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An inventory control model with consideration of remanufacturing and product life cycle

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ABSTRACT

This paper investigates inventory control policies in a manufacturing/remanufacturing system during the product life cycle, which consists of four phases: introduction, growth, maturity, and decline. Both demand rate and return rate of products are random variables with normal distribution; the mean of the distribution varies according to the time in the product life cycle. Closed-form formulas of optimal production lot size, reorder point, and safety stock in each phase of the product life cycle are derived. A numerical example is presented with sensitivity analysis. The result shows that different inventory control policies should be adopted in different phases of the product life cycle. It is also found that the optimal production lot size and reorder point are not sensitive to the phase length and the demand changing rate.

1. Introduction

For the past few decades, electronic companies have faced two major pressures: short product life cycle and environmental sustainability. First, technology advances have shortened the life cycles for many products. Product demand may increase rapidly at first and then decrease a few months later due to the emergence of new products. Inventory management under a short product life cycle is not easy. Many problems such as large safety stock, high obsolescence costs, and high forecasting errors will arise. It is necessary to consider the constantly varying demand and its uncertainty when making inventory control policy. In addition, due to the short product life cycle and the emergence of new products, an outdated product may be returned even if it is still in good condition. For example, a customer may buy a new mobile phone to replace his/her old mobile phone just because he/she likes the new one, although the old mobile phone is still in good condition.

Second, due to environmental and ecological responsibility, enterprises are trying to reuse, remanufacture, and recycle the used products in order to reduce the negative impact on environment. Companies in many countries are required to conform to the Waste of Electric and Electronic Equipment (WEEE) directives (Rahimifard and Clegg, 2007). Environmental sustainability and green supply chain management have received increasing attention since the 1990s (Seuring and Müller, 2008). Several international journals have published special issues about sustainable/green supply chain management in recent years (Piplani et al., 2007; Rahimifard and Clegg, 2007; Jayaram et al., 2007; Seuring et al., 2008; see also Srivastava, 2007; Seuring and Müller, 2008).

The pressures of a short product life cycle and environmental sustainability make remanufacturing a reasonable choice. Remanufacturing is an industrial process, whereby used/broken products are restored to useful life. Remanufacturing is also an important part of sustainable supply chain and reverse logistics. The motives for product remanufacturing include legislation, increased profitability, ethical responsibility, secured spare part supply, and brand protection. Reasons for returning used products include end-of-life returns, end-of-use returns, commercial returns, and reusable components (Östlin et al., 2008). After remanufacturing, the returned products, along with the new products, comprise the serviceable inventory and satisfy customer demand. Inventory control in such remanufacturing systems becomes complicated. In many cases, used products are assumed to be collected and remanufactured to a good-as-new state, such as car batteries, printer cartridges, one-time use cameras, and some electronic components. Customers cannot distinguish 'new' (i.e. manufactured) products from repaired products (i.e. remanufactured), or they consider these two products as interchangeable. For example, about 90% of Kodak one-time use cameras (OTUCs) are produced from recycled camera bodies, and about 90% (by weight) of a used Kodak (2005) OTUC body is directly reused in the manufacture of new cameras (Mukhopadhyay and Ma, 2009).

The purpose of this paper is to investigate the effects of the product life cycle on inventory control in a manufacturing/remanufacturing system and to determine the optimal production

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lot size, reorder point, and safety stock during each phase of the product life cycle. The product life cycle is divided into following phases: introduction (phase 1), growth (phase 2), maturity (phase 3), and decline (phases 4 and 5). Both demand rate and return rate of products are random variables with normal distribution; the mean of the distribution varies according to the time in the product life cycle. Before introducing our model, we present a brief literature review.

van der Laan et al. (1996a, 1996b) consider several inventory control strategies with remanufacturing and disposal. Product demands and returns are assumed to be independent Poisson processes; push and pull strategies are considered in the inventory model (van der Laan and Salomon, 1997; van der Laan et al., 1999a; van der Laan and Teunter, 2006) to coordinate production, remanufacturing, and disposal operations. Lead time effects are further investigated in a similar remanufacturing system to improve system performance (van der Laan et al., 1999b; Kiesmüller, 2003a, 2003b). Recently, Mukhopadhyay and Ma (2009) review joint procurement and production decisions in remanufacturing under quality and demand uncertainty. Three different cases are presented, and the optimal procurement and the production quantity for the firm are determined.

All the above articles have an assumption that the demand rate and return rate are independent. In contrast, Kiesmüller and van der Laan (2001) develop an inventory model in which the random returns depend explicitly on the demand stream. They assume a constant probability that an item is returned. Dobos (2003) considers inventory strategies for a reverse logistics system in which demand is a known continuous function in a given planning horizon and the return rate of used items is also a given function of time; there is a constant delay between these two functions. To take stochastic demand rate and return rate into consideration, most relevant articles assume that demand rate and return rate follow specific distributions with fixed parameters, which are consistent through the product life cycle. However, Östlin et al. (2009) have developed strategies to balance supply and demand for remanufactured products during the product life cycle, but they do not present a clear inventory control policy.

As previously mentioned, the product life cycle is shorter than before, especially in the electronics industry. Product demand may increase rapidly at first and then decrease a few months later. In addition, the product may be returned even if it is still in good condition. Therefore, the product life cycle influences not only long-term strategies but also operational activities. If the product life cycle is not considered in inventory control, then product shortage or overstocking is more likely to occur. Reiner et al. (2009) point out that when the life cycle structure is not considered in the demand model, forecasting errors may become uncomfortably high, leading to large safety inventories and a substantial risk of high obsolescence costs.

To our knowledge, very few articles consider product life cycle, inventory control, and remanufacturing simultaneously. Ahiska and King (2010) use a discrete-time Markov decision process to find the optimal inventory policy (i.e. the manufacturing and the remanufacturing strategy that have the smallest cost) in each life cycle stage. Unlike in our paper, the same inventory policy is adopted within a stage, because the mean demand and the mean return are both assumed to be constant within each stage. Also, the length of a stage is considered to be long enough so that the problem can be treated as a set of infinite-horizon problems. Chung and Wee (2011) also develop an integrated production inventory model with short life cycles to consider green product design and remanufacturing with re-usage concept. An optimal replenishment policy is derived. The result of the analysis shows that the re-manufacturability and the component life cycle of product design are interrelated. They have shown that new technology evolution, remanufacturing ratios, and system's holding costs are critical factors affecting decision making in a green supply chain inventory control system.

The rest of this paper is organized as follows. Section 2 presents the assumptions and notations. Section 3 explains the mathematical modeling. Section 4 provides numerical examples and sensitivity analysis. The paper concludes in Section 5.

2. Assumptions and notations

2.1. Notations

Decision variables:

y_i	number of production activities in phase i of the product life cycle
s_i	safety stock in phase i of the product life cycle

Dependent variables:

$Q_{i,j}$	production lot size in the jth production activity in phase i
$ROP_{i,j}$	inventory level of reorder point for the jth production activity in phase i
$D_{i,j}$	mean of the total demand during the lead time of the jth production activity in phase i
TC_i	sum of the fixed cost of manufacturing orders and the holding cost in phase i
$I(t)$	expected inventory level at time t

Parameters:

$\lambda(t)$	mean of the demand rate at time t
σ^2_λ	variance of the demand rate
$\gamma(t)$	mean of the return rate at time t
σ^2_γ	variance of the return rate
$Cov_{\lambda\gamma}$	covariance between the demand and return rates
$\tilde{\lambda}(t)$	mean of net demand rate at time t; $\tilde{\lambda}(t)=\lambda(t)-\gamma(t)$
T_i	length of phase i
τ	lead time for manufacturing
K	fixed cost per manufacturing order
h	holding cost of a product per unit time
a_i, b_i	constants
β	preset fill rate, referring to the fraction of product demand that is met from products in inventory, i.e., the probability of no stockout

2.2. Assumptions

The scheme of the manufacturing/remanufacturing system in this paper is illustrated in Fig. 1. The serviceable inventory stocks the manufactured and remanufactured products to satisfy the demand. There are two ways to replenish the serviceable inventory: by manufacturing new products or by remanufacturing returned products. The remanufactured products are assumed to be as good as the new ones. We also assume that both the demand and the return rate of products are random variables with normal distribution and that the mean of the distribution varies according to the time spent in the product life cycle (Fig. 2). We can see that the return rate is not independent of the demand rate. There is a time lag between the two functions, and the peak of the return rate function decreases.

The product life cycle has four phases (i.e., introduction, growth, maturity, and decline) that can be demarcated according to several factors (e.g. sales, demand, profits, and competitors).