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A multiple-retailer replenishment model under VMI: Accounting for the retailer heterogeneity

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ABSTRACT

Vendor managed inventory (VMI) is a well-established supply chain practice where the supplier is responsible for managing inventory at the retail point. In particular, the supplier takes care of *when to order* and *how much to order* on behalf of the retailer. This paper considers a single supplier – multiple retailer setting where the supplier takes inventory replenishment decisions for retailers such that the replenishment quantity for each retailer is within an upper bound that is mutually agreed upon in the VMI contract. We develop a nonlinear mixed-integer programming model to compute the optimal replenishment frequency and quantity for each of the retailer, such that the total system cost is minimized. A conceptual and numerical comparison is made with the existing models in the VMI literature. The proposed model is found to perform better for all levels of retailer heterogeneity, thereby establishing generalization among the class of models. We also propose an efficient heuristic for solving the proposed model by utilizing the concept of *cycle ratio (setup cost/holding cost ∗ demand)*, thus reducing the computational time drastically. Lastly, through a numerical analysis, we find that the proposed model with integer ratio policy structure is more stable as compared to the existing alternative replenishment models.

1. Introduction

In a world of increasing competition and uncertainty, it has become indispensable for companies to revisit their operations continuously. To be able to extract and deliver maximum value to customers, companies have to think beyond their organizational scope by collaborating and coordinating with other entities of the supply chain (SC). Only those with high levels of supply chain practices can gain a competitive advantage over other players in the market (Li, Ragu-Nathan, Ragu-Nathan, & Subba Rao, 2006). A recent report by SCM World (2014) finds company executives pointing out that cost reductions, in general, and collaborative cost reductions with the supplier, in particular, are the most important factors to gain competitive advantage.

Coordination can be defined as a strategic response to or an instrument for managing inter-firm dependencies in an SC (Malone & Crowston, 1994; Xu & Beamon, 2006). The consequences of having non-coordinated supply chains are realized in the form of excessive inventory, low capacity utilization, low quality, and low customer satisfaction (Ramdas & Spekman, 2000). On the other hand, having a well-coordinated supply chain helps in reducing excessive inventory, tackling demand uncertainty, providing increased flexibility, etc. (Horvath, 2001; Lee, Padmanabhan, & Whang, 2004).

Vendor managed inventory is a retailer-supplier partnership, popularized by Wal-Mart and P&G in the 1980s (Waller, Johnson, & Davis, 1999). Since then, it has proved to be a successful supply chain integration and coordination practice (Danese, 2006; Pohlen & Goldsby, 2003). VMI helps retailers gain competitive advantage (Waller et al., 1999) and therefore has been gaining a lot of attention (Govindan, 2013; Marques, Thierry, Lamothe, & Gourc, 2010). Moreover, with the growing data storage and data sharing technology in today's world, VMI is increasingly being adopted by many companies (Datalliance, 2016). Unlike in a traditional inventory system where the retailer places an order and the supplier fulfills it, in VMI the supplier takes on the responsibility of managing inventory at the retailer's place by deciding how much to replenish and when to replenish the product. One of the important focus areas in this context has been that of developing optimal replenishment models in a single-supplier multiple-retailer environment. For such models, one may refer to Darwish and Odah (2010), Hariga, Gumus, Daghfous, and Goyal (2013), Hariga, Gumus, and

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Daghfous (2014), and Verma, Chakraborty, and Chatterjee (2014). A major limitation of such models is that they do not account for the retailer heterogeneity present in the real world.

This paper situates itself in a single supplier – multiple retailer VMI system with contractual storage agreements, and develops a generalized joint replenishment model with integer ratio policy structure. The same has been identified as an area for future research in a recent article by Hariga, Gumus, and Daghfous (2014). The first contribution of the paper is the development of a non-linear mixed-integer mathematical programming formulation of the generalized replenishment policy. Second, we compare the proposed model with the existing models in the literature. We show that due to the inherent assumption of homogeneity among retailers, the existing models use either a stationary nested policy structure or a periodic non-nested policy structure. As a consequence, existing models are optimal only under certain specific conditions and are sub-optimal otherwise. We establish the generalization of the proposed model both conceptually and numerically. Third, we suggest an efficient heuristic to solve the proposed non-linear mixed-integer programming model. The proposed heuristic is time-efficient as the number of steps required to reach the solution are substantially reduced. Lastly, we introduce a measure for calculating the level of retailer heterogeneity in a VMI system. This enables us to consider in our analysis all possible scenarios of retailer heterogeneity that may be observed in real life. Through numerical analyses, we examine the suitability of the various replenishment policies for the supplier and the retailer on the basis of cost and non-cost parameters. We find the proposed model to be the least sensitive towards different levels of retailer heterogeneity in a VMI system.

The paper is organized as follows: Section 2 presents the literature review. Section 3 covers the problem statement and the illustration of the proposed mathematical model. Section 4 presents the heuristic along with an illustrative example. Section 5 covers the numerical analysis and the discussion. A generalization of the proposed model is also brought out clearly in this section. Lastly, Section 6 concludes the paper.

2. Literature review

In a VMI system, the supplier decides upon the appropriate inventory level and the replenishment frequency for the product requested by the retailer. Over time, VMI has evolved into different forms. In one of the forms, the ownership of the item remains with the supplier until it is sold, and it is referred to as VMI on consignment (Valentini & Zavanella, 2003; Wang, Jiang, & Shen, 2004). In some other cases, the supplier receives the money as soon as the items are transferred to the customers (retailers), which is known as VMI (Fry, Kapuscinski, & Olsen, 2001; Lee & Chu, 2005) or VMI with no consignment. This paper considers VMI with no consignment. Irrespective of the form adopted by various companies, VMI, in general, has proven beneficial in terms of reduced inventory cost, improved customer service level, greater transparency and a lower bullwhip effect (Angulo, Nachtmann, & Waller, 2004; Cetinkaya & Lee, 2000; Reiner & Trcka, 2004; Waller et al., 1999; Yao, Evers, & Dresner, 2007). From the retailer's perspective, the benefits come from the reduced administrative cost as the retailers are no more responsible for placing the order themselves (Aichlmayr, 2000).

In the VMI literature, various issues related to a retailer-supplier relationship have been modeled. These include studies on the evaluation of the time-benefit the supplier has under VMI (Kaipia, Holmström, & Tanskanen, 2002), shipment coordination mechanisms (Cheung & Lee, 2002), inventory cost sharing (Nagarajan & Rajagopalan, 2008), shipment consolidation by the supplier (Çetinkaya, Tekin, & Lee, 2008), retail shelf allocation under VMI (Hariga & Al-Ahmari, 2013), multiple-retailer VMI systems under stochastic demand (Mateen, Chatterjee, & Mitra, 2015), etc. Apart from these issues, another area that has received researchers' attention is the development of optimal replenishment policies. Replenishment models in the context of VMI can be thought of as an extension of the joint economic lot size (JELS) model. For excellent surveys on JELS models and on lot sizing problems, one may refer to (Glock, 2012) and (Glock, Grosse, & Ries, 2014), respectively. In this paper, we restrict ourselves to the replenishment models developed under the VMI setting.

Under the single supplier – single retailer scenario, Yao et al. (2007) analyzed the inventory cost and the replenishment frequency with and without VMI. They concluded that unlike in a non-VMI setting, the optimal replenishment frequency is higher and the replenishment quantity is smaller in a VMI setting. Van der Vlist, Kuik, and Verheijen (2007) pointed out that the study by Yao et al. (2007) does not consider the shipping cost and their policy is such that the supplier carries extra inventory. They found out that adjusting for these changes results in a larger optimal replenishment quantity. In this regard, Wang, Wee, and Tsao (2010) and Huang and Ye (2010) analyzed the factors and conditions in a VMI setting that can cause the optimal replenishment quantity to decrease or increase.

Single supplier – multiple retailer settings have also received attention in the VMI literature. Viswanathan and Piplani (2001) proposed a replenishment policy under which the supplier sets up at fixed intervals/epochs and retailers are replenished at those intervals/epochs only. Woo, Hsu, and Wu (2001) developed an investment and replenishment model while considering the ordering and procurement cost of raw materials in their model. Zhang, Liang, Yu, and Yu (2007) developed a model by considering the supplier's production cycle as a constant and assuming that retailers have different replenishment cycles, i.e., they can order more than once in one production cycle of the supplier. Zavanella and Zanoni (2009) considered a similar problem under VMI on consignment.

One of the important operational considerations in a VMI scenario is the upper limit for the replenishment quantity of a product. In the absence of such a condition, the supplier has an incentive to replenish as much as possible to reduce its setup cost (and in turn its total cost). The retailer, however, has to bear extra inventory holding cost in that case, which is sub-optimal. To avoid such a situation, the supplier is penalized every time it replenishes a quantity that exceeds the upper limit.

Under a single supplier – multiple retailer setting with an upper limit contractual constraint, Darwish and Odah (2010) devised a replenishment policy such that all retailers have equal replenishment intervals (ERI). Hariga, Gumus, Daghfous, and Goyal (2013), Verma et al. (2014) and Hariga et al. (2014) generalized their model by relaxing the assumption of ERI by allowing retailers to have unequal replenishment intervals (URI). They showed that URI policies perform better than ERI policies. The proposed model as presented in the next section belongs to the category of URI policies.

As stated earlier, the URI policy developed in this paper is an integer ratio policy, unlike existing URI policies that are either stationary nested policies (Hariga et al. (2013) and Hariga et al. (2014)) or periodic non-nested policies (Verma et al. (2014)). A policy is termed stationary if each entity orders a constant amount at equal time intervals. It is termed nested when every time the supplier orders, the retailer orders too and may order at other times as well. In periodic policies, the order quantities of the supplier are not stationary, but are equally spaced in time. Integer ratio policies assume that the ratio of the replenishment cycle of a retailer and the order cycle of the supplier, or it's reciprocal, is an integer.

It may be noted here that when there are no upper limit restrictions from the retailer side, the URI class of problems reduces to a