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A vendor managed inventory supply chain with deteriorating raw materials and products

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ABSTRACT

Fast deteriorating raw materials such as raw milk, fruit and vegetables are commonly used to produce slowly deteriorating finished products such as milk powders, cheeses, and pastas. This paper studies a Vendor Managed Inventory (VMI) type supply chain where the manufacturing vendor decides how to manage the system-wide inventories of its fast deteriorating raw material and its slowly deteriorating product. The decision variables are a common replenishment cycle of the product and the replenishment frequency of the raw material. We assume the deteriorating rates are known constants and every retailer's demand is deterministic. We develop an integrated model to calculate the total inventory and deterioration cost for such a system. We prove the convexity of the cost functions, and based on this a golden search algorithm is developed to find the optimal solution of the model. Our numerical results show that the deteriorating rate of the product may increase the total cost by more than 40% compared to the zero-deteriorating rate, while the deteriorating raw material has less impact on the total cost (commonly less than 5% in our numerical examples). This indicates that more attention should be paid to the product than the raw material. Further, an increase in the number of retailers can make the replenishment frequency of the raw material increase significantly but the common replenishment cycle of the product decreases a little. This indicates that adding a new retailer would not be felt strongly by the other retailers but would be felt by the supplier of the raw material.

1. Introduction

A long evolution of supply chain cooperation led to the emergence of Vendor Managed Inventory (VMI) type supply chains in the 1980s. A VMI system suggests that the vendor manages the inventories of its own and its multiple downstream retailers. The inventory management of one vendor and "m" retailers is centralized to reduce total supply chain inventory costs. In practice, VMI partnerships have increased inventory turnovers of Wal-Mart and Procter & Gamble (P&G) by 30% (Buzzell and Ortmeyer, 1995), and have contributed to Barilla gaining a competitive edge as the largest pasta vendor in the world, with 35% of the pasta sold in Italy and 22% of the pasta sold in Europe (Hammond, 2003).

Food vendors, such as Barilla from Italy, Kraft Foods from the United States, and McCain Foods from Canada, constantly deal with deteriorating items. One of the greatest advantages of implementing VMI is to provide their retailers and their end customers with foods (like cheeses and pastas) as fresh as possible. For example, by adopting VMI, Barilla uses a common replenishment cycle policy to replenish its retailers. This policy suggests that:

(1) Every retailer is replenished once in a common replenishment cycle. For example, the cycle is 3 days for three retailers, and each retailer can be replenished on one of these 3 days (see also Yu et al., 2009a, 2009b; Zhang et al., 2007).
(2) Every retailer's inventory is replenished immediately after its product is produced by the manufacturer to the amount meeting the requirement of the retailer in the common replenishment cycle. The redundant stock of deteriorating foods is then prevented.

Moreover, the raw materials such as raw milk and strawberries of these manufacturers (vendors) deteriorate quickly and have also to be replenished to the manufacturer in a high frequency from agricultural producers. To reduce deterioration,

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the raw materials are commonly replenished several times in every common replenishment cycle of the finished product.

Therefore, many food manufacturers as the vendors in VMI systems face the following critical question:

What is the optimal common replenishment cycle of its product and how often should the raw material be replenished in a common replenishment cycle so as to minimize the system-wide inventory and deterioration costs?

To the best of our knowledge, the above question challenging food manufacturers is still left unanswered in the literature (for the details refer to Section 2). This paper aims to answer this question by focusing on a VMI system consisting of a food manufacturer and m retailers. The manufacturer determines the common replenishment cycle of the product and the number of order times of the raw material in a common cycle to produce the product. The product is produced by the manufacturer at a fixed production rate, and is replenished to its retailers without delay in accordance with the above VMI policy. The demand of each retailer is deterministic.

The contribution of this paper is two-fold. It is one of the first to study a food-industry VMI system where a common replenishment policy is used to manage the inventories of a fast deteriorating raw material and a slow deteriorating product. An integrated model to obtain the total inventory and deterioration costs is given in a closed form. Next, we prove the convexity of the cost function in the common replenishment cycle, and develop an exact algorithm to find the optimal solution of the model in seconds. The application of the algorithm is demonstrated with numerical examples.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the research problem and lists all required notations used throughout the paper. In Section 4, we analyze the VMI system and develop an integrated VMI model considering a deteriorating product and a raw material. Section 5 develops a corresponding algorithm to find the optimal solution of the integrated model. Section 6 conducts a detailed numerical study on the application of the algorithm and analyzes the influence of deterioration rates of the product and the raw material on the total cost. Section 7 concludes the paper.

2. Literature review

This section focuses on reviewing the literature closely related to our research, including studies on inventory models for VMI systems and those for deteriorating items.

2.1. Inventory models for VMI-type supply chains

Inventory problems about VMI systems have been extensively studied for non-deteriorating products. Some earlier papers by Goyal (1977), Goyal (1988), Banerjee (1986), and Goyal (1988) propose integrated models for an inventory system in which the vendor makes all replenishment decisions for its buyers to minimize the joint inventory cost. They assume the lot-for-lot policy; the vendor replenishes its buyers with their purchase quantities of the product. Banerjee and Banerjee (1992) extend the above research to consider an EDI-based VMI system with an integer-ratio policy. In a VMI system, Woo et al. (2001) apply the integer-ratio policy into a three-level supply chain in which the replenishment cycle of the raw material is assumed to be an integer-ratio of the VMI common replenishment cycle. They take into account multiple retailers and introduce a common replenishment cycle for product replenishment between multiple retailers and the manufacturer. After this, VMI is widely studied by other researchers (De Toni and Zamolo, 2005; Disney and Towill, 2003; Dong and Xu, 2002; Rusdiansyah and Tsao, 2005; Yao et al., 2007; Yu and Huang, 2010) where vendors are often expected to synchronize their production cycles with their retailers' orders by introducing a common replenishment cycle. Most recently, Yu et al. (2009b) and Yu and Huang (2010) also study VMI systems based on a common replenishment cycle where game theories and marketing policies on products are introduced and Yu et al. (in press) combines routing with a VMI policy.

2.2. Inventory models for deteriorating items

Over the past several decades, various models for dealing with deteriorating inventory have been studied by many researchers. Misra (1975) first studies the economic production quantity (EPQ) model for deteriorating items with the varying and constant rate of deterioration. Park (1983) considers an integrated production-inventory model where deteriorating raw materials are purchased from outside suppliers to support the production of a finished product, but the product is not subject to deterioration. Raafat et al. (1991) extend Park's model to allow the finished product also to deteriorate at a constant rate. The models in these papers consider only the manufacturer, instead of a supply chain with at least one manufacturer and one retailer. For this line of research, a comprehensive literature survey up to 2001 is given by Goyal and Giri (2001). Wee (1993) develops the production lot size model for deteriorating items with constant production and demand rate with partial back-ordering. Yang and Wee (2003) is the most related one to our paper, and they study a system where both the finished product and raw material are deteriorating. However, the main contribution and focus of their paper is the derivation of the total cost, while our contribution is mainly given to prove convexity properties of the total cost function and find the unique solution. Next, even for derivation of the total cost, they formulate a different system where the production cycle has to be longer than the replenishment cycle of every retailer. A common replenishment cycle is not used in their paper. Finally, for solving the model, they use a heuristic approach without proving the uniqueness of the solution, while we prove and find the unique optimal solution. Compared to our earlier published paper (Yu et al., 2011), in this study the raw material is deteriorating and its fast deterioration has to be coordinated with the VMI common replenishment cycle—a deteriorating raw material is not considered in Yu et al. (2011). Moreover, Yu et al. (2011) focus on the study of the impact of pricing on the VMI system, and propose a metaheuristic for solving their complex model. However, this study focuses on a cost-based VMI system and proposes an exact analytical methodology of solution. More related research may be found in several review papers (e.g. He et al., 2010; Jong and Wee, 2008). Our difference from these papers will be summarized in Section 2.3.

2.3. Result of literature review

The combination of the two respective research streams in Sections 2.1 and 2.2 is scarce and this paper aims to fill the gap. Compared with the first research stream including Yu et al. (2009b, in press) and Yu and Huang (2010), the product and raw material in this study are deteriorating items but are non-deteriorating in these literatures. This makes the derivation of the total costs different by introducing differential equations, and then requires a different solution method to solve a different model.

Compared to the research in Section 2.2, this paper considers a VMI system with the common replenishment cycle policy, which is basically missing in the previous literature. Considering the common replenishment cycle in this paper, the retailers' order