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Optimizing an integrated vendor-managed inventory system for a single-vendor two-buyer supply chain with determining weighting factor for vendor's ordering cost

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ABSTRACT

This paper considers a two-echelon supply chain model with a single vendor and two buyers in which the vendor supplies the same item to both buyers at a finite production rate. The purpose of this study is twofold. First, mathematical models are developed for the integrated vendor-managed inventory (VMI) policy as well as the traditional retailer-managed inventory (RMI) system and solution algorithms are presented to determine the optimal lot size and total inventory cost of the supply chain. Then, the effect of key parameters including buyer's demand, buyer's transportation cost, vendor's ordering cost, and vendor's holding cost on lot size variation is studied in each policy. A weighting factor is also determined for the vendor's ordering cost which is used to compare the two policies. Detailed numerical experiments are provided to illustrate efficacy of the proposed approach. Results indicate that greater reduction in total cost of supply chain can be achieved by using VMI and provide a comprehensive insight into selection of inventory policies to improve commercial business and supply chain performance.

1. Introduction

Vendor-managed inventory (VMI) is a coordination program between a vendor, often a manufacturer or supplier, and a buyer, often a retailer, in which the supplying organization takes full control of inventory management and replenishment decisions for retailers. Under VMI, the buyer provides the vendor with inventory information and the vendor uses this information to monitoring inventory or placing orders. Hence passing retailer's inventory management duty and responsibility of inventory replenishment decisions from buyer to vendor is the cornerstone of VMI (Copacino, 1993; Waller et al., 1999; Kaipia and Tanskanen, 2003; Holweg et al., 2005; Tang, 2006; Dong et al., 2007; Gronalt and Rauch, 2008). The retailer's role in a VMI arrangement shifts from managing inventory to simply renting retailing space to the vendor (Chen et al., 2012).

VMI is not a new strategy. The beginning of VMI conceptual framework can be traced back to Magee (1958) when discussing who should be responsible for the inventory control. The VMI policy was first implemented by Wal-Mart, one of the successful retail businesses, and Procter & Gamble in the late 1980s. It has been also applied by many other industries, such as Campbell Soup, Johnson & Johnson, and the pasta maker, Barilla (Waller et al., 1999; Yu et al., 2012).

Implementing a VMI program has significant benefits for the supply chain and each of the participants. It offers a competitive advantage for retailers with respect to higher product availability and provides the supplier with opportunities to improve production and marketing efficiencies (Ryu et al., 2013). The VMI leads the supplier to increase replenishment frequencies with smaller quantities and reduces inventory level for all involved in distribution and the supply chain (Waller et al., 1999; Dong et al., 2007; Yao et al., 2007; Chen and Chang, 2010). It also causes greater inventory cost saving and improved customer service levels (Achabal et al., 2000; Williams, 2000; Zavanella and Zanoni, 2009; Kang and Kim, 2012).

In VMI applications, supplier achieves more flexibility in production scheduling and decision making on quantity and distribution (Cheung and Lee, 2002; Rusdiansyah and Tsao, 2005; Danese, 2006; Claassen et al., 2008; Wong et al., 2009; Xu and Leung, 2009). Supplier has a better insight of the customer demand that results in better resource usage in production as well as reduced raw material and finished product inventories (Yang and Wee, 2002; Kaipia and Tanskanen, 2003; Yu et al., 2004; Zhang et al., 2007; Sana, 2011). It means that supplier achieves

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higher forecasting accuracy (Achabal et al., 2000; De Toni and Zamolo, 2005; Nagarajan and Rajagopalan, 2008) and better response to any random customer demand and market changes (Disney and Towill, 2002; Kuk, 2004; De Toni and Zamolo, 2005). Furthermore, the supplier is able to smooth the fluctuations in demand (Kaipia and Tanskanen, 2003) due to better visibility leading to reduce the bullwhip effect (Disney and Towill, 2003a; Zhu and Peng, 2008) and demand uncertainty (Disney and Towill, 2003b).

According to previous studies (Aviv and Federgruen, 1998; Corbett, 2001; Mishra and Raghunathan, 2004; Kim, 2008; Yao and Dresner, 2008; Wang, 2009), VMI has some advantages comparing to other models such as RMI, continuous replenishment, and information sharing. Some authors have proposed simulation models to realize the advantages of VMI among various business scenarios in the supply chain (Southard and Swenseth, 2008; Sari, 2008). Kiesmuller and Broekmeulen (2010) have presented a two-echelon inventory system with multi-product serial where demand is stochastic and used as a simulation model to examine the advantages of the VMI system from economies of scale in order picking activities at the upstream location by adapting order quantities. Fry et al. (2001), De Toni and Zamolo (2005), and Southard and Swenseth (2008) have explained and compared the benefits of VMI and traditional RMI policies in the supply chain.

In this paper, we focus on a supply chain comprising a single vendor and two buyers where the vendor purchases an item in terms of raw material or work-in-process and then produces finished item and ships to both buyers for an infinite horizon. The contribution of the study is twofold. First, a mathematical model is developed for the integrated single-vendor two-buyer supply chain under the VMI system. The lead time is assumed to be proportional to the order quantity in addition to a constant delay time due to transportation, moving, etc.

We study the VMI system under the continuous review policy that has not been adequately addressed in previous research (Guan and Zhao, 2010). We identify the optimal lot size in the VMI and traditional RMI systems and discuss the difference in total cost of supply chain as well as the lot size variation in different settings. Second, we make a distinction between the cost of ordering raw materials or work-in-process products and the cost of setting up the production equipments in order to produce finished products for the buyers, so that the performance of the VMI and RMI systems is more deeply analyzed under different scenarios for vendor's ordering cost.

The remainder of paper is organized as follows. Section 2 provides an overview of previous works in the field. In Section 3, mathematical models for the two policies are developed and an algorithm is proposed to find the optimal solution. Section 4 discusses a set of numerical experiments to compare the policies as well as results of sensitivity analysis for the key parameters. Finally, the paper concludes in Section 5 with a brief summary and some hints for further research.

2. Literature review

The academic studies on VMI can be categorized in three groups: (1) general papers that define VMI and describe benefits of its application, (2) industrial case studies that determine the boundaries of VMI application and discuss the results and limitations, and (3) modeling papers that propose mathematical models to investigate the effect of key parameters on VMI performance. Herein, the literature review is restricted to important studies in the third group, i.e. modeling papers.

Probably, Goyal (1976) has been one of the first pioneers to present integrated vendor-buyer inventory problem. He has developed an integrated inventory model for a single-vendor single-buyer supply chain where the rate of production is infinite for the vendor. This model has been later generalized by Banerjee (1986) assuming the vendor as a manufacturer with finite production rate.

Considering different shipment strategies, Goyal and Nebebe (2000) have introduced optimal solutions for the single-vendor single-buyer model with the objective of minimizing total joint annual costs incurred by the vendor and the buyer. They have suggested that the first shipment is smaller and the next ones are determined by multiplying the first shipment size with rate of production over rate of demand.

In another study, an analytical model have been proposed based on the renewal theory to coordinate inventory and transportation decisions with VMI system to identify the optimal replenishment quantity and shipment-release policy. A time-based shipment-consolidation policy has been applied where the vendor experiences a sequence of random demands from a group of retailers (Cetinkaya and Lee, 2000). Lo and Wee (2005) have extended this model by developing a quantity-based deterministic model and applied it to show that transportation cost in the (s, S) system is more reduced than the time-based model.

The single-vendor single-buyer integrated model have been also investigated under the assumption that average demand during the lead time is controllable and follows normal distribution function (Pan and Yang, 2002). This model has been improved by assuming that the shortage is permitted during the lead time and the lead time demand is stochastic with either normal distribution or distribution-free (Ouyang et al., 2004).

Chang et al. (2006) have studied the single-vendor single-buyer problem with a continuous review inventory system with controllable lead time and set-up cost reduction in two different situations: when the ordering cost reduction does not depend on the lead time crash and when there is a relationship between the lead time and ordering cost reduction. Furthermore, Hoque and Goyal (2006) have proposed a heuristic solution procedure for this problem under controllable lead time to minimize the total cost of setup, inventory holding, and lead time crashing. The VMI system with a single vendor and single retailer applying continuous review policy has been also investigated by Guan and Zhao (2010) and a revenue-sharing contract has been designed for the consignment stock case and a franchising contract for the case where the inventory is owned by the retailer.

In some other studies, the performance of VMI has been compared with the traditional system. Fry et al. (2001) have suggested a (z, Z)-type VMI contract in which the retailer sets a minimum inventory level z as well as a maximum inventory level Z and the supplier pays a penalty if every unit of retailer's inventory falls outside these limits after customer demand. The authors have shown that the proposed model works better than the traditional RMI with information sharing in many situations. In another study, the ability of VMI to improve supply chain efficiency for a short life-cycle product has been illustrated where demand is uncertain and a solution algorithm has been proposed to find the optimal production and inventory decision (Wang, 2009). Also Razmi et al. (2010) have established the extent point between VMI and traditional system with a mathematical modeling approach helping the vendor to make more efficient decisions regarding order quantity. The results have shown that the VMI system works better than traditional mode in reducing the total inventory cost.

For the two-echelon single-vendor multi-retailers supply chain, an analytical model has been presented to optimize investment and replenishment decisions for buyers and vendors considering