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Component reuse in remanufacturing across multiple product generations

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Abstract

Remanufacturing has been considered as a viable way to mitigate the side effects of product disposal and reduce associated cost in the entire value chain. However, challenges still remain to be solved for remanufacturing practice. One of the negative facets lies in the fact that the opportunity of component reuse in remanufacturing will be jeopardized due to component obsolescence. In literature, it is claimed that higher profit can be generated if multiple generations of product are designed and manufactured concurrently in a forward-looking manner compared to a single product generation at a time. Furthermore, there is inherent delay in time-to-market of remanufactured products compared to manufacturing new products due to product useful lifespan and reverse logistics lead time. The possibility that remanufacturing will overlap with the life cycle of successive product generations is high. Therefore, it is imperative for designers and remanufacturers to jointly manage component reuse in remanufacturing by deliberately considering product diffusion dynamics and concurrent design of multiple product generations in their decisions such as component commonality, acquisition cost and time delay in remanufacturing. In this paper, we investigate how product diffusion dynamics in the market affect the volume of component reuse in remanufacturing across multiple product generations. The trade-offs with respect to component commonality in product family design among multiple product generations are identified and analyzed based on developed models. Numerical analysis is conducted to demonstrate the applicability of our methodology and generate managerial insights. We anticipate that the outcome of this study could contribute to a better understanding and planning of sustainable product design. In a longer perspective, the results may provide the necessary theoretical foundation for accelerating the development and integration of design, manufacturing, and services to improve responsiveness of the overall design chain and its efficiency from both technical and economic perspective.

Keywords: remanufacturing; green manufacturing; sustainable design.

1. Introduction

Solving environmental issues has posed a serious challenge to manufacturing industry. To this end, remanufacturing has been advocated as an important approach to achieve sustainable manufacturing by formulating a closed-loop product life cycle. For example, reuse of a cell phone during its end-of-life phase can reduce environmental impact as much as 47% compared to disposal [1]. In this remanufacturing diagram, end-of-life products are taken back from customers as feedstock in remanufacturing so that environmental issues regarding resources, energy, carbon dioxide emissions and waste disposal underlying manufacturing industry can be potentially resolved. Therefore, environmentally responsible manufacturers should make every effort to facilitate implementing end-of-life strategies with high environmental priority both economically and effectively. The key to fully achieve benefits of remanufacturing lies in the efficient and cost-effective reuse of components from end-of-life products. Major economic issues confronting remanufacturing management include reuse planning, component proliferation and component obsolescence. These issues need to be addressed upfront during product design phase. However, it is a challenging task to address the issues in remanufacturing management. Rapid technological advances and intensive global competition expedite product diffusion
dynamics and new product introduction in the market. Identity associated with end-of-life products is lost throughout remanufacturing processes due to disassembly, imperfect recovery rate as well as increasing product variety. The only linkage remaining manageable in remanufacturing lies on the component level, which is the reuse of components from end-of-life products to remanufactured versions. Secondly instead of being stationary, component reuse quantity fluctuates over time and even overlaps with multiple product generations. It is thus necessary to take a comprehensive perspective to measure component reuse in remanufacturing management taking time into consideration. In particular, there is a delay in time-to-market of remanufactured products due to product useful lifespan with customers and lead time in reverse logistics. In addition, those economic issues are not independently but interact closely with each other based on our analysis. Effective component reuse in remanufacturing thus requires systematic planning of all economic issues mentioned above, which can be best achieved during product design phase.

Research has been conducted to quantify the benefit of remanufacturing under product diffusion dynamics [2]. However, most of the papers focus on single product, at most within one product generation. Due to rapid introduction of new product models, the phenomenon of co-existence of multiple product generations simultaneous in the market can be commonly observed nowadays [9]. Beyond the single product generation, component reuse in remanufacturing can take place across multiple product generations provided that component commonality can exist across multiple product generations. In literature, it is claimed that higher profit can be generated if multiple generations of product are designed and developed concurrently in a forward-looking manner compared to a single product generation at a time [3]. The research on remanufacturing across multiple product generation has not received attention which it deserves. Therefore, this paper aims to investigate how product diffusion dynamics in the market affect the volume of component reuse in multiple-generation product remanufacturing. It is an extension of [2] which quantifies the economic benefit of remanufacturing under product diffusion dynamic for single product generation. Some innovative trade-offs with respect to component commonality in product family design among multiple product generations are identified and analyzed based on developed models. New managerial insights are generated for product designers and remanufacturers in the end of this paper.

2. A base model: component reuse for single product generation

2.1. Basic setting

The remanufacturing process starts when products that have reached their end-of-life for customers are returned as feedstock via reverse logistics and reprocessed by remanufacturers. A closed-loop product life cycle from cradle to grave can be realized via remanufacturing. From this perspective, remanufacturing can save enormous amounts of raw materials and energy while diminishing the waste generated from end-of-life product disposal and thereby promoting sustainable development. Moreover, compared to material recycling, not only the raw material value but the majority of the value added in component manufacturing can be salvaged through remanufacturing, which is thereby more economically attractive than material recycling. The remanufacturing supply chain is unique in terms of feedstock compared to a conventional supply chain. Instead of raw material, the feedstock in remanufacturing is the returned end-of-life products from customers, which are collected and transported to remanufacturing facilities for reprocessing operations as illustrated in Figure 1.

Fig. 1. The general mechanism of component reuse and product remanufacturing [2]

The general reprocessing operations include disassembly, cleaning, refurbishing and testing for quality control. For component under consideration, only a portion of the total volume after reprocessing will pass the quality control due to yield loss and then be stored in the component inventory for further reassembly; the remainder that cannot be reused will be outsourced for disposal or material recycling. $\beta$ is used to represent the yield rate. We assume that remanufactured products are reassembled by reusable components from the inventory together with other necessary new components to satisfy customer demand with the same performance and warranty as suggested by Geyer et al. [4].

2.2. Component reuse for single product generation

Based on the well-known Bass diffusion model in marketing science, a product diffusion dynamics can be represented by

$$n(t) = m[p + q]e^{-\beta t} + \left[p + qe^{-\beta t} \right]$$

where $m$ is the total market size, and where $p$ and $q$ are coefficients of innovation and imitation [5]. The corresponding product diffusion dynamic curve $n(t)$ (i.e., the product sales quantity curve in Figure 2) can be plotted as shown in Figure 2. It can well quantify the four stages of a product life cycle from introduction phase to growth, maturity and decline phases. We assume that after the sale of a product with time delay $\tau$, the product will be returned with probability $r$ (return rate). The time delay $\tau$ consists of both the product’s usage time $t_{usage}$ and the reverse logistic handling time $t_{rd}$. Therefore, the potentially remanufactured component also follows the same shape with $n(t)$ but with a different magnitude and time span due to the return rate and time delay (we assume that each product only consists of one component of interest which we want to reuse). The total volume of potentially reused components is

$$Q_{reuse} = r\beta h(t - \tau)$$

where $r$ is the return rate.
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