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Lot sizing for a recoverable product with inspection and sorting

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ABSTRACT

This paper studies an inventory system where demand is satisfied by recovered and new purchased items. Used units of a product, returned by (or collected from) customers, are kept in recoverable inventory until the start of a combined process of inspection and recovery. Recovered (remanufactured) items are assumed to be as-good-as new. However, some recovered items do not qualify to be classified as "remanufactured" and are perceived by customers to be of secondary quality. These refurbished items are sold to a secondary market at a reduced price. A simple formula that determines the optimal inventory level of recoverable (used) items is developed to be able to start the inspection and recovery processes and the economic order quantity for procurement. According to the relationships among the parameters, this paper proposes and analyzes models that describe the system of interest, which are considered extensions of the work of Koh, Hwang and Sohn [Computers and Industrial Engineering 43(1–2), 59–73, 2002].

1. Introduction

The management of forward logistics systems is concerned with the flow of raw materials, final products and related information along a supply chain; from the last tier of suppliers to the end customers. Reverse logistics (RL), and as the name indicates, is concerned with managing the backward flow, i.e., the return of used products from customers to the producers. RL includes product recovery and material recycling entities that reduce the need for virgin materials, thus conserving natural resources and subsequently reducing environmental costs.

There are four main steps in a reverse logistic process as discussed by de Brito et al. (2002) and de Brito and Dekker (2003). The first step involves the collection of units of used products from markets (customers). In the second step, the collected units are inspected and sorted according to their quality characteristics. These steps are followed by a third step of re-processing or "direct recovery" of used items. In the fourth and final step, the cycle closes with the redistribution of recovered items to markets (customers). Note that the first step could either be performed by the company itself or by a contractual logistical party (Thierry, Salomon, van Numen, & Van Wassenhove, 1995).

Product recovery may take any of the following forms: repair, refurbishing, remanufacturing, cannibalization and recycling (see Thierry et al., 1995; King, Burgess, Ijomah, & McMahon, 2006). Repair brings faulty products to working status. Refurbishing restores the quality of used products and extends their service-life. Remanufacturing reconditions a used product to as-good-as new state. Cannibalization recovers a limited set of reusable parts from a used product, while recycling extracts materials and components from used products for reuse. This paper focuses on used products that are either remanufactured or refurbished. A schematic flow that describes the reverse logistics system of interest is depicted in Fig. 1.

Used items of a certain product that are collected from a market (i.e., customers) are stocked at a warehouse for recoverable inventory. Following the collection, and at some point in time, the inspection and sorting process starts. After an item is inspected it is classified as either remanufacturable or refurbishable. Remanufacturing and refurbishing processes are performed simultaneously and in parallel to inspection and sorting. Refurbished products are kept at the recoverable inventory warehouse and are later sold as a single batch in a secondary market at a reduced price. Prior to commencing the remanufacturing process, customers' demand is satisfied from the inventory of new items, which is replenished by shipments of orders from an outside supplier.

A deterministic model dealing with this kind of an inventory problem, but excluding the inspection and sorting process, was firstly proposed by Schrady (1967). Schrady analyzed an inventory situation with constant demand and return rates when production and recovery are instantaneous. A closed form EOQ-like solution was developed. Mabini, Pintelon, and Gelders (1992) extended Schrady's work to accommodate a multi-item case. Nahmias and Rivera (1979) studied a deterministic model, similar to that of Schrady, where the recovery rate is finite. Koh, Hwang, Sohn, and

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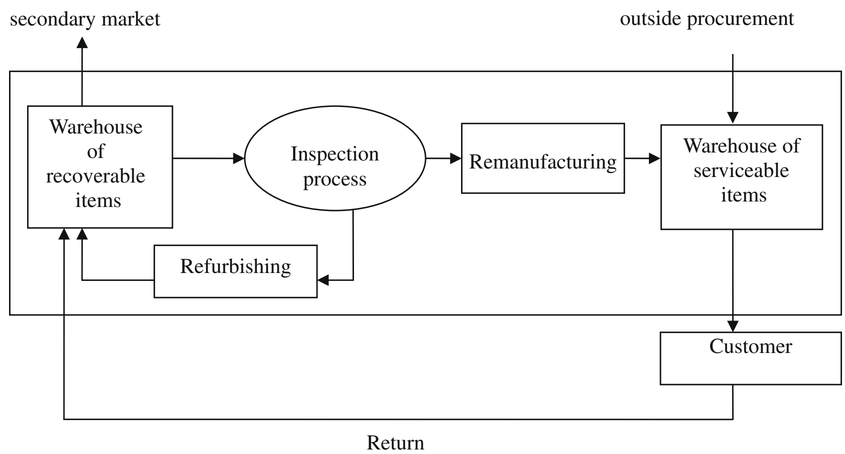

Fig. 1. Framework of the inventory system.

Ko (2002) generalized the model of Nahmias and Rivera (1979) by assuming a limited repair capacity. Following the works of Schrady (1967) and Nahmias and Rivera (1979), it was not until the mid-1990s when this research topic was revived. Richter (1996a, 1996b, 1997) and Richter and Dobos (1999) proposed an EOQ model that differs from Schrady's model, where it has a waste disposal option with the return rate of used items being a decision variable. In these works, the optimal numbers of remanufacturing and production batches in an interval of time were dependent on the return rate. Dobos and Richter (2000) investigated the characteristics of the cost function developed in a previous work (Richter & Dobos, 1999), where they showed that the cost is partly piecewise convex and partly piecewise concave function of the waste disposal rate. In a follow-up paper, Dobos and Richter (2004) presented a generalization of their earlier work (Dobos & Richter, 2000) by assuming a time interval to contain multiple repair and multiple production cycles. Dobos and Richter (2006) investigated the production–recycling model in Dobos and Richter (2004) by considering that the quality of collected used items (returns) is not always suitable for recycling. Along the same line of research, Teunter (2001) generalized Schrady's results by considering M manufacturing (production) lots of equal size and R recovery (remanufacturing) lots of equal size (in short (M, R) policy) and assuming the holding cost for recoverable items to be different from that of recovered and manufactured items.

In another work, Teunter (2004) relaxed the assumption of an instantaneous manufacturing and remanufacturing process in order to derive more general expressions for the manufacturing and remanufacturing lot sizes. Since only a heuristic proposal was introduced on how to determine the number of manufacturing and remanufacturing lots, Konstantaras and Papachristos (2008) improved Teunter's work by developing an exact solution that leads to the optimal number of manufacturing and remanufacturing lots and their corresponding lot sizes for certain parameter classes. Choi, Hwang, and Koh (2007) generalized the (M, R) policy proposed by Teunter (2001) by relaxing the assumption on the disposal of used items and treating the sequence of manufacturing and remanufacturing set ups in a cycle as a decision variable. Their sensitivity analysis showed that using the (M, R) policy, only 0.2% out of 8,100,000 tested problems have an optimal solution in which both M and $R$are greater than one. This indicates that with a maximum deviation of 0.2% from the optimal solution one may as well use (1, R) or (M, 1) policy rather than the (M, R) policy. Also, Liu, Kim, and Hwang (2009) generated and solved 60,000 problems and found that only 0.19% of them have an optimal solution in (M, R), where both M and R are greater than one. Other researchers have also developed models along the same lines as Schrady, Richter and Teunter, but with different assumptions (e.g., Minner & Lindner, 2004; Konstantaras & Papachristos, 2006; El Saadany & Jaber, 2008; El Saadany & Jaber, in press; Jaber & Rosen, 2008; Jaber & El Saadany, 2009, in press). Although inspection and sorting of returns are noted as operational activities in reverse logistics (e.g., Fleischmann, Krikke, Dekker, & Flapper, 2000), they have not been considered in any of the above studies.

The above surveyed works adopted a total cost minimization approach. Contrary to these works, this paper adopts a profit maximization approach where revenues are generated from selling new, remanufactured and refurbished products. The models considered herein are deterministic and the values of the parameters pertaining to the components of the system depicted in Fig. 1 are assumed to be known and constant. This paper extends the work of Koh et al. (2002) in two ways. First, a combined inspection and sorting process is introduced with a fixed setup cost and a unit variable cost. Second, this paper assumes that remanufactured and new purchased items are sold in a primary market, while refurbished units are sold in a secondary market (e.g., Jaber & El Saadany, 2009). In this paper, two models are developed. The first model (Model I) considers a policy of a single inspection and sorting and a single recovery (remanufacturing and refurbishing) batch, and multiple batches of new items (in short (M, 1) policy). The second model (Model II) considers a policy of multiple batches of recovery and of inspection and sorting, and a single batch of new items (in short (1, R) policy).

The remainder of this paper is organized as follows. The assumptions, notations and the description of the inventory problem considered are presented in Section 2. Sections 3 and 4 are for mathematical modeling and finding analytical solutions to Models I and II, respectively. Section 5 presents and discusses the numerical results. Finally, this paper summarizes, concludes and proposes future research extension in Section 6.

2. Description of the inventory problem

This paper studies an inventory situation that consists of a combination of inspection and sorting, recovery (remanufacturing + refurbishing), and ordering new items of a product from a supplier. The flow of used, remanufactured, refurbished and new items are depicted in Fig. 1. Used items are collected from customers and brought to a warehouse facility where inspection, sorting and refurbishing occurs. Once a returned used item is inspected, it is