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A novel methodology for simultaneous consideration of remanufactured and new products in product line design

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ABSTRACT

Recovering end-of-life (EoL) products after customer use is a promising solution for manufacturers to respond to the challenges of increasing global awareness of environmental protection and enforcement of environmental regulation. This research focuses on the remanufacturing of EoL and returned products, which aims to restore them functionally and aesthetically to their original condition and even with better features. Remanufactured products are normally reprocessed from returned new products and quite often launched in the markets where new products exist. Thus, they can be considered together with new products in product line design (PLD) to acquire the maximum profit and market share of the product line. However, simultaneous consideration of remanufactured and new products in a PLD was not found in previous studies. This paper proposes a novel methodology to address the simultaneous consideration in PLD. The proposed methodology mainly involves the development of dynamic demand models, discrete choice analysis, formulation of a multiobjective optimization model, and a nondominated sorting genetic algorithm II. Based on the methodology, Pareto optimal solutions of PLD can be determined which include specifications of both remanufactured and new products, and the time of launching remanufactured products. A case study of simultaneous consideration of remanufactured and new tablet PCs in PLD was conducted to evaluate the effectiveness of the proposed methodology. Results of the case study indicated that the profit and market share of a PLD for the maximum profit scenario estimated based on the proposed methodology was better than those estimated based on the separate processes.

1. Introduction

Growing environmental concerns and strict regulations have driven companies to focus more on the eco-design of their products. Eco-design has been found effectively to enhance resource and energy efficiency in the production and usage phases, avoid the use of hazardous materials and components, minimize weight, increase product usage life, and reduce waste (Cerdan et al., 2009). Research on eco-design commonly involves studies of eco-design tools, life cycle assessment, design for X, and product end-of-life (EoL) analysis. Comprehensive review of them can be found in Chang et al. (2014), Ramani et al. (2010), Chiu and Chu (2012) and, Ilgin and Gupta (2010). On the other hand, the increasing social concerns on environmental protection and enforcement of environmental regulations of EoL products (i.e., manufacturers take full responsibility for the entire lives of their products including recycling, remanufacturing, and disposal), have also led companies to adopt several product recovery strategies in response to the challenges (Ramani et al., 2010). Various strategies, such as remanufacturing, recycling, reuse, and/or refurbishment have been incorporated in product design and/or business operations (Kumar and Putnam, 2008). Remanufacturing of EoL and returned products aims to restore them functionally and aesthetically to their original condition and even with better features. Several companies, such as Apple, Dell, Sony, and Fuji Xerox, have offered remanufactured (or named refurbished) products in markets. Offering remanufactured products not only allows companies to address the social concerns and legal regulations, but also to respond to market needs. From a business point of view, launching remanufactured products would definitely help companies to access green consumer markets and second markets (less developed regions) as well as to improve the company image in terms of social responsibility and environmental friendliness. Remanufactured products can be produced from EoL products. Apart from that, faulty produced and shipping damaged products or products that were returned within a few months because of customer dissatisfaction can also be remanufactured (Vorasayan and Ryan, 2006).

Quite a few studies have considered various recovery strategies and remanufactured products in the product design stage. Mangun

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and Thurston (2002) incorporated reuse, remanufacturing, and recycling into a product portfolio design to maximize the total portfolio utility while considering the tradeoff among cost, reliability, and environmental impact of products. Debo et al. (2006) investigated the diffusion of new and remanufactured products in a market based on a modified Bass diffusion model. However, product design attributes were not considered in their study. Vorasayan and Ryan (2006) developed a queueing network model to determine the optimum quantity and price of remanufactured products by maximizing the total profit. Kwak and Kim (2011) developed a mixed-integer programming model to evaluate the profitability of a product family design for selling reused products with respect to an EoL recovery approach. Kwak and Kim (2013) later developed a model for optimal market positioning of remanufactured products with consideration of product take-back, upgrading product features, and pricing.

Some previous studies were conducted to investigate the competition between new products and remanufactured products as well as original equipment manufacturers (OEM) and remanufacturers. Vorasayan and Ryan (2006) studied the competition between new and remanufactured products in a competitive market. Guide Jr. and Li (2010) examined cannibalization between new and remanufactured products using an empirical approach. Ostlin et al. (2009) examined different product life-cycle dynamics for product remanufacture and component remanufacture as well as the cannibalization of remanufactured components on new components. Wu (2012a) examined the price and service competition among a manufacturer which produces new products, a remanufacturer which produces remanufactured products and a common retailer which sells both new and remanufactured products. Wu (2012b) developed a two-period game theoretical model with respect to product design and pricing decisions for remanufacturing. The price competition between an OEM and a remanufacturer was examined by Wu (2013), in which the OEM aimed to determine the interchangeability of its new products in the design stage in order to keep its competitiveness and to increase the cannibalization cost of the remanufacturer. Chen and Chang (2013) examined dynamic pricing strategy for new and remanufactured products in a multi-period scenario considering price-dependent market demand. Bernard (2011) proposed a competition model which involves two identical original manufacturers and one independent remanufacturer in a duopoly market. Yalabik et al. (2014) developed a model to compare the profitability of a traditional and a green companies, where the green company produces remanufacturable products for lease markets and also launches them in a secondary market. Chuang et al. (2014) examined closed-loop supply chain models with consideration of environmental and operational performances in which product collection is undertaken by manufacturers, retailers, or third-party firms. He (2015) established a closed-loop supply chain model to determine the optimal take-back price of returned products and optimal remanufacturing decisions under centralized and decentralized supply chain networks. Atasu et al. (2008) found that remanufacturing could enhance the competitiveness of an OEM as a profitable marketing strategy in a competitive market, since remanufactured products also cannibalize the product sales of competitors.

Some other related studies exist. Lin et al. (2010) adopted niche green technologies into PLD to examine consumer preferences for environmental friendly technologies based on conjoint analysis. Ferrer and Swaminathan (2010) examined the optimal product returns for remanufacturing and pricing of new and differentiated remanufactured products to maximize firm's profit in a monopoly market. Chang et al. (2015) extended the work of Ferrer and Swaminathan (2010) by proposing a two-period profit maximization model for a hybrid manufacturing/remanufacturing system with consideration of carbon cap and trade mechanism. In their work, the quantity and prices of new and remanufactured products can be determined. Debo et al. (2005) addressed the simultaneous pricing of new and remanufactured products and selection of appropriate investment in reusability. Galbreth et al. (2012) studied how the optimal amount of product reuse (remanufacturing and/or upgrading) relates to the rate of innovation. Frota Neto et al. (2015) investigated the selling prices of new, used, and remanufactured products by compiling a database of iPods from eBay.

Since remanufactured products could cannibalize the sales of new products because of price advantages (Debo et al., 2006), consideration of remanufactured and new products should not be separate. Although some previous studies were attempted to consider remanufactured products in the product design stage, the simultaneous consideration of remanufactured and new products in product line/family design has not been considered in the previous studies. In this paper, a novel methodology for simultaneous consideration of remanufactured and new products in PLD is proposed by which profit and market share of the product line can be maximized. Several major research issues are addressed in the development of the methodology: (1) the competition between remanufactured and new products in markets; (2) demand estimation of remanufactured products in markets; (3) downgrading and upgrading the features of remanufactured products and (4) the time of launching remanufactured products in markets. The main contribution of this study is to consider new and remanufactured products in PLD that was not addressed in previous studies. The validation results indicated that the proposed methodology outperformed the current methodology (separate consideration of new and remanufactured products in PLD) in terms of total profit and total market share of product lines. In addition, the dynamic issues of product lifecycle, the time of launching remanufactured products and price settings of both new and remanufactured products can also be addressed in the proposed methodology through the development of dynamic demand models.

The rest of this paper is organized as follows. Section 2 describes the proposed methodology for simultaneous consideration of remanufactured and new products in optimal PLD. Section 3 presents a case study of simultaneous consideration of remanufactured and new tablet PCs in optimal PLD based on the proposed methodology. Implementation results are shown in Section 4. Validation of the proposed methodology is presented in Section 5. Finally, the conclusion and future work directions are provided in Section 6.

2. Proposed methodology

In this study, remanufacturing involves the collecting back of used products, testing, disassembling, reconditioning, replacing some parts, reassembling, and final testing. Remanufactured products are assumed to have like-new condition and launched in both the first and second markets. The first market refers to a developed region where consumers in general are more interested in and willing to pay for brand new products than remanufactured products. However, some consumers in the first market, who are the supporters of environmental friendliness and/or highly sensitive to price, may be interested in remanufactured products. The second market is normally a relatively less developed region where consumers in general may not be able to afford the purchase of brand new products but they may be interested in remanufactured products because of much lower price. Since remanufactured and new products are launched at different times, two periods are specified in which new and remanufactured