INFORMATION SHARING AMONG SUPPLY CHAIN PARTNERS: CENTRALIZED VS. DECENTRALIZED INVENTORY MANAGEMENT

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Abstract

Many dramatic changes have recently occurred that exacerbated the need for even more sophisticated and responsive approaches to supply chain management. A promising strategic opportunity is the collaboration among supply chain partners through the integration of decision making process across the extended enterprise. Vendor managed inventory (VMI) is such a strategy, which includes a modern approach for inventory management, where the supplier takes on the responsibility of monitoring, planning and directly replenishing the inventory at the retailer’s site.

This research aims firstly to summarize the major quantitative research efforts on VMI systems, and secondly to evaluate the performance of a two echelon supply chain (one vendor and N retailers) under a VMI logic. We present optimal policies, obtained through a discrete event simulation model and a grid search algorithm, that maximize supply chain’s total profit. The VMI system performance is compared to the performance of a system where the retailer manages its own inventory (RMI – retailer managed inventory). Extensive numerical experimentation provides useful managerial insights.

Keywords: supply chain management, information sharing, vendor managed inventory, discrete event simulation, two echelon supply chain, VMI vs. RMI.

Introduction

The main objective of supply chain management is to minimize system wide costs while satisfying service level requirements, that means coordinating and integrating all included activities and channel members. Collaboration among partners through strategic alliances is a promising step towards coordination. A basic enabler for tight coordination is information sharing, which has been greatly facilitated by the advances in information technology. Vendor Managed Inventory (VMI) is a modern collaboration strategy for inventory management, which utilizes the shared information in an effective way. VMI is a growing agile logistics partnership where the supplier takes on the responsibility of managing the inventory at the retailer’s site for the products it supplies, i.e. monitoring, planning, and directly replenishing the inventory in the retailer’s distribution network [1]. Under a VMI agreement, it is the supplier who determines when stocks are to be replenished and in what quantities, rather than responding passively to orders placed by the retailers. The arrangement is usually guided by a contract which specifies the financial terms, inventory constraints, and performance targets as service measures. The arrangement is mutually beneficial for both parties since the retailer is relieved of the burden to specify, place, and monitor inventory orders while enjoying guaranteed service levels while the supplier benefits from reduced costs, reduced demand distortion, and reduced inventory and safety stocks.

The historical perspective of VMI can been traced back to the early development of QR for general merchandized retailers and their suppliers but VMI has become more popular in the grocery sector in the last 20 years due to the success story of the partnership between Wal-Mart and Procter & Gamble. Besides retailing industries, VMI has been adopted by leading chemical industries, high-tech industries such as Dell, HP and food industries such as Campbell Soup and Barilla [2]. However, VMI is not a new strategy since it was eloquently discussed by Magee in 1958 in a presentation of a conceptual framework for designing a production control system, in which he argues as to who should control inventories.

The motivation behind a VMI system is that both the retailer and supplier work together to maximize the competitiveness of the supply chain. The most obvious benefits are inventory reduction, less stockouts, and significantly reduced forecasting uncertainties. Moreover the reduced overall lead-times and improved service levels can lead to larger profit margin and rise in sales, which increase the competitiveness of the supply chain and give a significant advantage and primacy. However, in practice not all of the VMI
implementations achieve great success. In order a mutually beneficial partnership to be developed, a relationship of trust and respect must be formed, which requires investments in human resources, commitment to the relationship, joint development of new products, and sharing of sensitive information [3]. The main requirements for the implementation of a VMI system are organizational infrastructure, a regular negotiation mechanism, a decision support tool and an effective information system to incorporate planning, inventory, production, and distribution.

In this paper, we firstly review and classify the major VMI-related research efforts to gain a clear view of the existing literature. This literature review may be used to identify potential areas for further research and this is the first objective of our research. Moreover, in this paper we study a specific VMI system that may be implemented in practice. The system includes a two echelon supply chain comprised by one vendor and N retailers. The system performance is evaluated using a discrete event simulation model and a grid search algorithm using as optimization criterion the maximization of supply chain’s total profit. The main difference of our study from related research efforts is that we concentrate on the evaluation of VMI system performance in an information sharing environment, i.e. we compared VMI system profit to the profit of a system where retailers manage their own inventories (RMI - retailer managed inventory), while the vendor having full information on the inventory level of the lower echelon. Specifically, the paper describes the components and parameters that affect the successful implementation of a VMI system through a presentation of the existing literature and identifies potential areas for further research. Moreover it quantifies via simulation the effectiveness and efficiency of a VMI system in order to motivate suppliers and retailers towards a VMI agreement that could create competitive advantage for both of them.

The rest of the paper is organized as follows. In the following section, we present the existing scientific literature on VMI classified according to the OR technique employed. Then, in Section 3, we present the system under study and the developed mathematical model. The numerical experimentation and the principal managerial insights obtained are discussed in Sections 4 and 5 respectively. Finally, we wrap-up with summary, conclusions and future research directions.

**Literature Review**

Although VMI-related research is quite recent, there are several research papers covering from general discussions to analysis of specific model and case studies. In this review we concentrate mostly on papers presenting among others mathematical models that solve specific VMI systems. To better present these papers we classify them (see Figure 1) according to the type of the mathematical model into four categories: papers with analytical, simulative, empirical and transportation models, respectively. There is also a further classification of the papers with analytical models to those referring to a single retailer facing deterministic or stochastic demand and those in which the vendor services N retailers that either face stochastic demand or are competitors.

The only analytical research that refers to deterministic demand is that of Dong et al. [4] who evaluate the short and long-run impact of VMI on the profitability of a supply chain with a single retailer, focusing on inventory systems, purchase prices and purchase quantities. The VMI system is effective in reducing the inventory-related costs for the system as a whole, through optimizing shipment quantities.

Several are the researches that analyze systems with a single retailer who faces stochastic demand. Plambeck et al. [5] consider a make-to-stock model, in which the manufacturer bears the inventory-holding...
and backorder costs of the finished good but delegates the production to a supplier. The supplier dynamically controls the production rate and incurs a convex production cost. Fry et al. [6] analyze a $(z, Z)$-type VMI agreement between a single supplier and a single retailer and investigate the opportunities for savings due to better coordination of production and delivery over the traditional retailer-managed inventory. Under a $(z, Z)$ contract the retailer sets a minimum $z$ and a maximum $Z$ inventory level that wishes his stock to experience, while the supplier makes all decisions regarding the amount and timing of deliveries to the retailer, but is penalized if the retailer’s inventory falls below $z$ or remains above $Z$ after customer demand. The supplier’s optimal policy is calculated using Markov Decision Processes (MDPs).

Choi et al. [7] examine the role of conventional service levels such as fill rate and stockout rate in supply contracts under VMI programs. Using a decentralized two-party capacitated supply chain model consisting of one make-to-order manufacturer and one supplier in a VMI environment, it is demonstrated that supplier’s service level is in general insufficient for the manufacturer to warrant the desired service level at the customer end. They suggest a supply contract that offers a menu of different combinations of supplier’s service levels and expected backorders according to a linear function.

The only analytical model that we are aware of considering a VMI system with a single supplier and multiple retailers facing stochastic $(i.i.d)$ demand like the one in our analysis is that of Aviv et al. [1]. Aviv et al. analyze the benefits of information sharing and VMI-based partnerships in a two-stage distribution system focusing on inventory and distribution cost performance measures. Their analysis includes three models, the traditional decentralized system, a model without central management but with information sharing, and a model under a VMI program. The numerical study considers 24 instances, with different cost ratios and two patterns of replenishment cycles, the “peak” pattern in which all retailers order at the beginning of the replenishment cycle and the “staggered” one in which the orders are balanced across the cycle.

Extremely interesting is the response of a VMI system in a competitive environment. Cachon [8] studies competitive behavior in a supply chain with one supplier and multiple retailers facing stochastic demand, and shows that shifting the control to the supplier under a VMI program coordinates the supply chain as long as the firms are willing to use fixed transfer payments so that they can share the gains from VMI. Bernstein et al. [9] consider a supply chain model with one supplier and multiple competitive retailers, who have formed a specific VMI partnership, in which the supplier decides how the retailers are replenished and bears all production or distribution costs incurred. The VMI arrangement provides considerably easier perfect coordination mechanisms. Coordination is perfect if the decentralized cost and revenue structure in chain-wide profits are equal to those achieved under a centralized system. Bernstein et al. [10] move on to a broad characterization of the supply chain settings in which perfect coordination can be achieved with a simple wholesale pricing scheme based on constant unit wholesale prices or single quantity discount scheme. A two-echelon chain with a single supplier servicing a network of retailers who compete with each other by selecting retail prices (Bertrand competition) or sales quantities (Cournot competition) is considered. The VMI partnership with or without consignment (when ownership of the goods is transferred to the supplier) creates echelon operational autonomy, which is the general condition permitting perfect coordination under general cost and demand functions, where it otherwise would fail to exist.

There is also research discussing the problems related to dealing with a mix of VMI and non-VMI customers using simulation methods. Waller et al. [11] use simulation techniques to examine the effect of VMI adoption rates on inventory levels in a supply chain with high demand ability and multiple distribution channels. Småros et al. [12] study how manufacturing companies can benefit even from a partial increase in demand visibility, especially the situation in which manufacturer loads its production with a combination of data from non-VMI customers and sell-through data from a varying number of VMI customers. The simulation study indicates that there is a strong link between manufacturer’s production planning cycle and the potential benefit of VMI. Disney and Towill have been extensively worked on the response of VMI systems. Disney and Towill [13] consider the performance of a production or distribution-scheduling algorithm termed Automatic Pipeline, Inventory and Order Based Production Control System (APIOBPCS) embedded within a VMI supply chain where the demand profile is deemed to change significantly over time. They present a dynamic model using casual loops diagrams and difference equations to determine the optimum level of design parameters of systems that can operate in a localized region with small frequent deliveries and also on global scale where large batch sizes are needed to gain economies of scale in transport costs. Disney and Towill [14] go on and study the dynamic stability of the mentioned VMI system using casual loop diagrams, block diagrams, difference equations and $z$-transforms. They particularly focus on the importance of obtaining accurate estimates of production lead-times and they determine the general stability conditions for VMI-APIOBPCS.

Besides the analytical and the simulation models there is also the empirical approach of the VMI systems. Holmström [15] analyzes the implementation of a VMI program between a vendor and a wholesaler examining how an information system like SAP R/3 based on the EDIFACT environment can be
implemented in a VMI partnership. Achabal et al. [16] describe the market forecasting and inventory management components of a VMI decision support system and how this system was implemented by a major apparel manufacturer and over 30 of its retail partners. Vergin et al. [17] examine the experiences of 10 consumer products manufacturing companies in applying VMI system. While wide part of literature focuses on the determination and quantification of the information value through analyzing VMI systems, little has been said about the coordination of the transportation decisions. Kleywegt et al. [18] address the inventory routing problem (IRP) and specifically the problem of determining optimal policies for the distribution of a single product from a single supplier to multiple customers using a fleet of homogeneous tracks. They consider the case in which only one customer is visited on each vehicle tour, namely Direct Delivery IRP (DDIRP), and the customers demands follow a known probability distribution. Cetinkaya et al. [19] consider the case in which the vendor adopts a time-based policy for shipment release timing, having the autonomy of holding small orders until an agreeable dispatch time with the expectation that an economical consolidated dispatch quantity accumulates. They compute optimum replenishment quantity and dispatch frequency simultaneously. Disney et al. [20] investigates the impact of a VMI system upon transportation operations and specifically the issue of batching to enable better use of transport vehicles. They use a system dynamics methodology and the concept of cost escapability to show that transport cost savings are possible in both the short and long term.

**System and model description**

Specifically, we consider the two-echelon supply chain depicted in Figure 2, which consists of one vendor (manufacturer) and N retailers (stocking locations). Each retailer i faces non-negative random demand $D_i$ independent and identically distributed in each time unit. Any demand that cannot be satisfied immediately from available stock is backordered and filled as soon as inventory becomes available. The inventory of the retailers is replenished periodically only by the vendor with a lead time $L$. There is upstream information flow in terms of demand and inventory level of the retailers.

![Figure 2. Supply chain’s logical flowchart](image)

The vendor manufactures various products with a production cycle of $T$ time units, which depends on the production schedule. We assume that every $T$ time units only one batch with size $Q$ of a specific product is manufactured. When the vendor’s stock is not adequate to satisfy demand the excess inventory is covered by outsourcing with a negligible lead time.

The criterion for evaluating the system performance is the expected total profit per time unit. The cost structure of the model includes the vendor inventory holding cost ($h_v$ per unit held per time unit), the manufacturing cost ($c_v$ per unit), the outsourcing cost consisting of a fixed cost ($f_v$ per order) and a variable cost ($p_v$ per unit), the shipment cost ($f_s$ per shipment), the retailer inventory holding cost ($h_{Ri}$ per unit held per time unit) and the retailer backorder penalty cost ($p_i$ per unit backordered per time unit). Moreover, there are the vendor’s revenue ($v_i$ per unit) and the retailers’ revenue ($p_i$ per unit).

The inventory of retailer $i$ is managed by a $(R_i, s_i, S_i)$ periodic review policy with period $R_i$. At the beginning of each review period if the on-hand inventory is less than $s_i$, an order of $S_i-IP_{Ri}$ items is placed to increase the retailer inventory position $IP_i$ to the base stock level $S_i$. In the remainder of this paper we assume that the critical inventory level $s_i$ is predefined by a contract between the vendor and the retailers.
The inventory control policy for the vendor affects the batch quantity $Q$ of the products to be manufactured and the quantity of outsourcing. The former is determined under capacity constraints and the latter is determined to avoid backlogging at the vendor.

The expected long-term profit per time unit of the retailer $i$ can be expressed as

$$E(P_i) = \frac{\text{mean sales profit}}{\text{mean shipment cost}} \times E(D) - \frac{\text{mean holding cost}}{\text{mean penalty cost}} \times E(NR_i) + \frac{\text{mean manufacturing cost}}{\text{mean outsourcing cost}} \times E(QR_i) - \frac{\text{mean penalty cost}}{\text{mean holding cost}} \times E(OH_{R_i}) - E(BO_{R_i}) \times p_i$$

(1)

where $NR_i$ denotes the number of shipments from the vendor to the retailers, $QR_i$ denotes the quantity shipped, $OH_{R_i}$ is the on-hand inventory of retailer $i$, and $BO_{R_i}$ is the backorders of retailer $i$. Similarly, the expected long-term profit per time unit of the vendor can be expressed as

$$E(P_v) = \sum_{i=1}^{N} \left[ \frac{\text{mean manufacturing cost}}{\text{mean outsourcing cost}} \times E(Q) + \frac{\text{mean shipping cost}}{\text{mean penalty cost}} \times E(NR_i) \times f_i + \frac{\text{mean sales profit}}{\text{mean holding cost}} \times E(QR_i) \times v_i \right]$$

(2)

where $OH_v$ denotes the vendor’s on-hand inventory, $NO$ is the frequency of outsourcing, and $QO$ is the outsourcing quantity.

The decision variables are a) the base stock inventory level $S_i$, b) the review period $R$, and c) the quantity $Q$. When the system operates on a Vendor-Managed Inventory (VMI) logic, the economically optimal solution, i.e. the optimal decision variables values, are obtained using as objective function to be maximized the expected long-term total profit $E(TP)$ of the system given by

$$E(TP) = E(P_v) + \sum_{i=1}^{N} E(P_i)$$

(3)

On the other hand, a Retailer-Managed Inventory (RMI) logic, requires the determination of the optimal solution in two steps: first we determine the optimal values of $S_i$ and $R$ that maximize eq. (1) and then the optimal quantity $Q$ that maximizes eq. (2).

**Numerical experimentation**

The system performance is evaluated via the combination of a dynamic, stochastic, discrete-event simulation model and a grid search algorithm (see Hooke and Jeeves [21]) that provide optimal values for the decision parameters either for the VMI or the RMI logics. The simulation results presented in this paper refer to a supply chain consisting of a vendor and $N = 2$ retailers. We designed two statistical experiments for the system evaluation. Firstly, we selected six critical factors and then we set two outlying values to each factor (see Tables 1 and 2). So we designed two $2^6$ factorial experiments, that is we created $2 \times 64$ scenarios. In the first experiment (see Table 1) we assumed that the two retailers are identical in terms of demand characteristics, while in the second experiment (see Table 2) the demand characteristics of the two retailers are quite different.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Low level</th>
<th>High level</th>
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<tbody>
<tr>
<td>Demand size distribution</td>
<td>Normal</td>
<td>Gamma</td>
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<tr>
<td>Distribution’s mean and standard deviation ($\mu, \sigma$)</td>
<td>Retailer #1 $\mu = 100, \sigma = 20$</td>
<td>$\mu = 100, \sigma = 91.29$</td>
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<tr>
<td>Retailer #2 $\mu = 100, \sigma = 20$</td>
<td>$\mu = 100, \sigma = 91.29$</td>
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<tr>
<td>Lead time (L)</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Manufacturing period (T)</td>
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<td>30</td>
</tr>
<tr>
<td>Penalty cost per unit and week ($p_i$)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Outsourcing cost per unit ($p_o$)</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Critical inventory level ($s_i$)</td>
<td>300</td>
<td>700</td>
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Table 1. Factor levels for the first experiment

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</tr>
<tr>
<td>Retailer #2 $\mu = 500, \sigma = 100$</td>
<td>$\mu = 500, \sigma = 456.44$</td>
<td></td>
</tr>
<tr>
<td>Lead time (L)</td>
<td>10</td>
<td>25</td>
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Table 2. Factor levels for the second experiment
All these $2 \times 2^6$ scenarios for system parameters are used for both the VMI and the RMI system. The results obtained was then be used to compare VMI and RMI systems in terms of profit maximization. The values of the other model parameters are the following: The manufacturing cost per unit is $c_v = 5 \text{ €/unit}$, while the holding cost per unit is $h_v = 1.5 \text{ €/unit/year}$. We assume that the per unit holding cost is equal to the 10% of the per unit revenue of the product. In the case of outsourcing the fixed cost equals $f_v = 0 \text{ €/order}$. With regard to the retailers’ cost parameters the shipment’s fixed cost is $f_i = 4 \text{ €/shipment}$, while the holding cost is $h_{rl} = 2 \text{ €/unit/year}$. The vendor’s revenue is $v_v = 15 \text{ €/unit}$, while the retailers revenue is $p_{rl} = 20 \text{ €/unit}$. Finally, the warehouse capacity is set to 2000 units. The simulation program is executed for a time horizon of 2000 days assuming a long warm-up period of 1000 days. Moreover every scenario is executed 1000 times to provide accurate estimates of the various model variables.

**Results analysis and discussion**

The analysis of the simulation results revealed several interesting findings. A general finding is that the optimization procedure is quite sensitive at initial values, since the objective function is quite flat and it is easy to be captured in local optima. Figure 3 depicts, in 3-D and contour diagrams respectively, the expected total profit of a specific scenario we considered with parameters $S$ and $Q$. We observe that there are several local optima.

![Figure 3. Total system profit with parameters S and Q](image)

Especially for the case of similar retailers (first experiment), we observe that the VMI system outperformed RMI in 15 out of the 64 scenarios we study with an average improvement of 3.89%. The maximum total profit difference we observe is 21%. The VMI system performs generally better in scenarios with higher demand variability, longer lead times, higher penalty cost, lower outsourcing costs and lower values of reorder point $s$, as depicted in figure 4.

![Figure 4. Impact of various factors on total profit (similar retailers)](image)

Especially for the case of different retailers (second experiment), we observe that the VMI system outperformed RMI in 28 out of the 64 scenarios we study, with an average improvement of 7%. The maximum total profit difference we observe is 52%. The VMI system performs generally better in...
scenarios with higher demand variability, longer lead times, higher penalty cost, higher outsourcing costs and higher values of reorder point, as depicted in figure 5. Thus, it is more preferable to adopt VMI logic in cases of retailers with quite different demand characteristics.

Finally, another interesting point is that the profit of either the vendor or the retailers in the VMI’s optimal solution may be less than the expected profit in case they employ the optimal decision variables of RMI. In this case the maximum profit obtained through the centralized optimization should be shared to the supply chain partners via appropriate contracts.

Conclusions and future research

In this paper, we firstly review and classify the major VMI-related research efforts to gain a clear view of the existing literature. Then, we study a new VMI system that may be implemented in practice, which includes a two echelon supply chain comprised by one vendor and N retailers. The system performance is evaluated using a simulation model and a grid search algorithm. The main finding of our research is that VMI systems hold a tremendous potential in further optimizing the supply chain in process and in other industries towards the goal of supply chain coordination.

The evaluation of Vendor Managed Inventory policies is certainly not exhausted. The model and the analysis presented in this paper is illustrative and needs further work to support the validity of its findings in case of three or more retailers. Moreover, the design and study of similar VMI system may be proven useful to decision maker in selecting the right system for a particular real-world problem.

References


