieve the optimum of the channel-wide system, Lagrange function is introduced. By using the Lagrange function, we made the optimal profit of the upstream and downstream entity under the Stackelberg game VMI model as the starting point of negotiation, and proposed an improved VMI model. The experimental results showed that the proposed method is effective.

The main contribution of this paper is twofold. First, we developed an efficient VMI model with two-level system consisting one supplier and one retailer, which provided a theoretical basis for future research of VMI. In specific, the revenue share mechanism and the Stackelberg game were introduced, and the distribution proportion of the profits and the optimal inventory replenishment quantities were appropriately modified, and Lagrange multipliers were set to construct the Lagrange function. Ultimately, the profit of each member and the overall coordination power of the channel-wide system have been enhanced by using the improved VMI model. Second, we analyzed the mechanism of the pure VMI model and pointed out its shortcoming, and presented the proposition 1. In the simulation experiment, we designed an appropriate simulation experiment to compare the performance of the improved VMI model proposed in this paper with other two representative models. Considering the different cases, we set five groups of different parameters used as input, and used the Matlab 10 to simulate the decision-making process, and presented the performance charts of several models.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the research problem and presents the notions. In Section 4, we develop an improved VMI model. Section 5 provides numerical example and simulation, and discusses the performances of several models. Section 6 concludes the paper.

2 Literature review

The research literature related to this paper can be divided into four categories. In the first category, how to effectively coordinate a VMI supply chain for reducing the bullwhip effect was discussed. Paper [13] emphasized the impact of VMI supply chain and traditional serially linked supply chain on the bullwhip effect, and presented the suppliers production ordering activities by a simulation model based on the difference equations. Paper [14] quantified the bullwhip effect for each part of supply chain and proposed a nonlinear optimization model to what extent the bullwhip effect can be reduced using the VMI. In the second category, the operation mode of VMI supply chain was analyzed. Paper [15] discussed how a upstream entity and a downstream entity interact with each other for enhancing respective profit by adjusting production marketing and inventory policies. Paper [16] proposed a reverse VMI supply chain model for green electronic products. In the third category, profit performance of each member in a VMI supply chain was analyzed. Paper [17] considered a periodic-review stochastic inventory model to balance the profit in a global environment. Paper [18] presented a VMI model with multi-product and multi-constraint, and solved it by an alternative heuristic algorithm. Paper [19] presented an economic order quantity and production quantity model with three-layer supply chain and a collaborating expected profit function. In the forth category, aiming at the problem of obstacle in the process of implementing VMI, some collaboration mechanisms were presented. Paper [20] presented a dynamics VMI model based on the differential game theory and analyzed the dynamic coordination of key decision variables by the supply chain partners in the VMI relationship. Paper [21] presented an integrated vendor selection and inventory optimization model and utilized Generalized Benders Decomposition to solve the model. Paper [22] presented an incentive contract between a supplier and a retailer under a VMI arrangement for gaining market share. Although the above-mentioned literatures analyzed the VMI coordination strategy and presented some effective methods to optimize the VMI system from various different perspective, these methods still need to be improved based on the consideration for win-win outcome and maximization of total profits in the VMI system and optimum of the overall supply chain.

3 Problem statement and notations

In this section, we describe the problem and the notations. Our problem focuses on a two-level supply chain system consisting of one supplier and one retailer. Suppose the retailer purchases a kind of product from the supplier, and the retailer faces the stochastic market demand. The variance of market demand d is non-negative and continuous, and its distribution function is $F(d)$, and its density function is $f(d)$.

h : Inventory holding cost per unit of the product.

g : Stock out cost per unit of the product.

c : Production cost per unit of the product.

w : Subscription price per unit of the product of retailers.

p : Sale price per unit of the product of retailers.

t : Operation cost per unit of the product.

Furthermore, it is assumed that the suppliers manufacturability is unrestricted at any time, and the inventory volume is unlimited. In order to facilitate the research, the transportation cost is neglected. At the same time, the problems and assumptions in this paper are based on information-symmetric.

4 Model development

First, a pure VMI model with a two-level supply chain system is developed. Then, we present the model of the traditional inventory management, and analyze the profit changes of the supplier and the retailer under the two models in detail. On the basis of the above analysis, an improved VMI model is developed, and in the policy of the improved VMI, each member in the supply chain has enough coordination power, and the profit of each member is increased, and the overall profit of the channel-wide system achieves the optimum.

4.1 A pure VMI model

In this section, we will develop a pure VMI model where we seek to analyze the shortcomings of the pure VMI. In the frame of pure VMI, there are not any coordination mechanism between the supplier and the retailer, and the supplier is charged with the inventory holding cost and the stock out cost. Under the pure VMI policy, the objective of the supplier and the retailer is to maximize its own profit, and each member does not take into consideration the overall profit of supply chain. With the problem statement and notation in the previous section, the profit function of the supplier under the pure VMI policy can be expressed as equation (1).

$$\pi_V^s(q) = ws(q) - hI(q) - gL(q) - cq - ts(q) \quad (1)$$

Where $\pi_V^s(q)$ denotes the profit of the supplier, and $s(q)$ denotes the expected sales volume and $I(q)$ denotes the expected inventory quantity and $L(q)$ denotes the expected stock out volume when the inventory replenishment quantity is q. In the equation (1), $s(q)$ and $I(q)$ and $L(q)$ can be expressed as follows:

$$s(q) = \int_0^q x f(x) d_x + \int_q^{+\infty} q f(x) d_x \quad (2)$$

$$I(q) = q - s(q) \quad (3)$$

$$L(q) = E(d) - s(q) \quad (4)$$

In the equation (4), $E(d)$ denotes the actual market demand. Using a similar method developed in the pure VMI policy, the profit function of the retailer can be expressed as equation (5).

$$\pi_V^r(q) = (p - w)s(q) - K(x) \quad (5)$$

Where $K(x)$ denotes the promotion effort level of the retailer, and $K(x) = \alpha q^{\frac{1}{2}}$, and α represents the promotion effort factor and $\alpha > 1$, and the higher the promotion effort level of retailers, the more the market demand of products.

Under the pure VMI policy, the supplier determines the optimal inventory replenishment quantity on the basis of maximizing its own profit. Suppose q_V^* denotes the optimal inventory replenishment quantity, and q_V^* can be obtained by calculating the profit function of the supplier and the retailer.

$$q_V^* = F^{-1}\left(\frac{w+g+\alpha-t-c}{w+g+h}\right) \quad (6)$$

However, if the supplier and the retailer do not cooperate, that is to say, in the state of the traditional inventory management, the supplier will not be charge of the inventory holding cost and the stock out cost, and the retailer has to manage the inventory, thus the profit function of the supplier and the retailer is calculated, respectively, as follows:

$$\pi_T^s(q) = (w - c)q \quad (7)$$

$$\pi_T^r(q) = ps(q) - hI(q) - gL(q) - wq \quad (8)$$

In the mode of the traditional inventory management, the retailer chooses the optimal inventory replenishment quantity according to the actual market demand. Suppose q_T^* denotes the optimal inventory replenishment quantity in the mode of the traditional inventory management, and q_T^* can be obtained by equation (7) and equation (8), as follows:

$$q_T^* = F^{-1}\left(\frac{p+q-c}{p+q+h}\right) \quad (9)$$

According to the equation (9), the profit of the supplier and the retailer in the mode of the traditional inventory management is $\pi_T^s(q_T^*)$ and $\pi_T^r(q_T^*)$, respectively. Similarly, according to equation (1) and equation (5) and equation (6), in the mode of the pure VMI, the profit of the supplier and the retailer is $\pi_V^s(q_V^*)$ and $\pi_V^r(q_V^*)$, respectively.

Proposition 4.1. The profit of the retailer is increased and the profit of the supplier is decreased when the mode is transferred from the traditional inventory management mode to the pure VMI mode.

Proof. From the model of the pure VMI and the traditional inventory management above, it is clear that the inventory holding cost and stock out cost of the retailer are borne by the supplier. Obviously, after some mathematical operations of equation (6) and equation (9), Δq can be expressed, as follows:

$$\Delta q = q_V^* - q_T^* = F^{-1}\left(\frac{w+g-t-c}{w+g+h}\right) - F^{-1}\left(\frac{p+q-c}{p+q+h}\right) = \frac{w+g+h+p}{w+g+p-c-t}\int_0^{q_V^*} F(x) d_x \quad (10)$$

According to equation (10), $\Delta q > 0$ and the increased profit of the retailer equals $\Delta\pi^r = \pi_V^r(q_V^*) - \pi_T^r(q_T^*)$, and it is greater than 0. Similarly, the decreased profit of the supplier equals $\Delta\pi^s = \pi_V^s(q_V^*) - \pi_T^s(q_T^*)$, and it is less than 0. □

4.2 An improved VMI model

In order to enhance the coordination power and the profit of each member, and maximize the overall profit of the two-level supply chain system, we propose an improved VMI model. In the improved VMI model, revenue share mechanism is used to redistribute the profit of the supplier and the retailer. Suppose λ represents the distribution factor. When an unit of product is sell at p, the profit of the retailer and the supplier is λp and $(1-\lambda)p$, respectively. After implementing the revenue share mechanism, the profit of the supplier and the retailer is expressed, respectively, as follows.

$$\pi_M^s(q) = (1-\lambda)ps(q) - hI(q) - gL(q) - cq - ts(q) \quad (11)$$

$$\pi_M^r(q) = \lambda ps(q) - \alpha q^{\frac{1}{2}} \quad (12)$$

Where $\pi_M^s(q)$ and $\pi_M^r(q)$ is the profit function of the supplier and the retailer, respectively. By taking the first derivation of $\pi_M^s(q)$ with respect to and setting $\frac{\partial \pi_M^s(q)}{\partial q} = 0$, we get the optimal solution q_M^*, and q_M^* is expressed as follows.

$$q_M^* = \frac{(1-\lambda)p+g+t+\alpha-c}{p+g+t+\alpha+h} \quad (13)$$

In the pure VMI model, the overall profit of the two-level supply chain is expressed as follows.

$$\pi_V^o(q) = ps(q) - hI(q) - gL(q) - cq - ts(q) - \alpha q^{\frac{1}{2}} \quad (14)$$

Let q_o^* represent the optimal inventory replenishment quantity, after some mathematical operations of equation (14), q_o^* can be deduced as follows.

$$q_o^* = \frac{p+\alpha+g+t-c}{p+g+t+\alpha+h} \quad (15)$$

The optimal overall profit of the two-level supply chain in the pure VMI is expressed as $\pi_V^o(q_o^*)$. In order to maximize the overall profit of the two-level supply chain after implementing the revenue share mechanism, we set $q_M^* = q_o^*$ and obtain $\lambda = 0$. Therefore, when the overall profit of the two-level supply chain has the optimal solution, the profit of the retailer is 0, and the supplier gets the all of profits.

Considering the problem above, we model the relationship between the supplier and the retailer by introducing the Stackelberg game with the retailer as the leader and supplier as the follower. First, the retailer determines the distribution factor λ. Then, the supplier determines the optimal inventory replenishment quantity based on the distribution factor λ. Combining the equation (11) and equation (12) and equation (14) and equation (15), we can formulate the Stackelberg game VMI model as follows:

$$\max_{\lambda} \pi_M^r(q) = \lambda ps(q) - \alpha q^{\frac{1}{2}} \quad (16)$$

$$s.t. \quad \arg\max_q \pi_M^s(q) = (1-\lambda)ps(q) - hI(q) - gL(q) - cq - ts(q) \quad (17)$$

Let q_{M1}^* represent the optimal inventory replenishment quantity, and q_{M1}^* can be calculated by equation (17) as follows:

$$q_{M1}^* = \frac{w+\alpha+g+t-c}{w+g+t+\alpha+h} \quad (18)$$

By substituting equation (18) into equation (16), we obtain the optimal distribution factor . After obtaining q_{M1}^* and λ_1^*, we substitute q_{M1}^* and λ_1^* into equation (11) and equation (12), and get the optimal profit of the retailer $\pi_M^r(q_{M1}^*)$ and the optimal profit of the supplier $\pi_M^s(q_{M1}^*)$. By comparing the q_{M1}^* and q_o^*, we find $q_{M1}^* < q_o^*$. Therefore, when the optimal inventory replenishment quantity is q_{M1}^*, the overall profit of the channel-wide system does not achieve the optimum. In order to solute the problem, we make the $\pi_M^r(q_{M1}^*)$ and $\pi_M^s(q_{M1}^*)$ as the starting point of negotiations, and establish the model below:

$$\max_{\lambda} \prod(\lambda) = (\pi_M^r(\lambda, q_o^*) - \pi_M^r(\lambda_1^*, q_{M1}^*)) \cdot (\pi_M^s(\lambda, q_o^*) - \pi_M^s(\lambda_1^*, q_{M1}^*)) \quad (19)$$

$$s.t. \quad \pi_M^r(\lambda, q_o^*) - \pi_M^r(\lambda_1^*, q_{M1}^*) \geq 0 \quad (20)$$

$$\pi_M^s(\lambda, q_o^*) - \pi_M^s(\lambda_1^*, q_{M1}^*) \geq 0 \quad (21)$$

Where

$$\pi_M^s(\lambda, q_o^*) = \frac{((1-\lambda)p+g+t+\alpha-c)(p+g+t+\alpha-c)}{p+g+t+\alpha+h} - \frac{((1-\lambda)p+g+t+\alpha+h)(p+g+t+\alpha-c)^2}{2(p+g+t+\alpha+h)^2} \quad (22)$$

$$\pi_M^r(\lambda, q_o^*) = \frac{\lambda p(p+g+t+\alpha-c)}{p+g+h+t+\alpha} - \frac{\lambda p(p+g+t+\alpha-c)^2}{2(p+g+h+t+\alpha)^2} \quad (23)$$

Let η_1 and η_2 be Lagrange multiplier, and Lagrange function $L_M(\lambda, \eta_1, \eta_2)$ can be expressed as:

$$L_M(\lambda, \eta_1, \eta_2) = (\pi_M^r(\lambda, q_o^*) - \pi_M^r(\lambda_1^*, q_{M1}^*)) \cdot (\pi_M^s(\lambda, q_o^*) - \pi_M^s(\lambda_1^*, q_{M1}^*)) + \eta_1(\pi_M^r(\lambda, q_o^*) - \pi_M^r(\lambda_1^*, q_{M1}^*)) + \eta_2(\pi_M^s(\lambda, q_o^*) - \pi_M^s(\lambda_1^*, q_{M1}^*)) \quad (24)$$

From the above analysis, we can obtain the optimal distribution factor λ_2^*, and λ_2^* can be expressed as follows.

$$\lambda_2^* = \frac{p+g+h+t+\alpha}{p(p+g+2h+t+\alpha)} + \frac{p}{p^2-c^2} \cdot (\pi_M^r(\lambda_1^*, q_{M1}^*) - \pi_M^s(\lambda_1^*, q_{M1}^*)) \quad (25)$$

Based on the equation (22) and equation (23) and equation (25), the optimal profit of the supplier and the retailer is $\pi_M^s(\lambda_2^*, q_o^*)$ and $\pi_M^r(\lambda_2^*, q_o^*)$, respectively. In further contrast to the profit of each member and the overall profit of the channel-wide system, we can observe that the coordination power and the profit of the suppler and the retailer are enhanced in the improved VMI model, at the same time, the overall profit of the channel-wide system achieves the optimum.

5 Numerical example and simulation

In this section, some numerical analysis of an example is present. The purpose is to compare the improved VMI model proposed in this paper and the pure VMI model and the Stackelberg game VMI model. In order to demonstrate the profit improvement effect on the retailer and the supplier and the channel-wide system under the above three models, we use the Matlab 10 to simulate the decision-making process. In the example, a supply chain system with a supplier and a retailer is considered. The production cost of the supplier is c, and $c \in [20,30]$. The market demand is uniformly distributed in $[1000, 1600]$, and its distribution function and density function are $F(x) = \frac{x-1000}{500}$ and $f(x) = \frac{1}{500}$, respectively.

5.1 The parameter and simulation results

The basic settings with respect to the parameters used as input for model evaluation are presented in Table 1. The optimal inventory replenishment quantity and other decision variables are presented in Table 2. Performance measures and profit results from simulation are presented in Table 3. In this experiment, five cases with five groups of different parameters are set up. As shown in Table 3, $\pi_M^{sc}(\lambda, q_M^*)$, $\pi_M^{sc}(\lambda_1^*, q_{M1}^*)$ and $\pi_M^{sc}(\lambda_2^*, q_o^*)$ are the total profit of the channel-wide system under the three models with the pure VMI model and the Stackelber game model and the improved VMI model, respectively.

Table 1: Values of input parameters

Case	p	c	w	h	g	t	α
Case 1	70	20	35	10	12	4	2
Case 2	70	25	40	12	14	6	3
Case 3	80	25	40	10	12	5	2
Case 4	80	28	45	12	14	7	4
Case 5	90	28	45	14	15	8	4

Table 2: The optimal inventory replenishment quantities and the distribution proportion

Case	q_M^*	q_{M1}^*	q_o^*	λ	λ_1^*	λ_2^*
Case 1	1501.2	965.4	1501.2	0	0.658	0.425
Case 2	1439.6	892.1	1439.6	0	0.532	0.351
Case 3	1470.5	923.9	1470.5	0	0.549	0.387
Case 4	1221.3	760.4	1221.3	0	0.435	0.311
Case 5	1341.9	799.3	1341.9	0	0.496	0.337

Table 3: Performance measures and profit results from simulation

Result	Case 1	Case 2	Case 3	Case 4	Case 5
$\pi_M^s(\lambda, q_M^*)$	14451	13052	13997	12141	12993
$\pi_M^s(\lambda_1^*, q_{M1}^*)$	16421	15221	15673	14562	14976
$\pi_M^s(\lambda_2^*, q_o^*)$	18123	16782	17861	14942	15343
$\pi_M^r(\lambda, q_M^*)$	0	0	0	0	0
$\pi_M^r(\lambda_1^*, q_{M1}^*)$	23126	19783	21895	18993	19347
$\pi_M^r(\lambda_2^*, q_o^*)$	25438	21993	23796	20879	21762
$\pi_M^{sc}(\lambda, q_M^*)$	14451	13052	13997	12141	12993
$\pi_M^{sc}(\lambda_1^*, q_{M1}^*)$	39547	35004	37568	33555	34323
$\pi_M^{sc}(\lambda_2^*, q_o^*)$	43561	38775	41657	35821	37105

5.2 Discussion

A brief look at Table 2 and Table 3 reveals that the distribution factor λ equals 0, and the profit of the retailer equals 0 under the pure VMI model. In this case, the supplier gets the all of the profits, and the retailer can not gain the profit. Therefore, the retailer has no the coordination power with the supplier, and the channel-wide system can not achieve the optimal coordination. When the parameters used as input for model evaluation in five different situations are changed, the proportion of the distribution factor and the inventory replenishment quantities are presented under three models in Fig. 1 and Fig. 2. The curve of the inventory replenishment quantity under the VMI model is overlapping with that under the improved VMI model In Fig. 2.

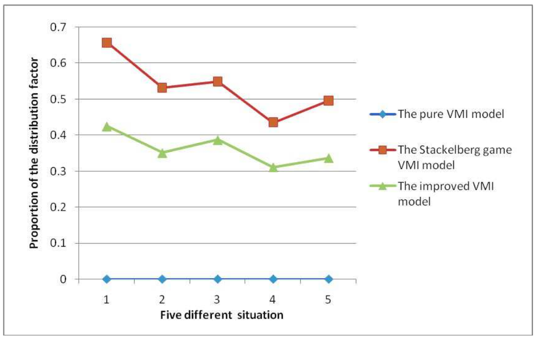

Fig. 1: Proportion of the distribution factor under three models

As shown in Fig. 1, the proportion of distribution factor under the Stackelberg game VMI model is higher than these values under other two models. In this case, the inventory replenishment quantity of the supplier for the retailer q_{M1}^* is smallest under the three models, and $q_{M1}^* < q_M^* = q_o^*$, and the coordination power of the supplier for the retailer is low, and the inventory replenishment quantity of the supplier for the retailer can not achieve the optimum. Therefore the profit of the channel-wide system can not achieve the optimum under the Stackelberg game VMI model.

As shown in Fig. 2, the inventory replenishment quantity under the VMI model is equals with that under

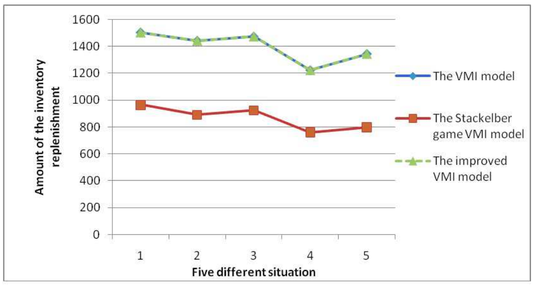

Fig. 2: The inventory replenishment quantity under three models

the improved VMI model, and it is greater than the value under the Stackelberg game VMI model, and the inventory replenishment quantity under the improved VMI model can achieve the optimum. In this case, there is greater coordination power between the supplier and the retailer.

The profit of the supplier under three models in five different situations is presented in Fig. 3. The profit of the retailer under three models in five different situations is presented in Fig. 4. The total profit of the channel-wide system under three models in five different situations is presented in Fig. 5.

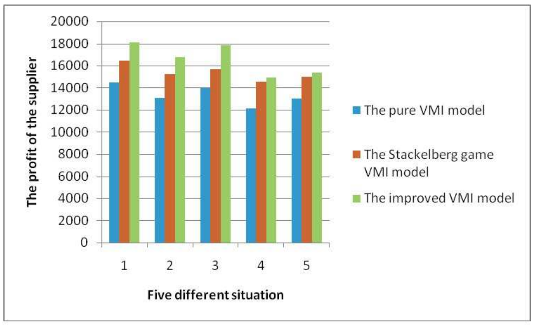

Fig. 3: The profit of the supplier under three models

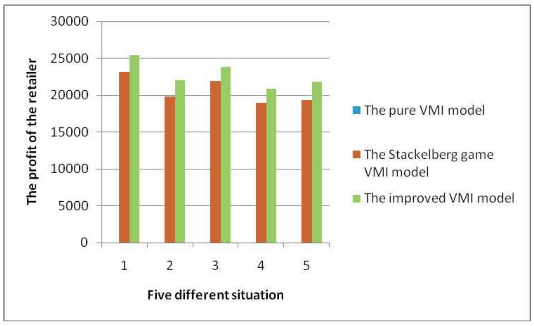

Fig. 4: The profit of the retailer under three model

It can be seen from Fig. 3 and Fig. 4 that the profit of the supplier and retailer is highest under the improved VMI model in five different situations. The profit of the supplier under the improved VMI model is increased by 19.8% and 7.5% than that under the pure VMI model and under the Stackelberg game VMI model, respectively. The profit of the retailer under the improved VMI model is increased by 100% and 9.4% than that under the pure VMI model and under the Stackelberg game VMI model, respectively.

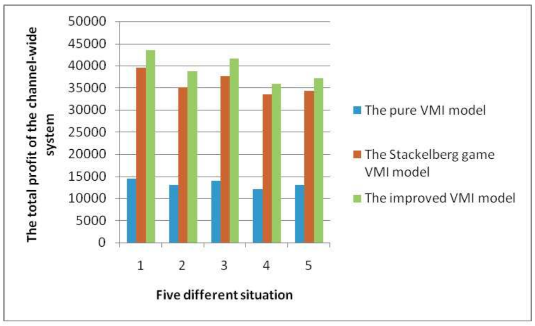

Fig. 5: The total profit of the channel-wide system under three model

As shown in Fig. 5, the total profit of the channel-wide system under the improved VMI model is highest. It can also be seen from Fig. 5 and Table 3 that the total profit of the channel-wide system under the improved VMI model achieves the optimum, and it has the improvement of 66.2% and 8.6% than that under other two models. At the same time, in this case, the profit of each member has greater improvement than that under the pure VMI model and under the Stackelberg game VMI model.

6 Conclusion

As an integrated inventory management method, vendor managed inventory was more and more concerned [23]. By implementing VMI in a supply chain system, the contract relations of upstream and downstream entity were fundamentally changed, and the bullwhip effect and the double marginal effect were effectively reduced, at the same time, the profit of each member and total profit of the supply chain were improved [24,25]. Therefore, it has very important significance to design a reasonable VMI coordination strategy for successfully implementing VMI in a supply chain system.

In the previous VMI model, the influences of the inventory holding cost and the stock out cost and the promotion effort level of downstream entity were usually neglected, and the market demand was also set to determination value [26,27,28]. These lead to the operability of the model is poor. Considering these problems, we presented an improved VMI coordination strategy. In the improved VMI model, we added the influences of the inventory holding cost and the stock out cost and the promotion effort level of downstream entity under the stochastic demand, and combined the revenue share mechanism and the Stackelberg game to redistribute the profits of upstream and downstream entity, and designed an Lagrange function to optimize the VMI supply chain system.

In the numerical simulation experiment, we utilized the Matlab 10 to simulate the proposed scheme, and compared the proposed scheme with other two representative schemes. We obtained good results. When

p, c, w, h, g, t and α were set to five different groups, we obtain the following managerial insights:

• In the five different cases, the average profit of the supplier under our proposed model is 16610.2, and the average profit of the supplier under the pure VMI model and under the Stackelberg game VMI model is 13326.8 and 15370.6, respectively. At the same time, the average profit of the retailer under our proposed model is 22773.6, and the average profit of the retailer under the pure VMI model and under the Stackelberg game VMI model is 0 and 20628.8, respectively. Obviously, the average profit of the supplier and the retailer under our proposed model is higher than those under other two models.

• Considering the total profit under our proposed models, under the pure VMI model and under the Stackelberg game VMI model, we find that the total profit of the channel-wide system under our proposed model is highest, and the average total profit under three models is 39383.8, 13326.8 and 35999.4, respectively.

• Under our proposed model, the overall profit of the channel-wide system achieves the optimum, and the average distribution proportion is 0.3622. Although the average distribution proportion under our proposed model is smaller than that under the Stackelberg game VMI model, the average profit of each member is higher. At the same time, we find that the overall profit of the channel-wide system under the pure VMI model also achieves the optimum, but the distribution proportion equals 0. It means that there is not the coordination place between the supplier and the retailer under the pure VMI model.

With the combination of other methods and theories, VMI will be thoroughly researched from different angles. Although our proposed VMI coordination strategy achieved good results, the performances of VMI coordination strategy still can be improved. Future researches are aimed as follows:

• How to design a reasonable VMI coordination strategy in an information-asymmetric VMI supply chain.

• VMI coordination strategy under one supplier multi-retailers mode will be further explored.

• Transportation costs will be considered in the VMI model.

• Evaluation method of VMI model will be highly concerned. These existing evaluation methods are single, which is generally costs evaluation method, profits evaluation method, times evaluation method and customer service levels evaluation method. How to utilize an integrated systematic evaluation method to evaluate the performance of VMI model is a worthy exploring problem.

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References

[1] Kristianto, Helo, Jiao, Sandhu, Adaptive fuzzy vendor managed inventory control for mitigating the Bullwhip effect in supply chains, European Journal of Operational Research, **216**, 346-355 (2012).

[2] Kristianto, Gunasekaran, Helo, Sandhu, A decision support system for integrating manufacturing and product design into the reconfiguration of the supply chain networks, Decision Support Systems, **52**, 790-801 (2012).

[3] Govindan, Diabat, Popiuc, Contract analysis: A performance measures and profit evaluation within two-echelon supply chains, Computers & Industrial Engineering, **63**, 58-74 (2012).

[4] Michaelraj and Shahabudeen, Replenishment policies for sustainable business development in a continuous credit based vendor managed inventory distribution system, Computers & Industrial Engineering, **56**, 260-266 (2009).

[5] Seifbarghy and Gilkalayeh, SUPPLY CHAIN INTEGRATION UNDER VENDOR MANAGED INVENTORY MODE OF OPERATION CONSIDERING STOCKOUT, Economic Computation and Economic Cybernetics Studies and Research, **46**, 197-218 (2012).

[6] Shen-Tsu and Meng-Hua, Multi-criteria decision analysis method and management information system reengineering for solving vendor-managed inventory bottlenecks in the notebook computer industry, Advanced Materials Research, **282**, 74-81 (2011).

[7] Shnaiderman, Myopic control of stochastic inventories with intermittent updates: continuous versus periodic replenishment, Journal of the Operational Research Society, **63**, 991-1005 (2012).

[8] Adarme Jaimes, Arango Serna, Alexander Balcazar, A coordination agents' model for the Colombian shipbuilding industry's logistics system, Revista Ingenieria E Investigacion, **31**, 102-111 (2011).

[9] Barros, Barbosa-Povoa, Castro, Performance measurement in buyer-supplier collaboration programmes: Implementing the common scorecard, International Journal of Procurement Management, **4**, 259-273 (2011).

[10] Borade and Bansod, Neural networks based vendor-managed forecasting: A case study, International Journal of Integrated Supply Management, **6**, 140-164 (2011).

[11] Borade and Bansod, Interpretive structural modeling-based framework for VMI adoption in Indian industries, International Journal of Advanced Manufacturing Technology, **58**, 1227-1242 (2012).

[12] Cannella, Ciancimino, Framinan, Inventory policies and information sharing in multi-echelon supply chains, Production Planning & Control, **22**, 649-659 (2011).

[13] Disney and Towill, The effect of vendor managed inventory (VMI) dynamics on the Bullwhip Effect in supply chains, Int. J. Production Economics, **85**, 199-215 (2003).

[14] Hohmann and Zelewski, Effects of Vendor-Managed Inventory on the Bullwhip Effect, International Journal of Information Systems and Supply Chain Management, **3**, 1-17 (2011).
[15] Yugang Yu, George, Liang Liang, Stackelberg game-theoretic model for optimizing advertising, pricing and inventory policies in vendor managed inventory (VMI) production supply chains, Computers & Industrial Engineering **57**, 368-382 (2009).
[16] Hui-Ming Wee, Ming-Chang Lee, Jonas Edward Wang, Optimal replenishment policy for a deteriorating green product: Life cycle costing analysis, Int. J. Production Economics **133**, 603-611(2011).
[17] Jun-Yeon Lee, Louie Ren, Vendor-managed inventory in a global environment with exchange rate uncertainty, International Journal of Production Economics, **130**, 169-174 (2011).
[18] Leopoldo Eduardo, Gerardo, Hui Ming Wee, A simple and better algorithm to solve the vendor managed inventory control system of multi-product multi-constraint economic order quantity model, Expert Systems with Applications, **39**, 3888-3895 (2012).
[19] Shib Sankar Sana, A collaborating inventory model in a supply chain, Economic Modelling, **29**, 2016-2023 (2012).
[20] Bowon Kim and Chulsoon Park, Coordinating decisions by supply chain partners in a vendor-managed inventory relationship, Journal of Manufacturing Systems, **29**, 71-80 (2010).
[21] Burcu Keskin, Halit uster, Sila Cetinkaya, Integration of strategic and tactical decisions for vendor selection under capacity constraints, Computers & Operations Research, **37**, 2182-2191 (2010).
[22] Yuliang Yao, Yan Dong, Martin Dresner, Managing supply chain backorders under vendor managed inventory: An incentive approach and empirical analysis, European Journal of Operational Research, **203**, 350-359 (2010).
[23] Xiaohui and Youwang, Information Flow Management of Vendor-managed Inventory System in Automobile Parts Inbound Logistics Based on Internet of Things, Journal of Software, **6**, 1374-80 (2011).
[24] Darwish and Goyal, Vendor-managed inventory model for single-vendor single-buyer supply chain, International Journal of Logistics Systems and Management, **8**, 313-329 (2011).
[25] Solyali and Sural, A Branch-and-Cut Algorithm Using a Strong Formulation and an A Priori Tour-Based Heuristic for an Inventory-Routing Problem, Transportation Science, **45**, 335-345 (2011).
[26] Quan, Liu, Cheng, Wang, Coordination of Profit among Partners in VMI System, Journal of Wuhan University of Technology (Information & Management Engineering), **33**, 665-659 (2011).
[27] Tsan-Ming, Coordination and Risk Analysis of VMI Supply Chains with RFID Technology, IEEE Transactions on Industrial Informatics, **7**, 497-504 (2011).
[28] Shu-Hsien, Chia-Lin, Yu-Siang, A multi-objective evolutionary optimization approach for an integrated location-inventory distribution network problem under vendor-managed inventory systems, Annals of Operations Research, **186**, 213-229 (2011).

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