European Journal of Operational Research 242 (2015) 402–423

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

The optimal replenishment policy for time-varying stochastic demand under vendor managed inventory

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ARTICLE INFO

Article history:
Received 22 March 2012
Accepted 24 September 2014
Available online 13 November 2014

Keywords:
Time-varying stochastic demand
Adjusted Silver–Meal (ASM) heuristic
VMI supply chain
Pharmaceutical industry
Safety stock

ABSTRACT

A Vendor Managed Inventory (VMI) partnership places the responsibility on the vendor (rather than on buyers) to schedule purchase orders for inventory replenishment in the supply chain system. In this research, the supply chain network considers the Silver–Meal heuristic with an augmentation quantity replenishment policy between both traditional and VMI systems. We consider time-varying stochastic demand in two-echelon (one vendor, multiple retailers) supply chains. This paper seeks to find the supply chain that minimizes system cost through comparing performance between traditional and VMI systems. A mathematical model is developed, and total supply chain cost is used as the measure of comparison. The models are applied in both traditional and VMI supply chains based on pharmaceutical industry data, and we focus on total cost difference compared through the use of Adjusted Silver–Meal (ASM) and Least Unit Cost heuristics. Finally, a numerical example and a sensitivity analysis are also illustrated to show the applicability of the model.

1. Introduction

The most common type of a supply chain system is a traditional model in which the downstream stage makes decisions regarding local stock levels and the risks associated with replenishment decisions (Lee & Chu, 2005). VMI is one such efficient replenishment system; it is designed to improve the profitability of the supply chain. In a VMI system, the supplier manages and monitors inventory and make purchase order decisions instead of the buyer, so it is essential for the vendor to select retailers and wholesale prices to maximize profit. Yugang, Zhaofu, Linda, Liang, and Chengbin (2013) formulated the retailer selection problem so a vendor could optimally select his retailers to form a VMI system, and Verma, Chakraborty, and Chatterjee (2014) proposed an alternative model for a single vendor/multiple retailer case under a VMI partnership. Pasandideh, Niaki, and Nia (2010) point out that in a vendor managed inventory supply chain, the supplier controls the retailer's inventory level to ensure desirable customer service levels maintained. Emigh (1999) mention that VMI can improve supply chain performance by decreasing inventory levels and increasing fill rates.

In today's world, all industries face challenges due to demand variability; these challenges may be produced internally or externally (Ramesh, 2009). Internally, demand variability can occur due to the introduction of a new product that includes similar characteristics of an existing product. Another internal way of creating demand instability could be due to poor communication between different stages of the supply chain: demand is increased upstream in the supply chain, a factor known as the bullwhip effect (Lee, Padmanabhan, & Whang, 1997). Externally, demand variability can be created by the competition, who might utilize different campaigns or sales incentives to influence their own sales. Both internal and external challenges may impact demand fluctuations and result in demand uncertainty, which is called stochastic demand. Thus, a stochastic demand case represents a more complex situation for determining the best replenishment policy.

A vendor selling a product to multiple buyers may encounter demand variability due to fluctuations in the volume of orders placed because of differences in buyer demand. This situation was analyzed by Cachon (1999), who proved that reducing demand variability at the vendor level can be achieved if the buyers are limited to order at specific intervals or if their order frequency is constant. The advantage of decreasing demand variability is identified in lower supply chain costs. Chen, Hao, Li, and Yiu (2012) studied vendors' optimal distribution policies which are affected by demand uncertainty in a two-echelon setup with single supplier and two retailers; they analyzed the effects of demand variability and transshipment on policies in a VMI environment. Wang, Makond, and Liu (2011) addressed a facility location and task allocation problem of a two-echelon supply chain against stochastic demand, which revealed that the proposed algorithm could efficiently yield nearly optimal solutions against stochastic demands. Taleizadeh, Niaki, and Wee (2013) studied a joint single vendor-buyer supply chain problem with stochastic demand and fuzzy lead-time, which minimized

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http://dx.doi.org/10.1016/j.ejor.2014.09.045
0377-2217/

the expected total cost by determining the reorder point and order quantity. Several authors discussed the benefits of VMI (Achabal, McIntyre, Smith, & Kalyanam, 2000; Borade, Govindan, & Bansod, 2013; Claassen, Van Weele, & Van Raaij, 2008; Dong & Leung, 2009; Govindan, Grigore, Devika, & Senthilkumar, 2013; Disney, Potter, & Gardner, 2003; Razmi, Rad, & Sangari, 2010; Shen, Govindan, Borade, Diabat, & Kannan, 2013; Yu & Huang, 2010) and for a more detailed study about VMI benefits, refer to Govindan (2013).

Different industries encounter different characteristics of products which imply different characteristics of the demand patterns. Fisher (1997) categorized the nature of the products in two categories, functional and innovative products, and based on this classification a matching type of supply chain is suggested. Functional products are identified as those used on a daily basis which have been on the market for a long time, products for which demand is easy to predict without significant fluctuations. Innovative products, on the other hand, are newly introduced to the market and they are characterized by highly uncertain demand. Because different industries offer different characteristics of products, they will experience different demand patterns. In the pharmaceutical industry, the development of new products takes a considerable amount of time; typically, a newly developed product reaches the maturity stage before entering the declining life pattern. This means that an innovative pharmaceutical product can be categorized as an innovative product at the beginning of its life, but can become a functional product once the product reaches a mature stage.

Fisher (1997) also identified that the innovative products should be handled with a responsive supply chain. The responsive supply chain is characterized by the ability to react quickly to market changes; however, this speed does not necessarily result in the lowest costs for the product. Combining the two product types framework described by Fisher (1997) with the existing research within lot sizing procedures, the following framework has been developed and is shown in Fig. 1.

The rationale behind placing the replenishment policies as illustrated above is that for a product with stable demand, a replenishment policy focused on deterministic demand would already give optimal results without the complexity incurred when applying a stochastic replenishment policy. However, when dealing with products of uncertain demand, utilizing a replenishment policy which integrates the demand uncertainty is essential. Therefore, the stochastic replenishment policy is identified to be relevant for the innovative category of products. Consequently, identifying a replenishment policy capable of acknowledging future demand changes would bring important benefits to a supply chain. A replenishment policy, also known as lot sizing in the literature, refers to the method through which the replenishment lot size to be ordered in one period of time is determined by considering the tradeoff between inventory holding costs versus costs of transportation and set-up. Using the most relevant replenishment method that fits the characteristics of the supply chain can result in important cost savings for the organization (Silver, Pyke, & Rein, 1998). Baboli, Fondrevelle, Tavakkoli-Moghaddam, and Mehrabi (2011) studied pharmaceutical supply chain using two models: centralized and decentralized models. These models consider the multiple products based on joint optimization under stable demand. Also, the authors applied their models to a specific family of products with a numerical example taken from a real-case study.

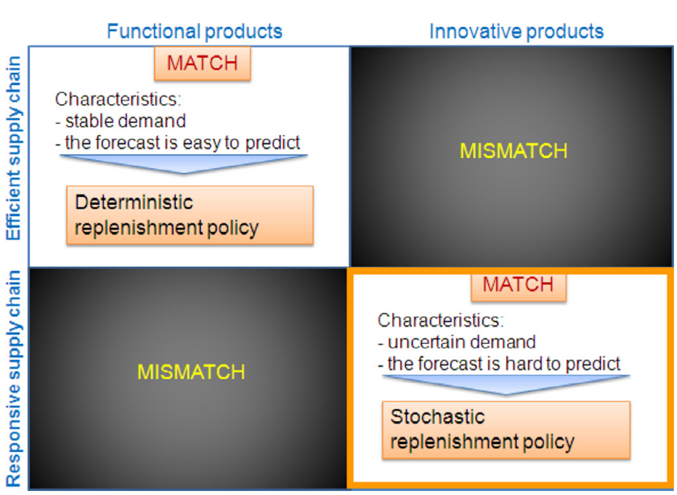

Fig. 1. Fisher's framework adjusted to evaluate the matching replenishment policy type.

Some research papers deal with lot-sizing algorithms and their adjustments including safety stock (Absi & Kedad-Sidhoum, 2009; Aloulou, Dolgui, & Kovalyov, 2014; De Bodt, Van Wassenhove, & Gelders, 1982; De Bodt & Van Wassenhove, 1983; Dolgui & Prodhon, 2007; Pochet & Wolsey, 2006; Van Kampen, Van Donk, & van der Zee, 2010). Kleywegt et al. explore VMI in a stochastic environment (Kleywegt, Nori, & Savelsbergh, 2002 , 2004; Yao & Dresner, 2008). No papers, however, have analyzed the stochastic demand with low and high variability under VMI systems using heuristics-based safety stock. In summary, this paper analyzes stochastic demand, including both low and high variability, in traditional and in VMI supply chain systems. We use two different replenishment quantity methods: first, Adjusted Silver–Meal (ASM) heuristics with augmentation quantity to deal with demand variability, and second, a Silver–Meal heuristic method with safety stocks.

This paper is organized as follows. Section 2 reviews the literature and research highlights, and Section 3 describes the problem and develops the mathematical model for the two methods, including the Silver–Meal heuristic with augmentation quantity and the Silver–Meal heuristic with SS. Section 4 applies the framework for numerical examples based on data from the pharmaceutical sector. In this section, the Adjusted Silver–Meal heuristic and the Least unit cost heuristic are compared. In Section 5, a sensitivity analysis is performed for the key parameters. The results of the application are summarized and discussed in Section 6, with a clear focus of identifying the method to determine the lowest supply chain costs. The final section, Section 7, provides our conclusions and recommends ways to further the scope of this research.

2. Literature review

In a traditional supply chain, buyers place orders to meet their requirements and decide upon replenishment quantities and timings. Conversely, in a VMI system, suppliers monitor the retailers' inventory levels and make replenishment decisions. According to the characteristics of the two systems, we provide the following review articles that relate to the augmentation and safety stock principles under a time-varying stochastic demand replenishment policy.

Ribeiro and Lourenço (2003) analyzed the inventory routing problem under customer managed inventory (CMI) and VMI case under period review to determine the route and quantities delivered at the random demand points, minimizing total cost. The heuristic algorithm is used as a solution method because of its good level of performance in term of solution quality and convergence. Guimarães, de Carvalho, and Maia (2013) presented a VMI case from the perspective of a downstream member, exploring dimensions of VMI benefits, risks, barriers, and enablers through periodic review and weekly basis replenishments. Yu, Zeng, and Zhao (2009) identified the conditions under which the VMI model is favorable over the traditional chain structure; it requires the downstream buyer to share profit with the upstream supplier to cover the supplier's initial loss in order to exploit and sustain the benefits of the VMI. The performance of VMI, compared to the traditional system, is also studied in several papers. Fry, Kapuscinski, and Olsen (2001) mentioned VMI as a way to outsource activities by