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Technical Paper

Optimizing a closed-loop supply chain with manufacturing defects and quality dependent return rate

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ABSTRACT

The paper considers a closed-loop serial supply chain consisting of a raw material supplier, a manufacturer, a retailer and a collector who collects the used product from consumers. The retailer's demand is met up by both manufacturing and remanufacturing. The manufacturing process is assumed to be imperfect as it can produce some defectives which are reworked in the same cycle itself. The remanufacturing of used items solely depends on the quality level of collected items. Two mathematical models are developed. The first model considers a single manufacturing–remanufacturing cycle, while the second model considers multiple manufacturing and remanufacturing cycles. Both the models are solved using algorithms developed for sequential and global optimizations. Numerical studies show that (i) the acceptance quality level of returned items and the length of the replenishment cycle for the retailer are lower in case of sequential optimization than those in global optimization, (ii) integration among supply chain members results in less number of shipments from the manufacturer to the retailer, and (iii) the joint total profit is higher when the integrated approach is adopted. The percentage increase in joint total profit with the integrated policy is 1.24% in the first model while it is 0.544% in the second model.

1. Introduction

In recent years, remanufacturing of used items has been gaining considerable attention of both researchers and practitioners due to increased environmental concerns [1], government legislations and worldwide awareness regarding limitations of natural resources. Due to economical benefit, managers of manufacturing firms are also interested to such product recovery programs. With the advancement of technology and competitive marketing strategies employed by various companies, the average life-cycle of a daily-used item is decreasing. The demand of a specific product may decrease due to emergence of new products in the market with added features. Some products may even be outdated although those are still in good conditions. For instance, a customer may buy a new mobile phone to replace his/her old one just because (s)he likes the new one, although the old mobile phone is still in good condition. Shorter life cycle and changes in customer's consumption behavior results in faster generation of waste and depletion of natural resources. This leads to the drive in remanufacturing the used/returned items in order to extend their usable lives and thus to conserve natural resources.

The process of remanufacturing starts with the process of collecting the used items from the consumers or end users. Then sorting and cleaning take place and finally remanufacturing is done to get 'newly produced items'. Schrady [2] was one of the early researchers who made an advancement in the area of reverse logistics. He proposed a deterministic inventory model with instantaneous rates of manufacturing and remanufacturing but with no disposal. Subsequently Schrady's [2] work was extended by many authors. For example, Nahmias and Rivera [3] assumed a finite repair rate; Mabini et al. [4] considered stock out service level constraint in a multi-product model; Koh et al. [5] analyzed finite manufacturing and remanufacturing rates. Several other studies have addressed collection issues. Savaskan et al. [6] determined the optimal collection channel configuration of a monopolist manufacturer. Dobos and Richter [7] studied a production/recycling system in which the constant demand is satisfied by production and recycling with a single repair and single

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production batch in each interval. Later, they [8] generalized their earlier model [7] considering multiple repairs and production batches in a time interval. They [9] further included the quality of returned items in their model and assumed that the proportion of items returned to be reused is dependent on buyback proportion and use proportion. El-saadany and Jaber [10] extended the works of Dobos and Richter [7,8] considering that the return rate of used items is a variable quantity depending on two decision variables – acceptance quality level and purchasing price of the returned items. Mitra [11] investigated a remanufacturing system with two recovery options and claimed that quality level would draw different prices in the secondary market.

In remanufacturing, uncertainty is always associated with the amount as well as the quality of returned items. Mukhopadhyay and Ma [12] determined joint procurement and production decisions in remanufacturing under quality and demand uncertainties. Zikopoulas and Tagaras [13] studied the impact of uncertainty on the quality of returned items in a single period refurbishing operation, while Shi et al. [14] developed a multi-product closed-loop supply chain considering stochastic customer demand and return. Chung et al. [15] analyzed a closed-loop supply chain considering a single-manufacturing single-remanufacturing cycle. Yang et al. [16] extended the model of Chung et al. [15] considering multiple manufacturing and remanufacturing cycles and deterioration in inventory.

One common assumption in all these models is that the manufacturing process is perfect. In any production system, a certain amount of defectives may result due to machinery defects and other related factors. Jamal et al. [17] proposed a deterministic model with the option of reworking of defective items produced in a single-stage production system. Inderfurth et al. [18] investigated lot-sizing decisions in a hybrid production/rework system characterized by defective items.

Several researchers have considered forward-flow of materials in supply chains. In this study, we consider the forward as well as the reverse material flows. In the reverse material flow, used products obtained from consumers are supplied to a reconditioning facility where those are stored, remanufactured and then shipped for retail sale. Management of closed loop supply chains is much more complicated than the traditional forward supply chains because returns are more uncertain than demands in terms of quantity, quality as well as timing [19], and also valuation and setting inventory holding cost for returns are not straightforward [20]. Correlation between demands and returns adds another dimension of complexity. Recently, Chung et al. [15] determined the optimal policy for a closed-loop supply chain involving a supplier, a manufacturer, a retailer and a collector for deterministic demand and return rates. However, in their model, manufacturing process is assumed to be perfect. In reality, production of defective items is inevitable due to many reasons such as machinery problem, transit in production process, flaws in transportation process, etc. This paper considers a closed loop supply chain where manufacturing is assumed to be imperfect and defective items are reworked in the same manufacturing set up. Specifically, it extends Chung et al.'s [15] work in the following fronts: (i) production process is imperfect with reworking of defectives, (ii) return rate of used/returned items is dependent on acceptance quality level of the returns and (iii) there are multiple manufacturing and remanufacturing cycles.

Ours is a hybrid production system in which manufacturer satisfies retailer's demand by both manufacturing and remanufacturing processes. The amount of items returned from the consumers/users is assumed to be dependent on their acceptance quality level as prescribed by the manufacturer. Two mathematical models are developed. The first model considers a single manufacturing–remanufacturing cycle, while the second model considers multiple manufacturing and remanufacturing cycles. The proposed models can be used for products such as IC chips, mobile phones and computers which may become out of date in a span of few weeks/months due to technological innovation. Such products can be remanufactured and then resold in the market. The remainder of this paper is organized as follows. The assumptions and notations are presented in the next section. Section 3 is devoted to mathematical modeling and solution methodologies. In Section 4, numerical examples are presented. Also, sensitivity analysis is carried out with respect to some key model-parameters. Finally, the paper is concluded and future research directions are indicated in Section 5.

2. Assumptions and notations

The proposed models are developed on the basis of the following assumptions:

(i) We consider a multi-echelon closed-loop serial supply chain consisting of a supplier, a manufacturer, a retailer and a collector. The system is engaged for trading a single product.
(ii) The manufacturing process is imperfect i.e. a certain amount of items manufactured are defective which are reworked in the same cycle itself. However, production of defectives at the time of reworking and remanufacturing is assumed to be negligible. This is true especially when rework and remanufacturing are done with utmost care by experienced/qualified workers in order to ascertain the quality as good as new ones.
(iii) The remanufactured products are comparable to newly manufactured products in terms of quality, durability, service rendered to end customers.
(iv) Manufacturing and remanufacturing rates are constant and are greater than the demand rate.
(v) The product demand rate is constant but the return rate is variable and depends upon the acceptance quality level of the returned items. The return rate is less than the demand rate. The return rate is assumed to be a decreasing function of acceptance quality level which means that the flow of used/returned items decreases as the acceptance quality level increases.
(vi) There is no deterioration or shortage of items in the system.
(vii) Planning horizon is infinite.
(viii) Lead time is zero.

The following notations are used for developing the proposed models: