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Analysis of a two-echelon inventory system with returns☆

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Abstract

Product take-back and recovery activities have grown in recent times as a consequence of stringent government regulations and increased customer awareness of environmental pollution. Inventory management in the context of product returns has drawn the attention of many researchers. However, the inherent complexity of the system with uncertain returns makes the analysis of the system extremely difficult. So far, the literature on this type of system is mostly limited to single echelons. The few papers available in literature on multi-echelon systems with returns base their analyses on simplified assumptions such as non-existence or non-relevance of set-up and holding costs at different levels. In this paper, we relax these assumptions and consider a two-echelon system with returns under more generalized conditions. We develop a deterministic model as well as a stochastic model under continuous review for the system, and provide numerical examples for illustration.

Keywords: Two-echelon inventory; Product recovery; Reverse logistics; Continuous review

1. Introduction

Product take-back after use for disposal or recovery is recently receiving growing attention for several reasons. First of all, government legislations in many developed countries hold organizations responsible for handling their products and packaging after being used and discarded by customers. Secondly, customers also have become more aware of the environmental pollution caused by the landfill and incineration of used products and packaging, and would like the manufacturers to take responsibility of recycling them. Customers would even prefer to buy environment-friendly products (Carter and Ellram [1] estimated the market to be over $200 billion), which would put pressure on the manufacturers to initiate returns of their used products and recover the economic value as much as possible. Adoption of environmentally friendly practices not only helps the manufacturers comply with the government regulations and customers' demand, but also enhances their corporate image. Finally, organizations are now taking a proactive approach to product recycling instead of a passive approach in the past from an economic point of view. For example, the cost of remanufacturing a product is generally much lower (40–60%) than that of manufacturing or procuring a new product [2], and a remanufactured product is considered to be "as good as new" and is sold in the primary market along with the new product at the same price and with the same warranty [3].

Inventory management in the context of product returns has drawn a lot of attention from researchers. The fact that returns are more uncertain than demands in terms of quantity, quality, and timing makes inventory control more difficult than that without returns. In an

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inventory system with returns, there are three types of inventory—returned units, recovered units and manufactured or procured units. It is difficult to ascertain the appropriate holding cost rates for returned and recovered units (Teunter et al. [4] compared the performances of different methods for setting the holding cost rates in an average cost inventory model with returns). If the holding cost rates are different for recovered and manufactured/procured units, then a stock depletion rule has to be put in place in case the recovered units and the manufactured/procured units exist simultaneously in the serviceable stock.

Literature on reparable item inventory management exists since 1960s. In these systems, return of every unit generates demand for one unit. So, there is a perfect correlation between demand and return. On the contrary, in inventory systems with returns, it is usually assumed that demand and return are mutually independent. Assumption of independence of demand and return is especially reasonable if the mean time-to-return is large compared to the time between placing orders. Examples of these systems include return of a photocopier after the expiry of the lease/rent period, which might not necessarily generate demand for a new machine. However, it may also be possible to have correlated demand and return for products with short life cycles, such as reusable containers [5] and single-use cameras [6]. Reviews of literature on inventory systems with returns are available in Fleischmann et al. [7] and Guide et al. [8]. Recent references include Teunter [9,10] for deterministic models, Mahadevan et al. [11] for a periodic review model and Fleischmann and Kuik [12] for a continuous review model.

The references cited so far consider a single location inventory system. The inherent complexity of the system makes it difficult to extend to a multi-echelon system. In a single location inventory system, customer demand occurs directly at the location where both recovered units and manufactured/procured units are stocked. But in multi-echelon systems, the higher echelons have to satisfy demand from the lower echelons, which might come in batches. This batch demand coupled with the existence of set-up costs for both recovery and manufacturing/procurement at the higher echelon complicates the system to a great extent. Literature on multi-echelon inventory systems with returns is few and far between. Those available in literature are based on simplified assumptions for tractability. Muckstadt and Isaac [13] developed a model for a one-warehouse, N-retailer distribution system with returns where the retailers did not have set-up costs and they followed an $(S-1, S)$ continuous review policy, S being the order-up-to level. Since customer demands faced by the retailers were Poisson distributed, the demand process at the warehouse could be described by compound Poisson. Moreover, the recovery process at the warehouse was described by a queuing system, which was independent of the choice of the policy parameters. Thus the set-up cost and holding cost at the level of recoverable units had no relevance in the model. The warehouse operated under an (R, Q) continuous review policy for its serviceable inventory where R was the reorder point and Q was the order quantity. Korugan and Gupta [14], for a similar distribution system, made the same assumptions about the retailers and the demand process at the warehouse. They even did not consider the set-up cost for the serviceable inventory, and developed a model based on an open queuing network with finite buffers. For a review on multi-echelon inventory research with returns, readers are referred to Fleischmann and Minner [15] and Dekker et al. [16].

The literature on multi-echelon inventory systems without returns is very rich. Efforts should be made to apply those results for systems with returns. Minner [17] extended his work on strategic safety stock placement in forward supply chains to supply chains with returns. His basic approach was based on Simpson's model [18] for a serial supply chain under a base stock policy. The variables were the service times at different locations, and the objective was to minimize the investment in safety stocks. Based on the definition of the system, set-up costs and shortage costs had no relevance in the model. The problem addressed in the current paper generalizes the description of the system for a two-echelon serial supply chain considering set-up costs and holding costs for all the inventory levels and shortage costs for the serviceable inventory levels. The item under consideration has a high demand justifying the increase in recycling activities for high-demand, low-value items in recent times compared with high-value, low-volume items in the past [19]. We develop a deterministic model and a stochastic model of the system. For the stochastic model, we assume that the system is under continuous review. Numerical examples are provided for illustration.

The motivation for the problem is derived from growing recycling of electronic products, such as television and photocopier, at the end of their useful lives. In many developing countries such as India, consumers are frequently bombarded with incentives/offers to exchange their used electronic products for new and technologically advanced models. Unlike in the developed countries, there is no separate market for remanufactured or refurbished products in developing