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Pricing decisions in a multi-criteria setting for product recovery facilities

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ABSTRACT

Unpredictability in the arrival time and quantity of discarded products at product recovery facilities (PRFs) and varying demand for recovered components contribute to the volatility in their inventory levels. Achieving profit under such capricious inventory levels and stringent environmental legislations remains a challenge to many PRFs. This paper presents a multi-criteria decision model to determine a pricing policy that can simultaneously address two issues: stabilize inventory fluctuations and boost profits. The model considers that PRFs passively accepts discarded products as well as acquires them proactively if necessary. Under a multi-criteria setting, the current work determines prices of reusable and recyclable components to maximize revenue and minimize product recovery costs. A genetic algorithm is employed to solve the multi-criteria decision making problem. Sensitivity analysis is performed to investigate the effect of sorting yield, disassembly yield, and reusable component yield on the profits, prices, inventory levels, and disposal quantities.

1. Introduction

The growing environmental awareness among consumers and the environmental hazards posed by heaps of discarded products, especially electronic products, have led to the enforcement of environmental regulations in the European Union [1], US [2–4], and many other countries across the globe. The central theme of these regulations is to require the original equipment manufacturers (OEMs) accept the end of life products to promote the environmentally benign practices such as, product reuse, recycle, and proper disposal.

Even though discarded products contain reusable and recyclable components, many OEMs hesitate to embrace product take back programs for the fear of cannibalizing the sales of their new products [5]. In addition, the labor intensity of product recovery operations and lackluster demand for reusable products discourage OEMs from entering into reuse-product markets. Encouraged by this stance from many OEMs, third party firms have started to enter the reuse-product markets. These third party firms, referred to as product recovery facilities (PRFs) thrive on the business of collecting the discarded end of life products, performing product recovery operations, and selling the recovered components as reuse or recycle items. The PRFs considered in this research predominantly operate as spare parts remanufacturers rather than as product remanufacturers.

PRFs are usually challenged from various quarters: (a) competition from OEMs and other PRFs; (b) meager revenue from sales; (c) environmental regulations; (d) fleeting and piling inventory levels of recovered components. Among all the challenges faced by PRFs, inventory control is a serious problem [6]. It is governed by the following issues: (a) holding costs of surplus inventory; (b) lost sales due to stockouts; (c) threat of quick inventory obsolescence; (d) disposal cost of leftover and obsolete inventory; and (e) promotional and clearance price discounts.

The uncertainties in timing and quantity of product disposal could contribute to either too low or too high inventory levels of recovered components. Appropriately modulating the price of the items in the inventory is an effective strategy to manage inventory under these circumstances. This strategy has a twofold impact: it facilitates inventory control and boosts the profit margin. The prices competitive with those of new products can promote the reuse and recycle of discarded products.

The present work determines the prices of reusable and recyclable components in a multi-criteria environment where

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the goal is to concurrently maximize the revenue and minimize costs. An empirical study is performed to investigate the effect of sorting yield, disassembly yield, and reusable component yield on the profits, prices, inventory levels, and disposal quantities. Although Kongar et al. [7,8] have addressed issues in a multi-criteria environment for PRFs, they have not exclusively considered pricing aspects in their study. This work is unique in the sense that it addresses pricing issues in a multi-criteria setting, when PRFs passively accept discarded products and proactively acquire as needed. This work is probably the first of its kind in the literature to look at the pricing problem from the perspective of satisfying multiple criteria. Also the current work is distinct as it adopts a multi-criteria methodology (genetic algorithms) instead of nonlinear programming, which has already been investigated by the authors [9] and other researchers [10].

1.1. Related research

Contemporary research on pricing of remanufactured products addresses issues faced by OEMs which sell remanufactured products along with their new counterparts. Setting the right price for products of both categories—which are highly interconnected—is key to their sales; price escalation of new products increases the demand for remanufactured products, but the reduction in the sales of new products eventually chokes the supply line for remanufactured products. Several scholars have addressed this issue: Majumder and Groenevelt [11] and Ferrer and Swaminathan [12] studied the impact of competition between an OEM and a local remanufacturer. Ferguson and Toktay [5] examined the effect of selling remanufactured products along with new ones on the sale volumes and profits. Vorasayan and Ryan [13] employed an open queuing network model to determine the prices of new and remanufactured products for a monopolist OEM. Ray et al. [14] analyzed the impact of offering trade-in rebates to customers. Debo et al. [15] investigated the remanufacturing technology for OEMs operating in heterogeneous markets; Debo et al. [16] studied the progressive market penetration issues of new and remanufactured products through their prices for products exhibiting well-pronounced life cycles. Malladi and Min [17] formulated the pricing problem as a mixed integer nonlinear programming model. Mitra [18] determined the optimal prices when the availability of discarded products, price, and quality affect the demand of remanufactured products. Bakal and Akcali [19] studied the effect of component yield on the sale prices of remanufactured components.

Guide et al. [10] determined the optimal product acquisition price and remanufactured product sale prices when an OEM influences the quality, quantity, and timing of product returns via quality-dependent price incentives. Mondal and Mukherjee [20], investigated the economic factors that impact the product acquisition decisions and determined the optimal time to acquire products. Savaskan et al. [21] evaluated different product acquisition configurations through the wholesale and retail prices of remanufactured products.

Very few research articles address the PRF issues in a multi-criteria environment. Kongar and Gupta [7,8] determined the quantity of returns to be acquired, using goal programming and fuzzy goal programming techniques, keeping in view the demand for their constituent components under various physical, financial, and environmental constraints. Their models simultaneously maximize the net profit and component sales and minimizing the disposed items, stored items, disposal cost, and preparation cost. Imtanavanich and Gupta [22,23], extended this work by considering stochastic yields of components during their disassembly.

The rest of the paper is laid out as follows: an analytical model for pricing in a multi-criteria setting is presented in Section 2; the genetic algorithm employed to solve the multi-criteria decision making problem is briefly discussed in Section 3; numerical study is presented in Section 4; and finally the conclusions and the plans for future research are discussed in Section 5.

2. Model formulation

In the proposed model, PRFs acquire discarded products through passive acceptance as well as proactive acquisition. This production control philosophy, a synthesis of push and pull production systems, can ensure that the demand is always satisfied without stockouts and backorders. This approach stabilizes plans for the resources required for performing product recovery operations, remanufacturing, refurbishing, and processing of recyclable components. Though the quantity of discarded products and demand for recovered components is stochastic, they are considered deterministic to keep the model simple and to make the solution feasible. The insights gained from this model can be useful to extend it to the stochastic returns and demand in future work.

It is assumed that PRFs impose no restrictions on the quantity and quality when they passively accept discarded products and that they can estimate the quantity and arrival time of discarded products through forecasting techniques [24]. Based on the these estimates, PRFs can plan ahead on the proactive acquisition of discarded products from customers, retailers, and collection agencies when the projected on-hand inventory of returns falls short of the demand for recovered components. PRFs initiate the acquisition process considering the time lags in acquiring returns and the lead times to process the recovered components in order to avoid delays in demand delivery. Obsolescence could catch up on remanufactured components if acquisition and lead times are long [6]. Although PRFs can advertise their need for discarded products, the acquisition process could be a prolonged affair, unless incentives are offered to customers. The incentive offered in effect determines the returns: the more lucrative the incentive, the more the volume of returns. Usually incentives are offered to products which meet pre-specified specifications on their configuration and age. This strategy ensures that PRFs acquire products that meet desired quality standards. The acquired products can bypass the initial sorting and inspection stage which separate the good products from the damaged ones.

In the chronicled literature, little research has been reported on the managerial decisions regarding the acquisition of discarded products. Guide et al. [10] were the first to identify and address this issue. They developed an economic model to determine the optimal cost to acquire discarded products. Unlike their work, the present work considers that the PRFs strictly abide by the disposal regulation of the local governing body when deciding on the acquisition quantity of returns, even at the cost of losing demand for recovered components.

Fig. 1 shows the proposed framework for a PRF. The passively accepted returns are first sorted and inspected to separate the good quality products from the poor quality ones which are characterized by inferior performance, blemished physical appearance, and low potential for reuse and recycle. The poor quality products are sold for recyclable material and the rest are disposed of at the end of the selling period. The good quality products and the proactively acquired products, if any, are fed to the disassembly production system to extract the constituent components. These components are segregated by skilled workers on the production line into reusable, recyclable, and disposable components. The reusable and recyclable components are categorized into four classes:

- *Reusable components*: These components are characterized by their good physical appearance and performance. They are