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A vendor managed inventory model under contractual storage agreement

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ABSTRACT

Vendor managed inventory (VMI) is a supply chain partnership strategy that allows a supplier to place orders on behalf of its customers. This paper considers a supply chain composed of a single vendor and multiple retailers operating under a VMI contract that specifies limits on retailers' stock levels. We address the problem of synchronizing the vendor's cycle time with the buyers' unequal ordering cycles by developing a mixed integer non-linear program that minimizes the joint relevant inventory costs under storage restrictions. We also propose a cost efficient heuristic to solve the developed optimization problem. We conducted computational experiments to assess the reduction in the total supply chain costs resulting from relaxing the restriction of equal ordering cycles. It is found that the heuristic generates greater cost savings in cases of increased variability in retailers' demand and cost parameters.

1. Introduction

To survive in the long run, companies try to stay competitive by decreasing their costs and enhancing their customer service. Matching supply with demand, preventing stock-outs, and improving customer delivery performance are among the common goals for every firm. Successful supply chains also depend on efficient and effective flow of goods to customers. However, the lack of coordinated decisions among its members may hinder that success [12]. Therefore, research and applications in supply chain management have looked for ways to increase coordination and integration among supply chain members (e.g., [10,17]).

Effective coordination strategies in a supply chain require the development of formal relationships among its different entities (Simchi-Levi et al. [23]). These relationships are often governed by clauses in supply contracts which may include stated conditions on pricing and volume discounts, minimum and maximum delivery quantities, lead times, product quality, and return policies. In this study, we consider a vendor managed inventory (VMI) partnership between a single vendor and multiple retailers. Under a VMI contractual agreement between retailers and the vendor, the latter initiates orders on behalf of the retailers who continue to hold purchased materials at the retailers' premises. To take advantage of VMI arrangement, the vendor is likely to ship much of its inventory to the retailers' warehouses by making less frequent shipments with large quantities. However, VMI contracts typically include predetermined conditions regarding maximum limit on stock levels at the retailers' storage facilities [8]. This maximum stock level is the retailer's storage capacity before joining a VMI partnership. It is usually set equal to the retailer's economic order quantity (EOQ), especially if the retailer is following the dedicated storage policy. Moreover, a VMI agreement usually stipulates that the vendor is responsible for acquiring storage space for the stock of items above a contracted upper limit. However, such tighter stock level limits would constrain the vendor's optimum replenishment schedule [19]. Therefore, the purpose of our paper is to develop near-optimal delivery schedules for the vendor when operating under constrained stock levels at the retailers' premises.

2. Literature review

There exists a growing body of recent research on vendor managed inventory (VMI), which has gained prominence in practice with the increasing collaboration and integration that is taking place in supply chains. Several studies found significant benefits from VMI implementation. Such benefits include improved service levels, reduced lead times and increased inventory turns, reduced stock-outs, improved control of the bullwhip effect, and reduction in costs [5,2,20].

VMI research under deterministic demand can be considered as an extension to the Joint Economic Lot Sizing (JELS) problem. The

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literature on JELS shows that several models were built on previous ones by relaxing assumptions, improving solutions, and incorporating new variables. While Ben-Daya et al. [4] provided an extensive review of the single-vendor single-buyer models, extensions of previous studies have progressed unabated and are expected to continue to do so.

In the case of single-vendor and single retailer supply chain, studies on JELS have been mostly based on deterministic EOQ models to minimize a total cost function that adds up the costs of both parties. Among these studies, the work of Goyal [14] was the first to study the benefit of coordination of inventory replenishment decisions in a single stage supply chain. Later, Goyal [15] extended the work of Banerjee [3] by taking the vendor's lot size as a multiple of that of the buyer's, while still assuming that the vendor can ship only after the lot is completed. This work was extended by Lu [21] who allowed the vendor to supply some quantity to the purchaser before completing the lot, while maintaining the assumption of equal-sized shipments. In turn, Goyal [16] used Lu's [21] example to prove that a better solution can be obtained by a shipment policy that assumes that each successive shipment within a production batch increases by the ratio of production over demand rates.

Subsequently, Hill [18] showed that neither Goyal's [16] nor Lu's [22] policies are optimal; and concluded that his shipment policy outperformed both. Later, Viswanathan [24] showed that the proposed policies of Lu [22] and Goyal [16] depend on the problem parameters. He considered a model that minimizes the sum of production setup, buyer ordering, buyer and vendor carrying costs. For a more recent and comprehensive review of the progression of JELS research, interested readers may refer to the seminal literature review undertaken by Glock [13].

The advent of VMI in supply chain management research and practice in the late 1990s brought along new supply chain models and results. Waller et al. [26] simulated the impact of VMI under various scenarios and found that inventory reduction was achieved through more frequent stock reviews and deliveries. Fry et al. [11] showed, through a periodic review inventory model, that VMI is beneficial in most scenarios; and that VMI effectiveness depends on the initial contract. Viswanathan and Piplani [25] devised a VMI strategy wherein the vendor specifies common replenishment periods to the retailers. Also for multiple retailers, Cheung and Lee [6] simulated the cost of the joint replenishment model with upper and lower bounds as shipment constraints and looked at what VMI may offer in shipment coordination and stock rebalancing.

Darwish and Odah [8] developed an algorithm that requires $(m+1)$ iterations to find the optimal solution for a problem involving a single-vendor and m retailers operating under a VMI contractual arrangement, wherein an upper bound was placed on each retailer's inventory level. This upper bound, which protects the retailer against excessive inventory, meant that a penalty would be imposed on the vendor exceeding this limit. However, their model was developed under the assumption of equal retailers' reorder intervals. A more recent study by Darwish and Goyal [9] considered a VMI setting between a manufacturer and a buyer with limited storage space. They proposed an algorithm that minimizes the total system cost consisting of holding and ordering cost, as well as the penalty cost for the manufacturer resulting from exceeding the pre-specified inventory limit of the buyer.

In this paper, we consider a practical situation when VMI partnership is implemented in a two-stage supply chain with limited retailers' storage capacities. Our study focuses on the synchronization of the vendor and buyers' ordering cycles by minimizing the total inventory costs over the entire supply chain. Compared to the related papers in the literature, the contribution of our paper is twofold. We present an optimization model for a single-vendor and multi-buyer supply chain under a VMI setting in which the retailers may receive different number of replenishments within every cycle of the vendor. Moreover, given the computational complexity of that optimization model, we propose a cost efficient heuristic procedure to generate near-optimal delivery schedules.

3. Model formulation and solution procedure

Consider a supply chain where a vendor supplies a single item to multiple retailers under a VMI agreement. End consumer demand at each retailer is known and constant, and must be met without backordering or lost sales. Moreover, the conditions under which the vendor operates are as follows:

(i) Vendor orders the item from an external source having unlimited supply.
(ii) Unit holding cost of the vendor is less than that of each one of the retailers.
(iii) Each retailer specifies an upper stock level under VMI, and the vendor is financially penalized whenever that level is exceeded.

Let j be the index for retailers, $j=1, 2, \ldots, m$, where m is the number of retailers.

For the jth retailer let:

D_j	demand rate per unit of time
A_{rj}	cost charged to the jth retailer for receiving its ordered shipment
A_{ij}	cost incurred by the vendor for initiating and releasing an order to the jth retailer
A_j	$A_{rj}+A_{ij}$
h_j	unit holding cost per unit of time at the jth retailer's facility
π_j	penalty cost paid by the vendor when the inventory level at the jth retailer exceeds the maximum allowed, such as the cost of renting extra storage space.
U_j	storage capacity of the jth retailer

Note that the ordering cost for the jth retailer is the sum of the vendor's order initiation and release costs and the retailer's order receiving cost since the vendor is responsible for issuing order on behalf of the retailer according to the VMI agreement.

For the vendor let:

h_v	unit holding cost per unit of time at its facility.
A_v	ordering cost per order.
D_v	$\sum_{j=1}^{m} D_j$, total demand to be supplied by the vendor.

Decision variables:

T_j	reorder interval for the jth retailer
T	vendor reorder interval
n_j	number of deliveries made during the vendor's reorder interval, T
q_j	T_jD_j, ordering quantity shipped to the jth retailer.

In the subsequent sections, we provide the optimization model with unequal reorder intervals, develop a heuristic procedure to generate near-optimal ordering policy, and illustrate the heuristic with an example.