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Preservation technology investment for deteriorating inventory

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ABSTRACT

The objective of this study is to develop a deteriorating inventory policy when the retailer invests on the preservation technology to reduce the rate of product deterioration. A solution procedure is presented to determine an optimal replenishment cycle, shortage period, order quantity and preservation technology cost such that the total profit per unit time is maximized. A numerical example and sensitivity analysis are presented to illustrate the model.

1. Introduction

Deteriorating inventory had been studied in the past decades (Dave and Patel, 1981; Kang and Kim, 1983; Wee, 1997; Lodree and Uzochukwu, 2008; Bhunia et al., 2009; Chang et al., 2010), and they usually focused on: (1) constant or variable deterioration rate, (2) quantity discount and (3) supply chain coordination. However, investing on preservation technology (PT) for reducing deterioration rate has received little attention in the past years. The consideration of PT is important due to rapid social changes and the fact that PT can reduce the deterioration rate significantly. Moreover, sales, inventory and order quantities are very sensitive to the rate of deterioration, especially for fast deteriorating products (see Fig. 1). The higher rate of deterioration would result in a higher total annual relevant cost and a lower demand rate (Yang and Wee, 2006; Johnny et al., 2007). Ouyang et al. (2006) found that if the retailer can reduce effectively the deteriorating rate of item by improving the storage facility, the total annual relevant inventory cost will be reduced. Wang et al. (2007a, b) focused on deciding on resources portfolio and allocating resources to various orders in each production period. Many enterprises invest on equipments to reduce the deterioration rate and extending the product expiration date. For example, refrigeration equipments are used to reduce the deterioration rate of fruits, flowers and sea foods in the supermarket. Murr and Morris (1975) showed that a lower temperature will increase the storage life and decrease decay. Moreover, drying or vacuum technology are introduced to reduce the deterioration rate of medicine and food stuff. Zauberman et al. (1990) developed a method for color retention of Litchi fruits with SO_2 fumigation. The tradeoff between the increased cost of investment and the increased profit due to decreased deterioration rate is the focus of our study.

Deteriorating inventory was originally studied by Ghare and Schrader (1963). Products are assumed to deteriorate with time resulting in a decreasing utility or price from the original one. Some of the examples are fresh seafood, battery, volatile chemicals and semiconductor chips. Nye et al. (2001) developed a model to predict optimal production batch sizes and investments in setup reduction. Lee (2004) developed a cost/benefit model to support investment strategies on inventory and preventive maintenance in an imperfect production system. Lin and Hou (2005) considered an inventory system with random yield in which both the setup cost and yield variability can be reduced through capital investment. Jie Li et al. (2008) constructed and analyzed a return-on-investment maximization model for inventory and capital investment in setup and quality operations under an investment budget constraint. Hsu et al. (2007) addressed a deteriorating inventory replenishment model with expiration date and uncertain lead time. Their model developed a strategy to reduce the supplier's lead time by investing in the supplier's managing cost.

Affisco et al. (2002) showed that improving deterioration is not necessarily a linear function of investment cost. They investigated the potential impact of investments in quality improvement and setup cost reduction. Uçkun et al. (2008) derived the optimal investment levels that maximized profit by decreasing inventory inaccuracy. Lee (2008) developed cost/benefit models for investments in quality improvements to measure the impact of quality programs and to predict the return of investment in these

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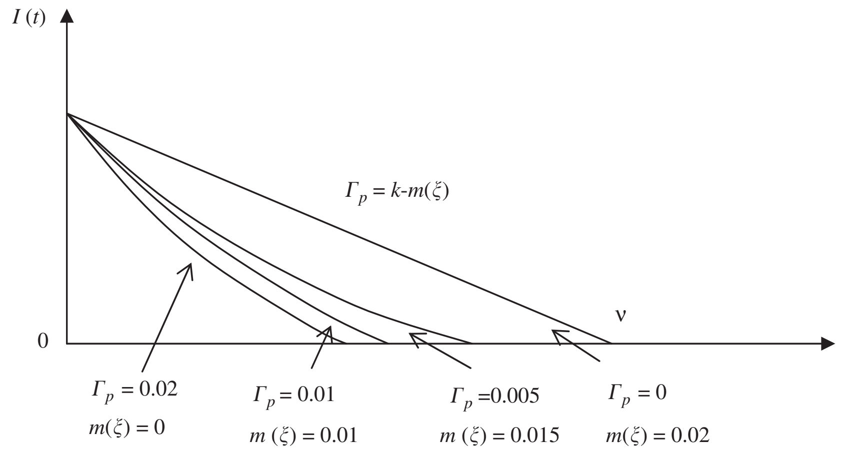

Fig. 1. Inventory system for various reduced deterioration rate $m(\xi)$. (k=0.02 is the original deterioration rate).

programs in a multi-level assembly system. Chung and Wee (2008) considered the green-component life-cycle value on design and reverse manufacturing in semi-closed supply chain. Other researchers such as Padmanabhan and Vrat (1990); Moon (1994); Hong and Hayya (1995); Banerjee et al. (1996); Yang and Wee (2001); Kogan and Spiegel (2006); Liu and Çetinkaya (2007); Gurnani et al. (2007); Wang et al. (2007a, b); Honggeng Zhou et al. (2009); Mathur and Shah (2008); Jaber and El Saadany (in press) considered investment constraint issue.

In this study, a solution procedure is developed to determine the retailer's replenishment and preservation technology investment policy for deteriorating items with a constant rate of deterioration and demand. The original deterioration rate is assumed to be k. A reduced deterioration rate of $m(\xi)$ is assumed when the retailer's investment cost on preservation equipments or technology is ξ. That means that the resultant deterioration rate of the product, Γ_p is $k-m(\xi)$ when the PT cost is ξ. When shortages occur, some of the customers will wait for the next replenishment, while others will seek alternative supply.

2. Assumptions and notation

The following notation is used throughout this paper.

T	Constant prescribed scheduling period or cycle length (time unit); a discrete variable
v	A critical time at which inventory level reaches zero; $0 < v \le T$
ξ	Preservation technology (PT) cost for reducing deterioration rate in order to preserve the products, $\xi \ge 0$
$m(\xi)$	Reduced deterioration rate, a function of ξ
d	Constant demand rate
k	Original deterioration rate of on-hand-stock, $k > 0$
Γ_p	Resultant deterioration rate, $k-m(\xi)$
h	Unit inventory holding cost per unit time
p	Sales price
c	Purchasing cost per unit
c_o	Ordering cost per replenishment cycle
r	Penalty cost per unit of a lost sale including loss of profit
$\theta(\eta)$	Probability that customers are willing to purchase the item under the condition that they receive their order after η units of time
$I(t)$	Inventory level during the scheduling period
W	Maximum capital constraint
Q_1	Sales amount without backordering over the replenishment cycle
Q_2	Back-ordered quantity at the end of replenishment cycle
Q	Order quantity
$F(T, v, \xi)$	Retailer's unit time profit

In developing the mathematical model, the following assumptions are made:

1. The sales price p and backorder price p_b are predetermined and set at prices such that: $P_b=\lambda p > c$, where $0<\lambda<1$.
2. Demand during the stockout period is partially lost due to impatient customers.
3. Backlogged demand is satisfied at the beginning of each replenishment period.
4. Shortage time is less than the planning interval T.
5. The proportion of customers backordered is assumed to be linearly decreasing with waiting time η and is assumed to be $\theta(\eta)=1-\eta/T, \quad 0 \le \eta < T$.
6. There is no replacement or repair of deteriorated items during a given cycle.

3. Modeling and analysis

In this section, we consider deteriorating items with the original deterioration rate k and a constant demand rate of d. Reduced deterioration rate $m(\xi)$ is assumed when the retailer invests ξ on the preservation technology cost. The purpose of this study is to maximize the unit profit by determining the replenishment cycle, the duration of the shortages, the order quantity and the preservation technology cost.

The inventory system during a given cycle is depicted in Fig. 2. Suppose the replenishment cycle is set at T. At t=0, an initial replenishment of Q is made, of which Q_2 units are delivered towards backorders. From t=0 to v time units, the inventory level decreases. At v the inventory level is zero.

Let $I(t)$ be the inventory level of the system at time t ($0 \le t \le T$), the differential equation governing the transition of the inventory system during the planning interval is

$$\frac{d}{dt}I(t)=[m(\xi)-k]I(t)-d, \tag{1}$$