Methods of vendor managed inventory control in supply chain management

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Abstract: By inducing the typical inventory control problem — the bullwhip effect, this paper presents vendor managed inventory (VMI) control methods on the basis of traditional methods of inventory management methods, constructs a VMI mathematics model, and analyzes the influence of VMI on inventory cost and channel profit. Finally, a special case is studied to verify that VMI is an effective supply chain strategy that can not only increase channel profit of supplier and customer but also improve full channel coordination, thereby reducing the bullwhip effect.

Key words: supply chain management; inventory control; vendor managed inventory; bullwhip effect

Accompanying the globalization of markets and the increase of competition, the competition has transformed from company versus company to supply chain versus supply chain. A supply chain (SC) is a network of organizations which is involved in different processes, through which raw materials are acquired, transformed and delivered to the customer, and activities that produce value in the form of products and services are put in the hands of the ultimate consumer[1]. Such activities are mainly the procurement of materials, the transformation of these materials into intermediate and finished product, and the distribution of finished products to the end customer. Supply chain management (SCM) is concerned with the integrated management of the flows of goods and information throughout the supply chain. In SCM, inventory control has a great effect on customer service levels, the total supply chain cost, and the quality of this supply chain. A recent investigation estimates that the supply chain cost accounts for a big part in the operation cost, sometimes as much as 75%. However, it is possible to reduce the supply chain cost by 65% through efficient management[2].

Many early inventory models have been presented to make inventory management efficient in SCM. For example, Achabal, et al. presented the market forecasting and inventory management components of a vendor managed inventory (VMI) decision support system[3]. Axsäter considered a two-level inventory system with a central warehouse and a number of identical retailers, and presented a joint replenishment policy for multi-echelon inventory management[4]. Tee and Rossetti focused on testing the robustness of a standard model of multi-echelon inventory systems and studied how the model performed under violated assumptions and the conditions where the model performed the worst in prediction the system performance measures[5]. Disney and Towill presented a distribution scheduling algorithm termed automatic pipeline, inventory and order-based production control system embedded within a vendor managed inventory supply chain where the demand profile is deemed to change significantly over time[6].

The paper is organized as follows. Firstly the typical inventory problem existing in all supply chains — the bullwhip effect, is presented. Then methods of vendor managed inventory control in supply chain management are studied. Finally, the conclusions and directions for future research are presented.

1 Typical Inventory Problem in SCM: the Bullwhip Effect

In SC, there is an information flow that proceeds upstream, in addition to the physical flow of goods downstream in the chain. Only the retailer has direct contact with the ultimate customer. The demand seen by wholesalers consists of orders from retailers, rather than consumers, and so on up the supply chain. That this distortion of demand in upstream activities becomes larger as we move up the supply chain from the retailer to the manufacturer is known as the "bullwhip" effect, as shown in Fig.1.

For example, P&G has observed the bullwhip effect in the supply chain of Pampers diapers[1]. Lee, et al. documented the effect in a number of specific

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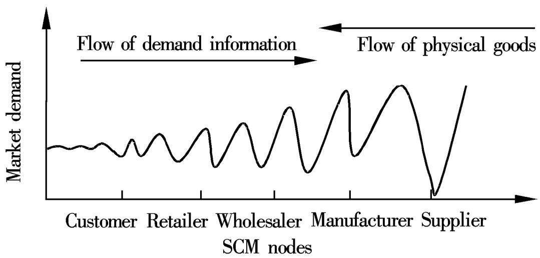

Fig.1 The bullwhip effect in SCM

businesses and offered both causes and cures[7]. The bullwhip effect is assumed to stem from rational and profit maximizing managers. Based on the conclusion of the study of the bullwhip effect, four specific sources of the effect are identified:

1) Forecasting based on orders, not customer demand. When forecasts are based on orders received, any variability in customer demand is magnified as orders move up the supply chain to manufactures and suppliers. Because different enterprises use different forecasting logic, the distortion will be magnified as we move up the supply chain.

2) Large replenishment lead times. Consider a situation in which a retailer has misinterpreted a random increase in demand as a growth trend. If the retailer faces a lead time of two weeks, it will incorporate the anticipated growth over two weeks when placing the order. If, in contrast, the retailer faces a lead time of two months, it will incorporate into its order the anticipated growth over two months. So the bullwhip effect is magnified if replenishment lead times between stages are long.

3) Price fluctuation. Trade promotions and other short-term discounts offered by a manufacturer result in forward buying, in which a wholesaler or retailer purchases large lots during the discounting period to cover demand during future periods. Forward buying usually results in large orders during the promotion period, followed by very small orders after that.

4) Forward buying practices for seasonal items by downstream wholesalers and retailers. As a general practice, wholesale level buyers often induce larger seasonality for manufacturers by purchasing overly large quantities of product during the peak demand season for that product in an attempt to get reduced prices per unit in purchase and transportation[8].

2 VMI in SCM

There are some main methods of stock control in traditional inventory management, such as economic order quantity (EOQ), just-in-time (JIT) and stockless methods. However, with the changes of enterprise structure and management mode, more requirements and new characteristics exist in inventory management of SCM. More efficient methods are required to resolve the new matters occurring in inventory management of SCM. Methods of vendor managed inventory control are discussed in detail in the following.

Vendor managed inventory, also known as consignment inventory, has been widely used in various industries. For instance, one survey found that in hospital materials management, VMI achieved higher penetration than just-in-time and stockless methods. The recent popularity of VMI has led to the claim that vendor managed inventory is the wave of the future and the concept will revolutionize the distribution channel.

A VMI-consignment is essentially an arrangement whereby the owners of goods, the consignor, delivers its goods to other party, the consignee, for use or for sale by the consignee, with the proceeds of the sale being remitted to consignor only after the actual sale, as shown in Fig.2. A typical VMI program involves a supplier which monitors inventory levels at its customer's warehouses and carries the responsibility for replenishing that inventory to achieve specified targets through using of highly automated electronic messaging systems. The supplier thus makes the replenishment decision, rather than waiting for the customer to reorder the product.

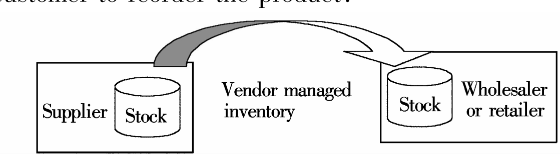

Fig.2 The mode of VMI

2.1 Structure of the model

To simplify the model, several assumptions commonly used in inventory-channel coordination research are made to facilitate the analysis of the consignment issue. Its assumptions are as follows[9]:

- Demand of market is continuous and homogeneous;
- The lead time of order is invariable;
- Purchase quantity and order setup cost are changeless at a time;
- The cost per unit of holding inventory is changeless;
- Rate of product supply (viz. service level) of a buyer is the same as a supplier's.

We can use a simple supply chain to analyze the impact of VMI on supply chain profitability by analyzing the inventory systems of the parties involved (a buyer and a supplier). Let y represent the market demand of the product, $p(y)$ is the reversed demand function (sale price) of the final product, w is the contract purchase price, s_B is the buyer's inventory order setup cost, Q_B is the EOQ of the buyer, C_1 is the product value per unit, C_2 is the shortage fee (loss of shortage per unit), I_B is the buyer's inventory carrying cost (percentage/year), α is the rate of product supply (viz. service level),then the buyer's profit function (Π_B) can be expressed as[10]

$$\Pi_B = p(y)y - wy - \left[\frac{s_B y}{Q_B} + \frac{I_B C_1}{2} Q_B + g(\alpha) C_2 y + ((1-\alpha) - g(\alpha)) \frac{s_B y}{Q_B}\right] \quad (1)$$

where $\frac{s_B y}{Q_B}$ is the order setup cost; $\frac{I_B C_1}{2} Q_B$ is the buyer's inventory carrying cost; $g(\alpha) C_2 y$ is the losing-sale cost; $((1-\alpha) - g(\alpha)) \frac{s_B y}{Q_B}$ is the reserving-order cost; $g(\alpha) C_2 y + ((1-\alpha) - g(\alpha)) \cdot \frac{s_B y}{Q_B}$ constitutes shortage cost.

Let $c(y)$ represent the other production and distribution cost of the supplier, and s_S be the supplier's revised order setup costs, and I_S be the supplier's inventory carrying cost (percentage/year), then the supplier's profit function Π_S can be expressed as

$$\Pi_S = wy - c(y) - \left[\frac{s_S y}{Q_B} + \frac{I_S C_1}{2} Q_B + g(\alpha) C_2 y + ((1-\alpha) - g(\alpha)) \frac{s_S y}{Q_B}\right] = wy - c(y) - \left(\frac{I_B C_1 s_B y}{2}\right)^{\frac{1}{2}} \left(\frac{s_S}{s_B} + \frac{I_S}{I_B}\right) - g(\alpha) C_2 y - ((1-\alpha) - g(\alpha)) \frac{s_S y}{Q_B} \quad (2)$$

For any given purchase price w from the buyer, the supplier chooses a quantity y to maximize its profit and it can be obtained from the following first-order condition:

$$w = c'(y) + \frac{1}{2}\left(\frac{I_B C_1 s_B}{2y}\right)^{\frac{1}{2}} \left(\frac{s_S}{s_B} + \frac{I_S}{I_B}\right) + g(\alpha) C_2 + ((1-\alpha) - g(\alpha)) \frac{s_S}{Q_B} \quad (3)$$

Realizing this relationship between purchase contract price and the quantity, the supplier is willing to provide, the buyer then maximizes its profit by choosing the optimal quantity y^*, such that:

$$p'(y^*)y^* + p(y^*) - c'(y^*) - c''(y^*)y^* - \frac{1}{4}\left(\frac{I_B C_1 s_B}{2y^*}\right)^{\frac{1}{2}} \left(\frac{s_S}{s_B} + \frac{I_S}{I_B}\right) - \frac{1}{2}\left(\frac{2 I_B C_1 s_B}{y^*}\right)^{\frac{1}{2}} - \left[2g(\alpha) C_2 + ((1-\alpha) - g(\alpha)) \frac{s_B + s_S}{Q_B}\right] = 0 \quad (4)$$

The channel profit is the sum of Π_B and Π_S.

$$\Pi_B + \Pi_S = p(y)y - c(y) - \left(\frac{s_B y}{Q_B} + \frac{I_B C_1}{2} Q_B\right) - \left(\frac{s_S y}{Q_B} + \frac{I_S C_1}{2} Q_B\right) - \left[2g(\alpha) C_2 y + ((1-\alpha) - g(\alpha)) \frac{(s_B + s_S) y}{Q_B}\right] \quad (5)$$

Now if the two parties decide to adopt a VMI system, the buyer no longer manages its inventory system and leaves it to the supplier to determine inventory levels, order quantities, lead times, etc. As a result, the supplier now has the combined inventory with order setup cost ($s_S + s_B$) and carrying cost ($I_S + I_B$)C_1. At the same time, if let w_c represent the new contract purchase price in the system of VMI, Π_B^c and Π_S^c represent the new profit function of the buyer and the supplier, respectively, then

$$\Pi_S^c = w_c y - c(y) - [2(s_S + s_B)(I_S + I_B) C_1 y]^{\frac{1}{2}} - \left[g(\alpha) C_2 y + ((1-\alpha) - g(\alpha)) \frac{(s_B + s_S) y}{Q_B}\right] \quad (6)$$

$$\Pi_B^c = p(y)y - w_c y \quad (7)$$

$$\Pi_S^c + \Pi_B^c = p(y)y - c(y) - [2(s_S + s_B)(I_S + I_B) C_1 y]^{\frac{1}{2}} - \left[g(\alpha) C_2 y + ((1-\alpha) - g(\alpha)) \frac{(s_B + s_S) y}{Q_B}\right] \quad (8)$$

As the supplier maximizes its profit with adopting a VMI system, the following relationship between purchase contract price and purchase quantity can be obtained from the following first-order condition of supplier's profit function:

$$w_c = c'(y_c) + \frac{1}{2}\left(\frac{2(s_S + s_B)(I_S + I_B) C_1}{y_c}\right)^{\frac{1}{2}} + g(\alpha) C_2 + ((1-\alpha) - g(\alpha)) \frac{s_B + s_S}{Q_B} \quad (9)$$

The optimal purchase quantity can be obtained from the first-order condition of buyer's profit function (10) by incorporating (9). At this time, the buyer maximizes its profit.

$$p'(y_c^*)y_c^* + p(y_c^*) - c'(y_c^*) - c''(y_c^*)y_c^* - \frac{1}{4}\left(\frac{2(s_S + s_B)(I_S + I_B) C_1}{y_c}\right)^{\frac{1}{2}} - \left[g(\alpha) C_2 + ((1-\alpha) - g(\alpha)) \frac{s_B + s_S}{Q_B}\right] = 0 \quad (10)$$

The difference of channel profit before and after a

VMI system can be easily obtained by

$$[\Pi_B^c(y) + \Pi_S^c(y)] - [\Pi_B(y) + \Pi_S(y)] = \left(\frac{I_B C_1 s_B y}{2}\right)^{\frac{1}{2}}\left[\left(1+\frac{s_S}{s_B}\right)^{\frac{1}{2}} - \left(1+\frac{I_S}{I_B}\right)^{\frac{1}{2}}\right]^2 + g(\alpha)C_2 y \geqslant 0 \quad (11)$$

To maximize the channel profit with adopting a VMI system, the optimal purchase quantity y_J^* can be obtained from the first-order condition of channel profit function (8).

$$p'(y_J^*)y_J^* + p(y_J^*) - c'(y_J^*) - \frac{1}{2}\left[\frac{2(s_S+s_B)(I_S+I_B)C_1}{y_J^*}\right]^{\frac{1}{2}} - \left[g(\alpha)C_2 + ((1-\alpha) - g(\alpha))\frac{s_B+s_S}{Q_B}\right] = 0 \quad (12)$$

where y_J^* is the optimal purchase quantity in full channel coordination in an ideal state.

With VMI, the channel profit has increased. If let INV and INV_c represent the total inventory cost with and without VMI, respectively, it also can prove that VMI reduces the total inventory-related cost of the whole system.

$$\text{INV} - \text{INV}_c = \left(\frac{I_B C_1 s_B y}{2}\right)^{\frac{1}{2}} \cdot \left[\left(1+\frac{s_S}{s_B}\right)^{\frac{1}{2}} - \left(1+\frac{I_S}{I_B}\right)^{\frac{1}{2}}\right]^2 + g(\alpha)C_2 y \geqslant 0 \quad (13)$$

2.2 Application of the model

We assume the demand function can be represented by a simple linear relationship between price and quantity:

$$p(y) = m - ny \qquad m, n > 0$$

In addition, the cost function of the supplier is assumed to be

$$c(y) = \delta y + 0.8\theta y^2 \qquad \delta, \theta > 0$$

Please note that $c'(y) > 0, c''(y) > 0, p'(y) < 0$. The stochastic function above rate of product supply is assumed to be $g(\alpha) = \frac{3}{4}(1-\alpha)$.

Based on the information from a certain refrigerator equipment manufacturer and its client (wholesaler or tradesman) before and after a VMI system, other demand and cost parameters are fixed at the following levels:

$m = 200,\ n = 0.01,\ \theta = 0.006,\ \delta = 60$

$s_B = 600,\ I_B = 20\%,\ C_1 = 100,\ C_2 = 35$

$I_S = 20\%,\ \alpha = 95\%$

As Fig.3 shows, the optimal buyer's purchase quantities y^* will increase over a longer period of time after VMI is implemented.

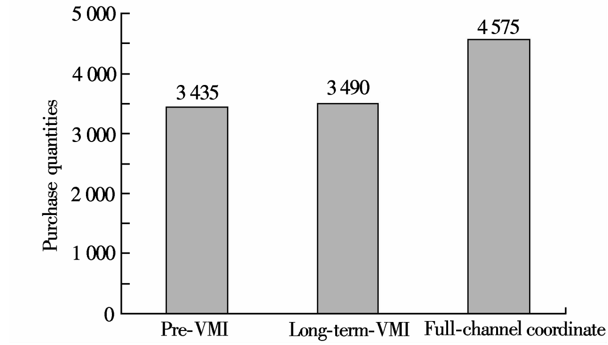

Fig.3 Changes of the optimal buyer's purchase quantities with VMI (s_S = 1 800)

Simultaneity, a conclusion can be drawn that the long-term channel profit goes beyond short-term, but it is less than full channel coordination (see Fig.4, where s_S = 300,600,900,1 200,1 800,2 400,3 600, 4 800).

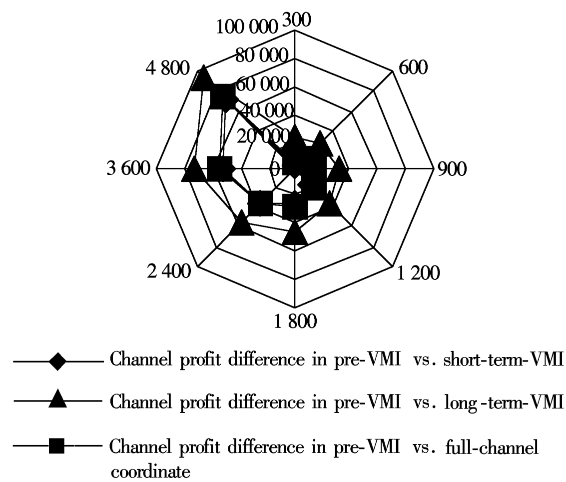

Fig.4 Changes of channel profit with VMI

After adopting a VMI system, furthermore, some changes have taken place to the inventory cost, as shown in Fig.5.

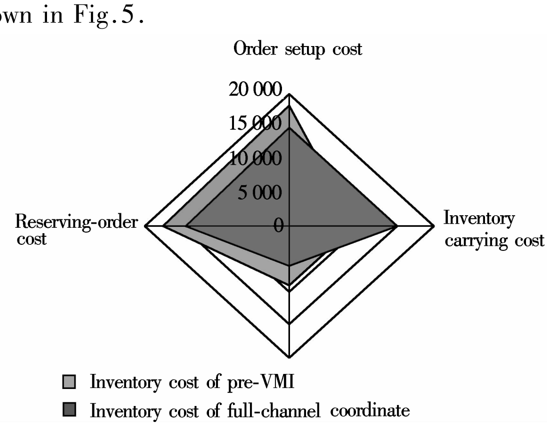

Fig.5 Changes of inventory cost with VMI

Although Q_B and the market demand of the product y have risen, the inventory cost is decreased with VMI. It is shown that the bullwhip effect gets alleviated after adopting a VMI system. VMI can allow a manufacture to increase its profits as well as profits for the entire supply chain by mitigating some of the effects of double marginalization. Profits increase only if both retailer and manufacture margins are considered when making inventory decisions. VMI also helps forward conveying customers' demand data to the manufacturer, who can then plan production accordingly. This helps to improve manufacturers' forecasts, match manufacturer production with customer demand better and reduce the bullwhip effect.

3 Conclusions

This paper presents vendor managed inventory control methods to eliminate the bullwhip effect and reduce the total inventory cost of SC. VMI is an efficient replenishment practice designed to enable the vendor to respond to demand in a timely fashion and efficiently increase the coordination of supply chain management.

However, there are a number of limitations. Future research can address some of these issues:

1) Establish a quantity model to precisely analyze the beneficial causes of VMI. One interesting implication also follows from our models when transportation costs need to be considered in a VMI relationship;

2) It is possible that after the supplier takes over the buyer's inventory via VMI, the order set up cost at the buyer's location can be reduced through new ordering procedures or a better communications scheme such as electronic data interchange. But we have not considered it in this paper;

3) The rate of product supply (viz. service level) is different between the buyer and the supplier.

References

[1] Giannoccaro Ilaria, Pontrandolfo Pierpaolo. Inventory management in supply chains: a reinforcement learning approach [J]. *Int J Production Economics*, 2002, **78**(2): 153-163.

[2] Sui Minggong, Wei Yi. Summary: study of supply chain inventory costs and its development trend [J]. *Logistics Technology*, 2000, **5** : 28-32. (in Chinese)

[3] Achabal D D, McIntyre S H, Smith S A, et al. A decision support system for vendor managed inventory [J]. *Journal of Retailing*, 2000, **76**(4): 430-454.

[4] Axsäter Sven. Scaling down multi-echelon inventory problems [J]. *Int J Production Economics*, 2001, **71**(1-3): 255-261.

[5] Tee Yeu-San, Rossetti M D. A robustness study of a multi-echelon inventory model via simulation[J]. *Int J Production Economics*, 2002, **80**(3): 265-277.

[6] Disney S M, Towill D R. A procedure for the optimization of the dynamic response of a vendor managed inventory system [J]. *Computers & Industrial Engineering*, 2002, **43**(1,2): 27-58.

[7] Lee H L, Padmanabhan P, Whang S. *The paralyzing curse of the bullwhip effect in a supply chain* [R]. Working paper, Stanford CA: Stanford Universtiy, 1992.

[8] Metters R. Quantify the bullwhip effect in supply chain [J]. *Journal of Operations Management*, 1997, **15**(2): 89-100.

[9] Ganeshan R, Boone T, Stenger A J. The impact of inventory and flow planning parameters on supply chain performance: an exploratory study [J]. *Int J Production Economics*, 2001, **71**(1-3): 111-118.

[10] Yan Dong, Xu Kefeng. A supply chain model of vendor managed inventory [J]. *Transportation Research Part E*, 2002, **38**(2): 75-95.

供应链管理环境下供应商管理用户库存控制方法

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摘　要　本文在总结传统库存管理方法的基础上,通过引入供应链管理环境下库存管理中的典型问题——长鞭效应,介绍了供应商管理用户库存(vendor managed inventory, VMI)的基本思想,建立了 VMI 的数学模型,系统地分析了 VMI 策略对库存总费用以及联合利润的影响.最后,通过一个实例从数据上验证了 VMI 策略不仅能提高供应商和用户的联合利润,还有利于他们达到充分合作,降低长鞭效应的影响.

关键词　供应链管理; 库存控制; 供应商管理用户库存; 长鞭效应

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