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Study on the inventory control of deteriorating items under VMI model based on bi-level programming

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ABSTRACT

We studied the inventory control of deteriorating items for suppliers under VMI model. The cost structure and the optional strategies for this model were first discussed. Bi-level programming models of integrated delivery strategies were established. We introduced the genetic algorithm to solve the problem. Finally the merit and demerit of each model and the adaptability were analyzed.

1. Introduction

Deteriorating items exist in abundance in the real life, while there has been no common definition of deteriorating items in the academic circle until now. In 1993, Wee (1993) proposed that deteriorating items generally referred to the items that were prone to decay, damage, evaporate, expire, invalidate and depreciate, etc. over time. Therefore, according to this definition, meat products, vegetables, fruits, medicines, flowers, film, computer chips, cell phones, fashion clothing and seasonal merchandise are all deteriorating items. The inventory problem of deteriorating items was first researched by Whitin (1957) who studied the outdated problem of fashion goods at the end of inventory cycle in 1957. Afterwards Ghare and Schrader (1963) found that the inventory consumption of deteriorating items was related with the negative exponential function of time, and on that basis, proposed inventory model for deteriorating items:

$$\frac{dI(t)}{dt} + \theta I(t) = -f(t)$$

In which, θ means deterioration rate of deteriorating items, $I(t)$ means inventory levels at time t, $f(t)$ means demand at time t. This inventory model laid a foundation for the follow-up studies on inventory of deteriorating items and the corresponding models. Then more and more researchers began to make research in this area. Raafat (1991) and Goyal and Giri (2001) made comprehensive literature reviews on deteriorating inventory items in 1991 and 2001, respectively, which introduced the trends in the deteriorating items inventory problem study at that time.

Acting as the driving force of the whole inventory system, demand is a key factor that should be taken into consideration in an inventory study. There are mainly two categories demands in the present studies, one is deterministic demand and the other is stochastic demand. Constant demand (Benkherouf, Boumenir, & Aggoun, 2003; Chung & Lin, 2001), time-dependent demand (Giri, Chakrabarty, & Chaudhuri, 2000; Teng, Chang, Dye, & Hung, 2002), inventory level-dependent demand (Chung, Chu, & Lan, 2000; Giri & Chaudhuri, 1998) and price-dependent demand (Wee & Law, 1999) are all deterministic demand. Stochastic demand includes two types of demands: the first type characterized by a known demand distribution and on the contrary the second type characterized by arbitrary demand distribution. Deteriorating rate is another key factor in the study of deteriorating items inventory, which describes the deterioration nature of the items. When it comes to the study of deteriorating rate, there are several situations. In the early stage of the study, most of the deteriorating rate in the models are constant, such as Ghare and Schrader (1963), Shah and Jaiswal (1977), Aggarwal (1978), Padmanabhana and Vratb (1995), and Bhunia and Maiti (1999). In recent research, more and more studies have begun to consider the relationship between time and deteriorating rate. In this situation there are several scenarios; including deteriorating rate is a linear increasing function of time (Bhunia & Maiti, 1998), deteriorating rate is two-parameter Weibull distributed (Mahapatra, 2005; Wee, 1999), deteriorating rate is three-parameter Weibull distributed (Chakrabarty, Giri, & Chaudhuri, 1998), and deteriorating rate is other function of time (Abad, 2001).

With the integration of the global economy, there is more and more diversity and uncertainty in the market. In order to deal with the uncertainties in the market and respond quickly to the diverse and personal demand of customer, enterprises need to cooperate with each other in the form of an integrated supply chain. The traditional inventory theory can not adapt to the current situation any more, the inventory problem should be considered in the supply chain. The high deterioration and depreciation rates of the

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deteriorating items makes it is important for the relative firms in the supply chain to make the optimal inventory policy together to minimize the total inventory cost across the supply chain. Therefore, establishing a reasonable inventory strategy has become important research content of supply chain management.

VMI, as an inventory management model of supply chain, has been improved gradually in theory and practice. The inventory control problem for suppliers and retailers under VMI model has aroused much concern of the researchers. Kwak, Choi, Kim, and Kwon (2009) studied the inventory replenishment problem in a VMI system composed of a supplier and a retailer under the case of uncertain demand. Arora, Chan, and Tiwari (2010) studied the integration of inventory and logistics under VMI model and put forward four delivery strategies. The following are the four delivery strategies: suppliers deliver goods to all the retailers; suppliers only deliver goods to some retailers whose demand exceeds a certain level; suppliers deliver goods to all the retailers only when the accumulated demand of all retailers reaches the agreed level; suppliers only deliver goods to some retailers whose demand exceeds a specific level when the accumulated demand of all retailers reaches the agreed level, which is the combination of strategy 2 and strategy 3. In their study, they constructed a three-level supply chain composed of a manufacturer, four suppliers and some retailers located in different regions. Assuming that the demand of the end customers is random, and the four suppliers adopt four different delivering strategies, then the indexes of the total cost and customer service are used to evaluate the four strategies.

The uniqueness of VMI lies that, under VMI model, suppliers, as the upstream enterprises of the supply chain, will no longer deliver goods passively in accordance with the needs of downstream enterprises (retailers) but gather the scattered and small demand of downstream businesses into proper batch and then organize the unified delivery according to the whole demand of downstream businesses and certain rules. This delivering method can not only meet the needs of downstream businesses but also make their own inventory control policy more reasonable so as to reduce the cost of suppliers and retailers on the supply chain. Therefore we can say that, under VMI model, the inventory control problem of suppliers consists of two aspects: first, what kind of rules and what extend of integration should be adopted to integrate the needs of downstream businesses before unified delivery; second, how to establish their own inventory policy based on the delivery to downstream enterprises, namely, when and how much stocks should be replenished, in which the two issues are closely related.

Cetinkaya and Lee (2000) made a representative study about the inventory control problems of suppliers under VMI environment. In their study, the VMI system is a three-level supply chain including manufacturers M, vendors V and retailers R located in different regions. The demand of many retailers in different regions is a discrete random variable, independent and identically distributed, which has the same minimal unit of measurement. Before delivering to retailers, suppliers can integrate the demand into a larger batch as long as suppliers are willing to pay a certain waiting cost to retailers. Suppliers will no longer deliver goods passively in accordance with the needs of downstream retailers but accumulate the demand to a certain degree and then organize delivery so as to meet the needs in the accumulation period according to scheduled delivery policy. In this case, suppliers can not only gain transportation economies of scale but also establish their own inventory replenishment policy accordingly. The task of manufacturers is to provide flowed products on the supply chain. When the inventory level of suppliers is below a predetermined level, the suppliers will send out purchase orders to manufacturers to replenish stocks.

Liu and Yuan (2003) extended this issue and studied three typical inventory control models of suppliers under VMI environment. The three models include time-based integrated delivery strategy, quantity-based integrated delivery strategy, and mixed delivery strategy based on time and quantity. This research was a typical study of inventory control problem of suppliers under VMI model, but the deterioration characteristic of products was not considered. Du (2007) focused on the inventory control model of suppliers under mixed delivery strategy based on time and quantity with considering the deterioration characteristic of products.

Bi-level programming is the study of planning and management (control) problems of the two-level system, which can realize global optimum very well and achieve maximal overall interests. Mathematical models of bi-level programming were appeared in an article of Bracken and McGill (1973). The bi-level programming term was appeared formally in the scientific report of Candler and Norton (1977). Since 1980s, the bi-level programming has attracted much attention and now has developed into a new branch of operational research. This new filed of the mathematical programming research has increasingly attracted people's attention in the past two decades because of its solid economic background and rich mathematical connotation. It has been applied well in the transportation field, now bi-level programming is used to describe the urban transportation network design problem (NDP) in lots of literatures. For example, Chen, Kim, Lee, and Kim (2010) established bi-level programming model to solve NDP; Xu, Wei, and Hu (2009) discussed how to solve the problem of continuous NDP. In addition, economic management is also an important filed to apply bi-level programming. In this paper, bi-level programming was introduced to inventory control problem.

In general, at present there is not much research on the inventory control problem of suppliers under VMI model meanwhile considering deterioration characteristic of the products and stochastic demand at the same time. Having adopted a different perspective from the past in this paper, the bi-level programming models of the time-based and the quantity-based integrated delivery strategies were established respectively. The genetic algorithm was designed to solve the models, and the validity of the models and the algorithm was verified by examples. It is expected to obtain instructive conclusions.

The following sections of this paper are arranged as follows: the second part describes inventory control problems under VMI model; the third part establishes two inventory control models respectively; the fourth part explains the methods and steps of genetic algorithm solving this problem; the fifth part is the empirical analysis; the sixth part is the concluding remarks.

2. Inventory control problem of deteriorating items for suppliers under VMI model

2.1. Description of the problem

The model established in this paper is the transformation of the system constructed by Cetinkaya and Lee (2000); Fig. 2.1 is a typical VMI system to study inventory control problems of suppliers under VMI model.

The system includes a manufacturer M, a vendor V and many retailers R located in different regions, in which vendors and retailers adopt operation model of vendor managed inventory (VMI), and the main function of manufacturer is to provide products for suppliers.

2.2. Two kinds of typical integrated delivery strategies based on VMI

When suppliers under VMI model make decisions on the inventory control problem, a certain decision should be first made on