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Tri-level decision-making for decentralized vendor-managed inventory

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ABSTRACT

Vendor-managed inventory (VMI) is a common inventory management policy which allows the vendor to manage the buyer's inventory based on the information shared in the course of supply chain management. One challenge in VMI is that both the vendor and buyer are manufacturers who try to achieve an inventory as small as possible or even a zero inventory; it is therefore difficult to manage inventory coordination between them. This paper considers a decentralized VMI problem in a three-echelon supply chain network in which multiple distributors (third-party logistics companies) are selected to balance the inventory between a vendor (manufacturer) and multiple buyers (manufacturers). To handle this issue, this paper first proposes a tri-level decision model to describe the decentralized VMI problem, which allows us to examine how decision members coordinate with each other in respect of decentralized VMI decision-making in a predetermined sequence. We then turn our attention to the geometry of the solution space and present a vertex enumeration algorithm to solve the resulting tri-level decision model. Lastly, a computational study is developed to illustrate how the proposed tri-level decision model and solution approach can handle the decentralized VMI problem. The results indicate that the proposed tri-level decision-making techniques provide a practical way to design a novel manufacturer-manufacturer (vendor-buyer) VMI system where third-party logistics are involved.

1. Introduction

Business firms nowadays usually work in a decentralized manner in a complex supply chain network comprised of suppliers, manufacturers, sales and logistics companies, customers and other specialized service functions. Inventory control, which often accounts for a large proportion of a business' costs [30], can be considered as the major driver of a supply chain owing to its strong influence on supply-chain performance [7,8]. In recent years, an creasing number of companies in retail business and the manufacturing industry have identified vendor-managed inventory (VMI) policy as one strategy for reducing inventory, speeding up the supply chain [21] and eliminating the bullwhip effect in supply chain management (SCM) [13].

VMI is defined as a concept for planning and control of inventory based on the fact that the vendor (or supplier) has access to the buyer's (or retailer's) demand data and is responsible for maintaining the appropriate inventory level and

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determining replenishment policies [17,26]. For instance, a bearing manufacturer (*vendor*) produces and supplies bearings (raw materials to manufacture automobiles) to an automaker (*buyer*). Different from the traditional inventory policy that the automaker manages its own inventory and places a purchase order with the bearing manufacturer, the bearing manufacturer in VMI needs to examine the automaker's inventory level and material demand in real time and is responsible for bearings supply to the automaker (buyer) timely to avoid the lack of raw materials.

An important issue in designing a VMI system is how to ensure optimal inventory planning, such as decision-making at the inventory level and replenishment frequency. The majority of research on VMI has been focused on centralized inventory control, which features inventory decisions that are only managed from the vendor perspective in a two-echelon supply chain [29,42]; this situation often appears in consignment and retail business [15,24]. However, centralized VMI cannot be applied to handle the inventory management in which both the vendor and buyer are manufacturers and try their best to achieve an inventory that is as small as possible, or even zero inventory. The bearing supply chain instance aforementioned can be taken as an example again, i.e., both the vendor (bearing manufacturer) and buyer (automaker) are manufacturing enterprises that consider production-manufacturing to be the core competence and tend to keep the inventory as low as possible or even at zero inventory under lean (or JIT, just in time) production environment. In contrast to centralized VMI which features operations managed from the vendor, each member in this VMI instance is given the power to make its own optimal inventory decision based on the local inventory conditions and decisions of other members; this can be therefore regarded as a decentralized VMI scenario. Thus, how to design an effective decentralized VMI system between these manufacturers becomes a challenging task in SCM.

Motivated by the aforementioned challenge, this paper aims to design a decentralized VMI system where one vendor and multiple buyers are involved and all of them are manufacturers. More specifically, the buyers (e.g. automakers) are MTO (make to order) manufacturers of end product, which are spread out over a large area, such as different industrial parks or cities; while the vendor (e.g. a bearing manufacturer) is responsible for raw material (e.g. automobile bearings) production and supply. Notably, both the vendor and buyers are manufacturers that consider production-manufacturing as their core competence rather than logistics distribution; thus, some third-party logistics companies, which are considered as the distributors, are given the power to control and manage the raw material distribution and inventory of the buyers through VMI hubs. VMI hubs are the warehouses that are geographically close to the buyers, which are owned or hired by the distributors. To response to the buyers' material demand efficiently, the distributors tend to store the raw material in these VMI hubs closed to their own buyers. In addition, to reduce stock-out risk and respond to fluctuation in production, the vendor and buyers are obliged to hold a certain amount of back-up inventory using their independent warehouses.

When planning the VMI, the vendor is able to recognize the optimal decision-making processes and reactions of its downstream distributors and buyers based on shared information and can give priority to designing an inventory plan that will minimize its own inventory cost. In response to this action by the vendor, each distributor then creates an optimal inventory plan of the VMI hub for maintaining the raw material supply for its downstream buyers while considering the impact on these buyers. Lastly, in full knowledge of the decisions made by upstream members, the buyers determine their respective back-up inventory plans to minimize their individual inventory costs. Clearly, although all members in this VMI system make their decisions on inventory planning in sequence with the aim of minimizing their individual inventory costs; however, the decision-making process of the upstream member must take into account the implicit reactions of the downstream members. Considering that each member is usually concerned with its own profit and costs when making inventory decisions, we thus need to achieve the harmonious functioning of all members for effective VMI results, that is also known as an inventory coordination problem between these companies in SCM.

The main contributions of this paper are threefold. First, the paper provides a tri-level decision model to characterize the decentralized VMI problem, which allows us to examine how the decision members coordinate with each other. Second, it examines the solution space of the resulting decision model and develops an effective vertex enumeration algorithm to find an optimal solution. Lastly, it shows how to improve the individual performance and the whole supply chain performance in a decentralized manufacturer-manufacturer (vendor-buyer) VMI system in which the vendor and buyers can achieve a minimal to zero inventory.

The remainder of the paper is organized as follows. In Section 2, we provide literature review of VMI and tri-level decision-making. The decentralized VMI problem statement and the tri-level decision model are proposed in Section 3. The vertex enumeration algorithm is developed to solve the resulting VMI model in Section 4. In Section 5, we construct a computational study to illustrate how to apply the proposed tri-level decision-making techniques to handle the VMI problem. Lastly, concluding remarks and further avenues of study are given in Section 6.

2. Literature review

2.1. Vendor-managed inventory

The academic studies on VMI are fairly substantial and can be categorized into two broad streams: (1) papers that focus on examining the achievement of VMI benefits, and (2) papers that are concerned with modeling studies on optimal decision-making in VMI and the impact of key parameters on VMI performance. This literature review is restricted to relevant research on the second stream.