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Storage constrained vendor managed inventory models with unequal shipment frequencies

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ABSTRACT

We consider a supply chain where a vendor manages its multiple retailers' stocks under a vendor managed inventory (VMI) contract that specifies upper stock limits at the retailers' premises and overstock costs for exceeding those limits. We formulate a mixed integer nonlinear program that minimizes total supply chain costs and allows unequal shipment frequencies to the retailers. We develop an algorithm to solve its relaxed version which provides a lower bound cost solution. We propose a cost efficient heuristic procedure to generate delivery schedules to the retailers. We conduct a sensitivity analysis to provide insights on the performance of the proposed heuristic. Results show that our heuristic finds optimal or near optimal solutions, and it proposes substantial savings compared to the total supply-chain cost in the cases where there is no VMI and where there is VMI but with equal shipment frequencies to retailers.

1. Introduction

Partners in a supply chain are interconnected with financial, information, product, and service flows. Maximizing customer value and profit for each supply chain member requires effective and efficient management of such flows through information sharing and coordinated decision making [47]. Thus, greater supply chain performance can be achieved by aligning all information and incentives to support global system objectives [49]. Moreover, retailers are increasingly realizing that their competitiveness rests on the collective performance of their supply chain [12]. Supply chain coordination and integration, however, is a challenging task that has motivated new industry-changing practices such as Vendor-Managed Inventory (VMI), which is the focus of this paper.

VMI requires sharing of information regarding the buyer's customer demand and inventory positions. VMI goes beyond mere collaborative planning among supply chain members to entail actually delegating, by the buyer to the supplier, the responsibility of determining the appropriate inventory levels and replenishment policies through contractual agreements. Research on VMI has grown significantly to keep up with its prominence in practice as firms, suppliers, and vendors alike increasingly discover the compelling benefits of closer collaboration and integration. Interest and research on VMI was greatly stimulated by Wal-Mart's VMI partnership arrangement with Proctor and Gamble in the 1980's, which was emulated by retailers such as K-mart, Home Depot, and JC Penny. The VMI partnership between Kimberly-Clark and Costco is another VMI success story as it significantly improved the management of merchandise and led to a substantial increase in net incomes for both firms [59]. Other companies such as Whitbread Beer Company, Barilla, Johnson & Johnson, Kodak Canada Inc. and Campbell Soup have also experienced successful implementation of VMI initiatives [10,38,52].

Under a VMI contract, the stocks remain under the ownership of the retailers who incur the resulting inventory holding costs. In order to reap maximum benefit from the adoption of VMI, the vendor tends to move much of its inventory to the retailers' warehouses by shipping large quantities. To respond to such practice, each retailer restricts the vendor to keep inventory levels below an agreed maximum level. Therefore, the VMI contract usually includes a clause according to which the vendor is penalized for the stock of items held at the retailer's premise exceeding a contracted upper bound [26,24].

In this paper, we study a supply chain that includes a single vendor and multiple retailers. End consumer demand for a single product is realized at the retailers. That demand is constant per unit time. The vendor manages the retailers' inventory under a VMI contract which specifies maximum stock levels allowed by the retailers. The upper stock limit is the retailer's storage capacity, which depends on the retailer's ordering quantity when acting independently of the vendor and it is usually set at a level just

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large enough to accommodate its economic order quantity (*EOQ*). If the stock at a retailer exceeds the allowed limit, the vendor is responsible for securing more storage space. In this case, the vendor incurs the storage cost for the extra quantity beyond the retailer's storage capacity, which does not include the capital cost as the stock is owned by the retailer. The vendor coordinates the product's deliveries by allowing unequal shipment frequencies for its retailers, who can receive multiple deliveries per the vendor's cycle. The objective is to identify the best cycle time for the vendor and the frequency of delivery to each of its retailers.

In a decentralized supply chain, each firm attempts to optimize its own objective. In one stream of VMI research, the partnership is regarded as a possible means to achieve coordination by helping firms to align their decisions and attain lowest supply chain costs (e.g. [15]). In another stream, the flexibility that VMI offers is used to access operational benefits such as consolidating shipments [21] and setting new delivery rates [19]. We take the approach of the latter stream and consider the benefits offered by VMI in coordinating replenishments.

Coordination of shipment deliveries under VMI can be regarded as a benefit of the partnership if it generates savings in the supply chain. However, coordinating those deliveries may be a complicated task to achieve when multiple retailers set upper stock limits at their premises and when the vendor pays a penalty for exceeding those limits. In our study, we assume that a central controller, such as the vendor itself, has full information of all the parties under VMI and uses that information to set best possible delivery schedules for the vendor and its retailers. With this approach, we consider the savings that VMI offers for the entire system. According to Bookbinder et al. [11], a successful VMI implementation implies that none of the partners is worse off compared to the no-VMI system. They also stated that a VMI is a potentially efficient system if there are system wide savings but at least one supply chain member is worse off. Moreover, it is an efficient system if VMI generates savings for all the parties involved, but an inefficient system if there are no system-wide savings. Therefore, the benefits of VMI implementation are assessed better if the vendor considers not just its own costs, but also the costs of its retailers. Moreover, the optimization of system-wide costs under VMI can be vindicated by the fact that costs incurred by the retailers may depend on the vendor's operational decisions [8]. If system-wide costs are lower under VMI, parties can then share the benefits through mechanisms such as transfer payments [13].

Angulo et al. [2] stated that sharing information between supply chain members under VMI is necessary to implement the partnership. Taking a system-wide approach under VMI with full information from the involved parties is an alternative to letting a VMI-vendor optimizes its decisions first without considering its retailers' cost parameters. For example, Aviv and Federgruen, [4] provided a VMI model for the entire supply chain system using the information from retailers. Fry et al. [26] included a discussion on central controller in their analysis as a possible decision maker also for the entire system. The vendor under VMI with multiple retailers acts as a central decision maker in the analysis provided by Bertazzi et al. [9]. It is also possible to have a VMI agreement between a vendor and multiple retailers when all parties belong to the same organization [37].

In our study, we assume that with VMI, parties share demand, storage capacity, and cost information. Hence, the total cost function under VMI includes the parameters of the vendor and also the retailers. According to the VMI contract, the vendor pays its own cost of ordering from its supplier, order initiation cost on behalf of its retailers, holding cost on its site, and cost of overstocking at the retailers. Retailers pay order-receiving cost and holding cost on their premises.

It is well documented in the supply chain literature that VMI does not always guarantee cost savings [26,60]. In the supply chain we consider, a VMI failure may be due to the upper stock levels retailers set under VMI, overstock cost the vendor pays, and the number of retailers under VMI. Hence, our aim is to investigate the system-wide costs savings VMI may offer by means of coordinating deliveries compared to the decentralized supply chain. If VMI generates system wide savings, those savings can be shared among supply chain partners using benefit sharing mechanisms. According to Xu and Leung [59] such sharing mechanisms are largely related to the industry standards, terms of the agreement, and the relative bargaining power of the parties involved in the supply chain. In their centralized VMI model, they assumed a fixed profit sharing ratio between the vendor and the retailer. Yao et al. [60] suggested that in case supply chain costs under VMI are not evenly reduced, side-payment arrangements would be conducive to a healthier long-term relationship. Interested readers can refer to several other studies such as those by Cachon and Lariviere [16], Palsule-Desai [46], Wang et al. [58], and Zhang et al. [62] for discussions on benefit sharing and supply chain coordination. In Zhang et al. [62], the authors proposed a cost sharing and promotional mechanism to coordinate the supply chain in which the manufacturer and the retailer share each other's advertising costs.

We formulate a mixed integer nonlinear model for the problem with the assumption of stationary and nested inventory policy. Our objective is to minimize the total supply chain cost under VMI where the vendor manages its retailers' stock, and thus decides upon replenishment schedules for itself and its retailers. In order to solve the problem, we first relax the nested policy assumption and obtain a nonlinear problem. We develop an algorithm to find the optimal solution to the relaxed problem, which is indeed a lower bound to the original problem. We then propose a heuristic to convert the lower-bound solution to a near optimal one for the original problem in an iterative approach.

The contribution of this paper is threefold. The first contribution is the formulation of a mathematical model for a supply chain that operates under VMI between an upstream vendor and multiple non-identical downstream retailers. The objective function of the model includes overstocking costs charged to the vendor when the inventory levels at the retailers' facilities exceed the contracted bounds. In contrast to existing models in the literature, our model does not restrict the retailers' reorder intervals to be equal. The second contribution of the paper is the development of a computationally and cost effective algorithm to solve the formulated problem. The cost performance of the algorithm is investigated empirically based on an extensive computational experiment. The last contribution is the assessment of the benefits realized by the supply chain as a result of the VMI adoption with constrained inventory levels at the retailers' storage facilities.

The remainder of the paper is organized as follows. In Section 2, we provide a review of the literature. In Section 3, we formulate the VMI problem under contractual storage agreement as a mixed integer nonlinear program for stationary and nested delivery schedules. In Section 4, we relax the formulated optimization problem to a pure nonlinear program and develop an algorithm to solve it optimally. In Section 5, we present a heuristic procedure to generate near-optimal delivery schedules using the solution to the relaxed problem. In Section 6, we report the results of an extensive computational study to assess the cost performance of the proposed heuristic procedure. In Section 7, we conclude the paper and suggest few extensions.

2. Literature review

Many VMI models extended joint economic lot sizing (JELS) models by improving solutions and computational efficiency,