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Production planning of new and remanufacturing products in hybrid production systems

Chih-Chiang Fang [a], Min-Hsiu Lai [b], Yeu-Shiang Huang [b,*]

[a] Department of International Business and Trade, Shu-Te University, Taiwan
[b] Department of Industrial and Information Management, National Cheng Kung University, Taiwan

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ABSTRACT

As recycling and remanufacturing become more common, companies may simultaneously operate two production processes for producing new and remanufactured products, and these are called hybrid production systems. However, such systems bring greater managerial complexity, and thus the determination of an appropriate operation strategy to set the recycling ratio of the old product and allocate the capacities of production to the new and remanufactured products is an important issue. This study mainly focuses on a hybrid production system in which the determination of the optimal operation strategy is based on the consideration of the related costs, the uncertainty about recycling, the demand substitution, the capacity limitation, and the component durability. Moreover, the competition between new and remanufactured products is also considered to construct the proposed model, with the aim of maximizing the profit of the manufacturer. The mathematical model are designed from several possible scenarios to estimate the expected revenue and related costs of the hybrid production system. A Hessian matrix and multivariate optimization methods are used to examine and obtain the optimal solution of the mathematical model. The impacts of related parameters are investigated by utilizing sensitivity analysis, and the results of this can give insights to the related production managers.

1. Introduction

Nowadays, due to increased environmental consciousness in the world, more and more consumers would be encouraged to purchase remanufactured products. Some durable products have often been remanufactured by replacing worn and damaged components. For an example, to recycle and remanufacture computers can prevent the related wastes by reusing them when computers were discarded. Moreover, due to the government incentives or regulations for recycling, many manufacturers start to recycle used products that are obtained from consumers and making them into new or remanufactured products, with such actions firms can have decent reputations of environmental friendly images which are often able to enhance their sales and market shares (Inderfurth, de Kok, & Flapper, 2001; Mitra, 2007). If the products can be recycled and remanufactured, the manufacturer can conserve materials, reduce energy consumption and decrease disposal. On the other hand, the customers can also benefit from buying remanufactured products in lower price with comparable quality. Consequently, more and more manufacturers have focused on the remanufacturing process or have both manufacturing and remanufacturing production processes. However, remanufacturing would also increase the extra costs and the complexity of production to the manufacturers. Moreover, the manufacturers may also face the difficulty of allocating the capacities of production between new and remanufactured products. The reasons includes the quality, price, demand and customers' acceptance between new and remanufactured products, and the manufacturers must consider the substitution between the two types of products and make the optimal decision of recycling and production in the hybrid production environment. Accordingly, the manufacturers would thus face a more complicated situation than the traditional one, and the development of an appropriate production strategy becomes an important issue.

Based on the above mention, the study mainly focuses on the optimal operation strategy in a hybrid production system with the consideration of the related costs, the uncertainty about recycling, the demand substitution, the capacity limitation, and the component durability. Moreover, the competition between new and remanufactured products is also considered to construct the proposed model. The rest of this paper is organized as follows:

* Corresponding author at: Department of Industrial and Information Management, National Cheng Kung University, 1 University Rd., Tainan 701, Taiwan.
E-mail address: yshuang@mail.ncku.edu.tw (Y.-S. Huang).

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Section 2 presents the relevant literature related to remanufacturing and hybrid production in the modern world. Section 3 states the research problem of hybrid production systems. Section 4 explains the development of the proposed approach. Sections 5 and 6 demonstrate the effectiveness of the proposed approach by examining a practical numerical case, with sensitivity analyses carried out to investigate the important factors which may influence the results. Finally, Section 7 presents the concluding remarks of this work.

2. Literature review

The review work mainly focused on the following issues: (1) the importance of recycle and remanufacture in the modern world (2) inventory control, stochastic demand, quality level, and related marketing issues in hybrid production systems and (3) the strategies and reactions of remanufacturing under the manufacturer being in monopolistic or oligopoly environment. All the discussions about the literature are as following:

Product regeneration refers to a series of recycling activities, such as disassembly and assembly, which reuse used products or components to meet the requirements of cost reduction and environmental protection (Jorjani, Leu, & Scott, 2004; Kim, Song, Kim, & Jeong, 2006). Manufacturers often utilize their original supply chain to develop a closed-loop supply chain system, and recycle the used products by so-called reverse logistics (Kiesmuller & van der Laan, 2001; Georgiadis & Vlachos, 2004).

Remanufacturing emphasizes the use of the waste generated during the normal production process, or the flawed products that fail quality examinations (Grubbstrom & Tang, 2006). Components which can be recycled, or flawed products which can be repaired, are thus overhauled to restore their functionality and reduce the costs resulting from post-sale repair or replacement services. However, due to the world's limited resources and the trend towards greater environmental protection, the focus is currently on product regeneration, especially for used products (Guide, Jayaraman, Srivastava, & Benton, 2000). If such products are recycled, different regeneration activities can be utilized to either give new life to or extend the life span of the focal items (Aras, Boyaci, & Verter, 2004; Mitra, 2007; Savaskan, Bhattacharya, & Van Wassenhove, 2004). This can help in both complying with environmental regulations and enhancing the reputation of the company (Vlachos & Dekker, 2003). Gungor and Gupta (1999) reviewed the state-of-the-art literature on environmentally conscious manufacturing and product recovery (ECMPRO), and proposed that the manufacturing of environmentally conscious products is worthwhile with regard to minimizing the use of virgin resources by considering the product life cycle information from design to retirement stages, and incorporating it into engineering design and production. ECMPRO has gained the attention of many stakeholders in industry, government and academia. Ilgin and Gupta (2010) reviewed the related ECMPRO literature with regard to stricter environmental regulations and increasing environmental awareness in society, and stated that companies should educate their employees to be more environmentally conscious to improve their reputations and competitive advantages. Dowlatshahi (2000) surveyed the literature on remanufacturing and reverse logistics and classified them into the five categories: (1) global concepts of reverse logistics; (2) quantitative models; (3) distribution, warehousing, and transportation; (4) company profiles; and (5) applications. In addition, Dowlatshahi also considered that the successful factors of reverse logistics implementation should include: strategic costs, overall quality, customer service, environmental concerns, and legislative concerns. Dowlatshahi (2012) further studied the appropriate warehousing sub-factors in reverse logistics, and proposed a framework for the effective design and implementation of reverse logistics operations. Research on remanufacturing has mainly examined the recycling and disassembly of used products, the related cost analysis, and the optimal production strategy, with more focus on the cost aspect rather than the issues of revenue and market demand (Ketzenberg, Souza, & Guide, 2003; Kim, Lee, Xirouchakis, & Zust, 2003; Langella, 2007). In this context, manufacturers would pursue only the minimization of their internal production cost and neglect the market demand, which can increase the holding inventory of remanufactured products, and thus the related operating costs (Kleber, Minner, & Kiesmuller, 2002).

In practice, manufacturers may have both manufacturing and remanufacturing processes running at the same time, which is called a hybrid production system. Accordingly, two types of inventory would thus be considered in a hybrid production system. One is for the manufacturing process in which new parts or components are produced for the first time. The other is required by a remanufacturing process which usually includes recycled products, reusable decomposed components, and remanufactured products. The inventory control system of a hybrid production is therefore more complicated, and also has to consider the interrelationships among these factors (Corbacioglu & van der Laan, 2007; Ferrer & Swaminathan, 2010; Takahashi, Morikawa, Myreshka, Takeda, & Mizuno, 2007). Manufacturers thus have to think about the scheduling of not only new products, but also recycled ones, considering factors such as recycling quantity, remanufacturing quantity, and the market demand. The production strategy should be determined through a process of coordination among these factors and the company's own capacity restrictions (Jayaraman, 2006; Nakashima, Arimitsu, Nose, & Kuriyama, 2004; Vlachos, Georgiadis, & Iakovou, 2007). Moreover, the demand and return rates may be considered as stochastic in remanufacturing systems. Naeem, Dias, Tibrewal, Chang, and Tiwari (2013) proposed a dynamic programming based model with consideration of stochastic demand and returns to determine the new or re-manufactured quantities in order to minimize the total cost. The effects of heterogeneous quality and costs of capacity readjustments are also important concerns for hybrid production systems. Mahapatra, Pal, Narasimhan, and Narasimhan (2012) examined how heterogeneous quality and non-uniform quantity of returns influence the optimal production rates and inventory levels in a hybrid production system, and provided useful insights into the effects of tradeoffs among different operational costs and the impacts of quality of returns. Behret and Korugan (2009) constructed a designed simulation model to investigate the performance of a hybrid system based on the quality of returned items. Aybek, Kemal, and Önen (2013) analyzed the effects of the proportion of remanufacturing on the quality and productivity of a hybrid production system. For this purpose, they conducted several numerical experiments and observed the behaviors of the system under different parameter settings. Guo and Ya (2015) proposed a decision model for recycling products to satisfy the quality level in a manufacturing/remanufacturing system Bulmus, Zhu, and Teunter (2014) incorporated two perspectives of remanufacturing, namely product acquisition management and marketing of the remanufactured products, and stated that original equipment manufacturers should carefully decide on the acquisition prices offered for returns from different quality types, and on the selling prices of new and remanufactured products. This study thus considers a hybrid production system with the aim of maximizing profits in which the issue of environmental protection is taken into account, and then determines the optimal production strategy according to the market demand and the remanufacturing quantity.

Moreover, manufacturers may face competition from other remanufacturers or even themselves, since they will all have two types of products, i.e., new and remanufactured ones (Debo,