Optimizing pricing, replenishment and rework decision for imperfect and deteriorating items in a manufacturer-retailer channel

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ABSTRACT

In an imperfect manufacturing system, the production cost, inventory holding cost, and the performance of the supply chain are usually affected by imperfect items. Many studies focus on developing inspection and rework models for an imperfect manufacturing system, but few develop models for deteriorating items. The present study deals with the imperfect manufacturing system problem using the case of a two-echelon supply chain consisting of one manufacturer and one retailer. The non-cooperation and cooperation policies were used to investigate the combined effects of the pricing scheme, the replenishment program, imperfect quality, and the rework process for the deteriorating items. Several numerical studies have shown the effects of changing parameters on decision-making, and the sensitivity of profit improvement on the whole channel.

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1. Introduction

In order to maintain the competitive advantage in the market, enterprises have lavishly applied new technology and concepts to improve supply chain performance, including electronic data interchange, radio frequency identification (RFID), flexible manufacturing, automated warehousing, rapid logistics, and lean manufacturing. Nonetheless, the performance of many supply chains has never been worse. Supply chains struggle with profit-sapping problems including stock-outs and discounting. One recent study of the U.S. food industry reveals that an overreliance on price promotions and poor coordination among supply chain partners wastes $30 billion annually (Fisher, 1997, Fisher and Raman, 2010).

Most studies of traditional inventory and production problems have restrictive and unrealistic assumptions, i.e., 100% of produced items are perfect quality. In practice, manufacturing firms often produce defective items due to imperfect quality in the production process and pass them on to customers. Customers then return the imperfect items for exchange or refund. Stock et al. (2002), Blackburn et al. (2004), Krikke et al. (2004), and David (2012) revealed that the annual value of product returns is estimated at $100 billion, and commercial returns in online retailing and e-commerce may reach 25% of sales. The average return rate in the apparel and the consumer electronics industry amounts to 19% and 8%, of which 49% and 35% are due to defects, respectively

(Greve and Davis, 2012; Yoo et al., 2012).

These defective/imperfect items influence production and inventory costs, affecting the performance of the manufacturer-retailer chain. Though this phenomenon has prompted many researchers to develop imperfect manufacturing/production models for investigating imperfect production processes and inspection and rework problems, few have investigated models involving deteriorating items. In the inventory control problem, many products suffer from deterioration, including agricultural products, volatile liquids, drugs, electronic components, high-tech products, and fashion goods. Depletion phenomena of deterioration usually include shrinkage, decay, spoilage, and obsolescence. The impact of shrinkage on the retail industry continues to be sizeable, and the problem of deterioration is both prevalent and important in the retail industry. The sale of perishable products amounts to 50% of U.S. retail grocery industry, which is equivalent to $200 billion (Ferguson and Ketzenberg, 2006). National Retail Security Survey (2015) observed that inventory shrinkage amounted to $44 billion in losses for retailers in 2014, where the inventory shrink includes shoplifting (38%), internal theft (34.5%), administrative and paperwork errors (16.5%), vendor fraud or error (6.8%) and unknown loss (6.1%). In order to reflect deterioration, the items considered in this study were assumed to have a short life-time under which both non-defective and defective items are subject to exponential decay across their entire life cycle, or an equivalent constant decay rate per unit of time.

The main achievement of this study is to extend the imperfect manufacturing problem by investigating the combined effects of pricing scheme, replenishment program, imperfect quality, and

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the rework process for deteriorating items. Previous studies have discussed the research areas of pricing schemes, lot-sizing coordination, imperfect manufacturing systems, and deteriorating item management in isolation. This study integrates these three streams of research using the case of a two-echelon supply chain consisting of one manufacturer and one retailer. In the model setting, the manufacturer produces and sells a homogeneous group of deteriorating products through one retailer exclusively to customers. The production system considered in this study is imperfect, and the imperfect products can be reworked in the production period. The market demands of the products are sensitive to the retail price, and the customers who bought the unscreened defective products can return them to the retailer.

The remainder of this study is organized as follows. The literature review is given in Section 2. In Section 3 we first outline the problem and summarize the necessary assumptions and notations, and then develop mathematical models for the non-cooperation and cooperation policies. The optimal properties of the underlying problem are also given in this section. The numerical study is conducted in Section 4. It provides the reader with a qualitative insight into the structure of the proposed models, and analyzes the sensitivity of the solutions in relation to the major parameters. Finally, conclusions are given in section 6.

2. Literature review

Many papers examine issues related to production, inventory control, and supply chain management. Below we review the literature on lot-sizing coordination, imperfect manufacturing systems, and deteriorating item management.

2.1. Lot-sizing coordination

Studies of vendor-buyer and lot-sizing coordination included Monahan (1984), Lal and Staelin (1984), Kohli and Park (1994), Oczkowski (1999), Cheung and Lee (2002), and Cárdenas-Barrón et al. (2014), who developed decision models and heuristic algorithms for determining the optimal order/production quantity, replenishment cycle, and number of shipments. These researchers found that lot-sizing integration and channel coordination practices can increase the channel wide profit or reduce the total relevant cost of the supply chain. Using a make-to-order production policy, Banerjee (2005) developed a model from the supplier's perspective to determine the sales price and lot size for obtaining a target unit gross profit. Cárdenas-Barrón (2006) further provided a detailed derivation of the equations to complete the research. In practice, the production process may shift randomly from an in-control state to an out-of-control state during a production run. Tsao et al. (2013) developed both preventive maintenance and corrective maintenance policies to determine the production run time and maintenance frequency with the aim for increasing the system reliability and minimizing the total cost. They found that the corrective maintenance cost and the defective cost have negative effects on the production run time, but positive effects on the preventive maintenance frequency. In an oligopolistic marketing environment setting, Cárdenas-Barrón and Sana (2014) developed the production inventory model by considering a promotional based demand. In order to maximize the profits of the retailer and the manufacturer, the authors used an analytical method for three centralized coordinating cases to obtain optimal production rate, production lot size, backlogging and the initiatives of sales terms. Although the aforementioned literature has made a strong contribution to our understanding of production and inventory control problems, these researchers also make the unrealistic assumption that the items are perfect in the production

period. In practice, systems that produce only perfect-quality items are largely non-existent.

2.2. Imperfect manufacturing system

Using an imperfect manufacturing system setting, Cárdenas-Barrón (2009) extended a classical inventory model with planned backorders to determine the optimal economic production quantity. The authors also established the range of real values of the optimal solution, and a closed form for the total cost of the inventory system. Their study made a contribution by involving the effect of backorders in the rework system. In order to reflect real life situations, Tsao et al. (2011) developed the production model by considering rework of defective items and trade credits. Unlike previous models, Tsao et al. calculated the interest earned based on the retail price, and illustrated the effect of interest charged, interest earned, and the impact of the percentage of defective items on both production and total cost. Pal et al. (2014) dealt with a two-echelon production model over two cycles involving single supplier and single retailer. The authors assumed that the production system is not perfect and it produces defective products at a random rate. Pal et al. (2014) considered the price dependent rate, and added one cycle period for remanufactured products sold at a discount. Defective items, as well as the learning effect, affect production and inventory costs, thereby shaping the performance of the manufacturer-retailer chain. Chen and Tsao (2014) used the Nash, Stackelberg, and cooperation games to model an imperfect production system. The major contribution of their study is to investigate the combined effects of lot-sizing integration, learning effect, and pricing scheme on an imperfect production system. They found that the cooperation game model results in a greater profit than either the Nash game or the Stackelberg game models.

2.3. Deteriorating items management

Deterioration is a fact of life in inventory items, such as volatile liquids, agricultural products, films, drugs, fashion goods, electronic components, and high-tech products. Chen and Chang (2010) developed deteriorating inventory models to investigate the combined effects of pricing scheme, joint replenishment program, and channel coordination. Both non-integrated and integrated channel policies were formulated to determine the optimal retail price and the replenishment period for exponentially deteriorating items. Chen and Chang (2010) showed that a profit sharing mechanism could create a win-win situation for self-interested channel members. Based on the economic order quantity setting, Sana (2010) developed an inventory model to explore issues of price-dependent demand, time varying deterioration rate, and partial backlogging. The major contribution of Sana (2010) is to generalize a shortage allowed inventory model for a more realistic demand function and illustrate the effect of partial backlogging. Khanra et al. (2011) developed an EOQ model for a deteriorating item with the consideration of a time dependent demand and a permissible delay in payments. The time-quadratic demand in their study provided a general demand function to fit the realistic demand patterns. They also found that if a supplier provides customers with a certain credit period without interest during the permissible delay time period, it could attract customers to order more quantities since paying later indirectly reduces the purchase cost. Sana (2011) further extended the EOQ model for the perishable items by considering two types of price-varying demands. These two demand functions reflected the real market phenomena, and were compared to the existing literature. His study provided a method for stimulating market sales. The aforementioned literature had been summarized in Tables 1a–1c.

Previous studies have investigated the research areas of lot-