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Optimizing multi-echelon inventory with three types of demand in supply chain

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ABSTRACT

This paper proposes multi-echelon inventory models with three types of demand. The stakeholders consist of a retailer, a plant and a number of middlemen. Because the modes of demand for stakeholders are different, the stakeholders have different inventory modes. Based on these different inventory modes, three models and the procedures to solve these models are developed. In computational experiments, the applicability of the proposed models and procedures is verified. Management insights are summarized through analyzing the composition of average total inventory cost. Finally, the relationship between the parameters and the optimal solutions is investigated by two sensitivity analyses.

1. Introduction

In order to ensure the normal operation, enterprises often keep some inventory. Excessive inventory takes up a lot of money and has a negative impact on cash flow. Insufficient inventory may cause shortages and result in the interruption of production or the loss of sales opportunities. Therefore, enterprises should not only prevent insufficient inventory but also excessive inventory. In other words, the level of inventory should be optimized (Cobb, 2016). The goal of inventory optimization is mainly to determine the reasonable inventory level or the quantity of replenishment to minimize the average cost per unit time (Escalona et al., 2015). Scientific inventory control is an important way to improve the profits of enterprises.

With the emergence of supply chain, the competition between enterprises has shifted into the competition between supply chains (Stock et al., 1998). Enterprises have realized cooperation and coordination should be strengthened in order to survive and develop in the competitive market, especially in the field of inventory control (Jaber et al., 2010; Zhao et al., 2016). There are two kinds of strategies for multi-echelon inventory control, that is, decentralized policy and centralized policy (Viswanathan, 1998). Though decentralized policy is simply in management, it can not realize the multi-echelon inventory optimization for supply chain because each enterprise/echelon adopts its own inventory policy. For the centralized policy, the inventory situation and the relationship of each enterprise/echelon are considered. Thus, the multi-echelon inventory in supply chain is optimized through the cooperation and coordination of each enterprise/echelon. In this paper, centralized policy is adopted to reduce more cost.

According to Hines (2014), most products in the market are demand-driven. Therefore, it is of great significance to study the inventory problem of products with different types of demand. Classical inventory model assumes the demand is constant or stochastic (Zolfagharinia et al., 2014), that is to say, the demand has nothing to do with the time. Nevertheless, the demand of different products is complex since the demand will change over time, such as linear demand (Donaldson, 1977), exponential demand (Hollter

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and Mak, 1983), and quadric demand (Khanra and Chaudhuri, 2003). The common point of these products is that the maturity is short or absent. However, the maturity of some products is long and can not be ignored. For example, life cycles of seasonal and fashion products are ramp-type (Hill, 1995). Substitutes for the origin products which are in maturity are reverse ramp-type demand. Electronic products and drugs such as mobile phone and vaccine are trapezoidal-type demand (Cheng and Wang, 2009). In this paper, the inventory problem of products with maturity is studied.

According to the theory of product life cycle, most products will experience three phases: growth stage, maturity stage, and decline stage. Because the original products are in maturity stage and people have enough understanding of these products, the growth stage of substitutes for original products is very short or absent. For these substitutes, there may be only maturity stage and decline stage. Thus, the demand type of these substitutes is reverse ramp-type. It is very important to study the inventory problem of reverse ramp-type demand products since this type of demand is neglected by researchers. In fact, substitutes with reverse ramp-type demand include many kinds of commodities which composed of expensive consumer durables and cheap consumer goods. Substitutes share the similar function as the original products. They are only slightly different in performances and different in brands. For the first case, manufacturers upgrade their original products and launch new substitutes, e.g. iPhone series of Apple Corp, automobile series of General Motors, refrigerator series of Siemens. For the second case, new manufacturers launch different brands of low-priced goods, such as different brands of toys, clothing, toothbrushes, roll-papers, cups, etc. Therefore, it is vital to study the inventory problem with reverse ramp-type demand.

In summary, this paper develops three inventory models with partial backlogging on the basis of centralized policy to determine the replenishment policy and cycle. Three inventory models deal with ramp-type demand, reverse ramp-type demand, and trapezoidal-type demand, respectively. Furthermore, the objective of three models is to minimize the average total inventory cost, which is the sum of holding cost of each echelon, ordering cost of each echelon, shortage cost, and lost sale cost. The models proposed in this paper are reasonable and build the foundation for future research.

The rest of this paper is organized as follows. Section 2 presents the literature review. In Section 3 gives the notation and assumptions used in this paper. The three models with three types of demand on the basis of centralized policy are formulated in Sections 4. Section 5 presents computational experiments. Finally, the conclusions and future research are provided in Section 6.

2. Literature review

In this section, the relevant literature is briefly reviewed. Literature is classified into three categories: inventory problem with ramp-type demand, inventory problem with trapezoidal-type demand, and optimization of multi-echelon inventory.

2.1. Inventory problem with ramp-type demand

Hill (1995) observed the demand of fashion and seasonal products gradually increased with the understanding of the customers. When the customers' understanding of products is relatively stable, the demand will eventually remain unchanged. He calls this time-varying demand as ramp-type demand. Subsequently, many researchers focus on this type of demand. Manna and Chaudhuri (2006) extended economic order quantity model with ramp-type demand through considering some factors such as production cost, shortage and deterioration. Panda et al. published three articles on ramp-type demand from 2008 to 2009a,b. In 2008, they discussed optimal inventory replenishment policy of seasonal and perishable products. In 2009, they put forward a single cycle inventory model with shortage and partial backlogging. This model assumes the increasing stage of ramp-type demand is quadratic. Then, they extended inventory model with ramp-type demand to production inventory through considering setup cost and optimizing production stopping time. Skouri et al. (2009) studied inventory problem of deteriorating items with ramp-type demand and Weibull distribution. Saha and Basu (2010) proposed an inventory model with ramp-type demand, which is affected by time and price. Panda et al. (2013) established an inventory pricing model to maximizing the average total profit. In this model, ramp-type demand is related to price. Agrawal et al. (2013) considered an inventory model with ramp-type demand and partially backlogged shortages for a two warehouse system. Pal et al. (2015) developed a production inventory model using fuzzy theory. The effects of production cost, shortage, inflation, and deterioration on the optimal inventory replenishment policy are discussed. Kumar and Rajput (2016) put forward and solve a general inventory model for perishable items with ramp-type demand and stock dependent consumption rate. The above researchers study the inventory problem with ramp-type demand under different scenarios. However, more complex demand such as trapezoidal-type demand is not involved.

2.2. Inventory problem with trapezoidal-type demand

Singh et al. (2010) developed an economic order quantity model with trapezoidal-type demand and partial backlogging under trade credit policy. Based on the research of Cheng and Wang (2009), Cheng et al. (2011) discussed the optimal inventory replenishment policy by assuming out of stock, partial backlogging, and trapezoidal demand in general form. Uthayakumar and Rameswari (2012) extended the inventory model with trapezoidal demand to production inventory. Lin (2013) developed a more general model with trapezoidal demand and pointed out some errors in the paper of Cheng et al. (2011). Lin et al. (2014) also found some questions in the paper of Cheng et al. (2011) and provided an enhancement. Debata et al. (2015) assumed the increasing and decreasing stage in trapezoidal demand is quadratic and put forward a deteriorating item inventory model with shortage and partial backlogging. Sadeghi and Niaki (2015) presented a bi-objective vendor managed inventory model with trapezoidal fuzzy demand and solved it using non-dominated ranking genetic algorithms. Wu et al. (2016) extended previous studies and proposed an inventory model with