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The impact of remanufacturing on total inventory cost and order variance

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ABSTRACT

In this study, a hybrid system with both manufacturing and remanufacturing options is considered. Traditional (without remanufacturing), and push- and pull-controlled hybrid systems are compared using a simulation model under different demand and return rates, manufacturing and remanufacturing lead times, setup and holding cost rates. Production order variances that are used to measure the bullwhip effect, and total recoverable and serviceable inventory costs are considered as the main performance indicators. In terms of total recoverable and serviceable inventory cost, our findings point out that hybrid pull-control policy outperforms the hybrid push-control policy. To measure the performance of a traditional system in contrast to push- and pull-controlled hybrid systems, total serviceable inventory costs are compared. It is noted that hybrid push- and pull-control policies have lower serviceable inventory costs than a traditional system. Especially for higher remanufacturing return rates, the cost performance of hybrid systems is even better. Furthermore, hybrid production systems have lower manufacturing and remanufacturing order variances than a traditional system.

1. Introduction

Increased product variety and shorter life cycles along with increasing environmental consciousness are forcing firms to reconsider how to recover the products reaching the end of their economic lives. In the past, there were lack of sufficient regulations or public awareness about the disposal of products, and thus manufacturing companies had limited concern for disposal of their products sold. Nowadays, product recovery is considered as one of the highest priorities on the agenda of most corporations not only because of the value recovery from the used products but also due to new regulations and growing environmental awareness. Kerr and Ryan (2001) emphasize that sustainable production and consumption will only be possible with closed loop systems in which resources are recovered from the waste stream at the end-of-life of a product.

Organizations consider alternative means of material recovery systems such as reusing, repairing, recycling, refurbishing, remanufacturing and cannibalization (Thieery et al., 1995; Guide et al., 1997; Oh and Hwang, 2006). In direct reusing, no components or materials are replaced and the products are reused without any changes. In repairing, damaged parts are replaced or upgraded by correcting the specified faults in a product (Tang and Naim, 2004). However, the quality of the repaired product is inferior to those of remanufactured and reconditioned ones. Recycling, on the other hand, is a series of activities through which discarded materials are collected, sorted, processed and used in the production of new products (King et al., 2006a). Refurbishing is to bring used products up to specified quality, but the quality standards are less rigorous than those for new products (Thieery et al., 1995). In remanufacturing, worn out parts of products are removed and replaced by new ones (Lund, 1983; Tang and Naim, 2004). It is the only process where used products are brought at least to the performance specification of original equipment manufacturer (OEM) (King et al., 2006a). In cannibalization, only a small proportion is reused, where the purpose is to recover a limited set of reusable parts from used products or components. These parts are reused in repairing, refurbishing or remanufacturing of other products and components (Thieery et al., 1995). All these systems are designed for environmental friendliness and sustainable development, and tend to be economically justified.

A major part of the recoverable product environment is the recoverable manufacturing system that focuses on the repair and

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remanufacture of products (Guide et al., 1997). It is important to note that there is a major distinction between material recovery (recycling) and added value recovery (repairing and remanufacturing) (Kenné et al., 2012). In terms of environmental and economic benefits, a closed loop recycling system is the least efficient means of product recovery. Returning and reusing manufactured components or subcomponents rather than recycling are much more efficient (Kerr and Ryan, 2001). Remanufacturing is also distinctly different from repair operations. The products are disassembled completely, and usable parts are cleaned, refurbished and put into inventory. Then, the new product is reassembled from the old one and returned to like-new condition (Lund, 1983; Guide, 2000; Oh and Hwang, 2006). Remanufactured products usually have shorter lead times. However, the high variability in remanufacturing operations makes the use of traditional operations management techniques difficult to implement (Ilgin and Gupta, 2010).

A recoverable manufacturing system capable of satisfying demand by direct manufacturing or remanufacturing is called a hybrid manufacturing and remanufacturing system (Laan at al., 1999; Zanoni et al., 2006; Zhou and Disney, 2006). Guide (2000) identifies the complicated characteristics of remanufacturing as uncertainty in the timing and the quantity of returns, balancing returns with demands, disassembly, uncertainty in materials recovered, reverse logistics, matching materials requirements, uncertainty in routing and processing times. Laan et al. (1999) suggest studying the hybrid systems in detail to explore the hidden operating cost which may make the total cost higher than traditional systems. These characteristics make it harder to manage a hybrid system compared to a traditional one, and encourage researchers to develop solutions to the production planning problems in remanufacturing.

Laan et al. (1999) define a hybrid manufacturing and remanufacturing system with push- and pull-control strategies, while assessing the performance of this system by total inventory cost only. Using a similar approach, we compare a traditional system (without remanufacturing) with push- and pull-controlled hybrid manufacturing and remanufacturing systems through a simulation model under different demand and return rates, manufacturing and remanufacturing lead time combinations. The performances of the systems are measured by total inventory cost and production order variance. Since one of the potential problems of hybrid systems is related to inventory management of recoverable products including the amount of inventory to hold and time to manufacture and remanufacture, these performance indicators are commonly used in the literature (Laan and Salomon, 1997; Laan et al., 1999; Inderfurth and Laan, 2001; Kiesmuller, 2002, 2003; Teunter et al., 2004; Bayındır et al., 2003; Behret and Korugan, 2009; Tang and Naim, 2004; Zhou and Disney, 2006; Zhou et al., 2006; Zanoni et al., 2006). This study enhances the work of Laan et al. (1999) in two ways. First, the impact of a variety of scenarios on performance indicators related to simulation parameters, namely, the stochastic demand and return rates, stochastic manufacturing and remanufacturing lead times, manufacturing and remanufacturing setup costs, and inventory holding rates are evaluated. Secondly, manufacturing and remanufacturing order variances are calculated for the control policies given in Laan et al. (1999), and the bullwhip effect discussed within the hybrid manufacturing and remanufacturing system.

The paper is organized as follows. In Section 2, related literature is reviewed. In Section 3, the hybrid production system is described and different policies used are defined within the system. In Section 4, details of the simulation model are provided. Section 5 discusses the findings of the study, while the paper concludes with final remarks.

2. Literature review

Increased awareness of environmental issues in public also catches the attention of researchers on product recovery and environmentally conscious manufacturing systems. In their life cycle analysis of Xerox photocopiers in Australia, Kerr and Ryan (2001) quantify the environmental benefits of incorporating remanufacturing into a production system. They state that remanufacturing can reduce resource consumption and waste generation over the life cycle of a photocopier. King et al. (2006b), while studying the processes to transform the old photocopier to a new one at Xerox in the UK, affirm that remanufacturing is a profitable business, but there are still many barriers to its widespread development. Similar to Xerox, Renault Trucks is also considering remanufacturing as an invaluable complement to production. Bourgeois and leleux (2004) asserts that remanufactured parts in Renault trucks have accounted for 16 per cent of parts revenues in 2001, and they are 30%–50% cheaper than the brand new ones. In their investigation of remanufacturing in the Brazilian automotive industry, Saavedra et al. (2013) state that the original equipment manufacturer has more advantages over the independent manufacturer in terms of establishing a relationship with used product suppliers, remanufacturing operations, and marketing of the remanufactured product.

Lund and Hauser (2010) appraise the last three decades of research in environmentally conscious manufacturing and discuss the benefits of remanufacturing and its implications. While reviewing academic studies, Gungor and Gupta (1999) and later Ilgin and Gupta (2010) classify the related literature under four categories: product design, reverse and closed-loop supply chains, remanufacturing, and disassembly. Among others, remanufacturing involves the accurate estimation of product returns, production planning and scheduling, capacity planning, and inventory management. The production planning of remanufacturing concerns itself with the size and timing of disassembly, remanufacturing and production, to decide the order size for new materials, and to coordinate the disassembly and reassembly processes (Ilgin and Gupta, 2010).

The inventory management of recoverable products and their components is also one of the areas receiving significant research efforts since the 1960s (Mitra, 2007). Laan and Salomon (1997) study a stochastic inventory system with production, remanufacturing and disposal. They define and compare push and pull disposal strategies. Laan et al. (1999) also consider a hybrid system for a product with a single component, where they present a methodology to analyze push- and pull-control strategies with custom defined cost functions. Both of these studies find that the pull strategy outperforms the push strategy when the cost of recoverable inventory is sufficiently lower than one of serviceable inventory.

The valuation of recoverable and remanufactured products has a critical impact on product recovery decisions. Teunter et al. (2000) and Teunter (2001) propose and compare different methods for calculating the opportunity cost of returned, remanufactured, and manufactured items in production systems. They state that the value of a new or remanufactured assembly is the cost of a new assembly, where the value of a recoverable assembly is its net profit.

After modeling a hybrid system, Behret and Korugan (2009) analyze remanufacturing operations for different quality levels of return flows, assuming that poor quality levels of returns require more remanufacturing efforts. Their analysis shows that a quality based classification of returned products yields significant cost savings. Wu (2012) discusses price competition between an OEM and a remanufacturer, and provides a set of conditions for higher