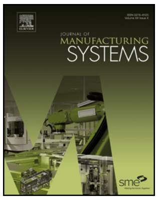
Journal of Manufacturing Systems 37 (2015) 265–276

Contents lists available at ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys



Modeling the merging capacity for two streams of product returns in remanufacturing systems

Mahdi Fathi[a], Farshid Zandi[b], Oualid Jouini[a,*]

[a] Ecole Centrale Paris, Laboratoire Génie Industriel, Grande Voie des Vignes, 92290 Châtenay-Malabry, France
[b] Department of Industrial Engineering, K.N Toosi University of Technology, Tehran, Iran

ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form 19 July 2014
Accepted 29 August 2014
Available online 27 September 2014

Keywords:
Remanufacturing
Closed loop supply chain
Queueing systems
Admission decision problem
Time value

ABSTRACT

We consider a remanufacturing system with two streams of returned products and different variability levels (high and low). The arrival of returns with high variability is modeled with a hyperexponential renewal process and that of returns with low variability is modeled with a Poisson process. The remanufacturing facility can process the returned products in two ways. For the first way, each type of returns is remanufactured by a dedicated capacity. For the second way, returns from two different markets are remanufactured by a merged capacity.

Analytical queueing models with the time value of money consideration are proposed for the admission decision, which decides on the acceptance or not of returned products based on quality and processing time. The proposed modeling determines the admission decision threshold value in order to maximize the total expected profit of the remanufacturing system. Our analysis also allows to study the interaction between the overall utilization and the arrival process variability. The results show the impact of the model parameters on the admission decision value and the total expected discounted profit. Also, the total expected discounted profit under the separated and merged capacities are compared.

1. Introduction

Product remanufacturing has been developed rapidly aiming to protect the environment and to reduce production costs in the supply chain. In today's market, consumers are usually allowed to return a purchased product. Many returned products are sometimes remanufactured and reused without even the customer knowledge [43]. Due to the large amount of returned products, the manufacturers should consider these returns in the production planning and inventory control processes. This is a new important issue for manufacturing systems. Remanufacturing is defined by [46] as: "An industrial process in which worn out products are restored to seem like new ones". Consider a capacitated facility which remanufactures returns to remarket as remanufactured products. High congestion levels at the remanufacturing facility may cause considerable delays and consequently remarketing value losses for time-sensitive products. By the development of technology, especially among electronic products, the useful lives of products are shortened. Making decision on return of products plays an important role for high remanufacturing costs and short product life cycles. Remanufacturing all returned products might not be possible because of increasing remanufacturing costs according to the spent time. Admission decision for remanufacturing is based on the quality and the required processing times of returned products. These are the main source of uncertainty. The returned products can be then classified into: waste to be disposed, or material and parts to be used in processes for producing parts and products. One possibility for a heavily-loaded remanufacturing facility, when the queue at the remanufacturing facility becomes too long, is to sell returned products as-is immediately at their salvage value.

Research on remanufacturing systems has been done under various perspectives. Remanufacturing is an important activity in closed loop supply chains (CLSC). Hence it has been successfully practiced in many industries, such as mobile phones, computers, cameras, and photocopiers. Guide and van Wassenhove [28] further investigated a closed loop supply chain where the quantity, quality, and timing of returns can be controlled by the price offered to buy back the used products. The demand and return rates are assumed to be price-sensitive. Inderfurth [33] investigated the impact of uncertainties on recovery behavior in a closed loop system. Through a numerical analysis, it is shown that the

---

[*] Corresponding author. Tel.: +33 141131502.
E-mail addresses: mahdi.fathi@ecp.fr (M. Fathi), f.zandi@sina.kntu.ac.ir (F. Zandi), oualid.jouini@ecp.fr (O. Jouini).

http://dx.doi.org/10.1016/j.jmsy.2014.08.006

product recovery management becomes much difficult, as the manufacturer should balance the production, recovery, and disposal decisions under considerable uncertainties of demand and return. New integrated models still need to be developed to link various disciplinary perspectives of CLSC [29] and the stochastic nature of demand and return should be paid more attention [50]. For other various quantitative studies on CLSC activities, we also refer the reader to Dekker et al. [13] and Shi et al. [51].

The motivation for this study is that remanufacturing systems are showing an increasing interest in incorporating the merging as an important input into the closed loop supply chains. Moreover, high congestion levels for returns at remanufacturing facility causes substantial delays and consequently remarketing value losses for time-sensitive products and high-tech products with short life cycles, such as consumer electronic equipment computers and printers. Guide et al. [26] report that prices of printers decay at 1% per week. Some PC components decay at even higher rates: 15% per month for compact flash memories and 8% per month for disk drives. Also, several recent trends motivate companies to merge the capacities that were previously dedicated to dissimilar demand processes. There are real case studies of such dissimilarity in demand processes such as: the case of Volvo heavy truck division distribution center that was studied by Narus and Anderson [48], the merging production capacity Alcan Aluminum Ltd. and Arco's Atlantic Ritchfield & Co. that was studied by Iyer and Jain [36]. Therefore, we believe that the merging perspective is needed to determine the admission decision threshold value that decides about acceptance of returned products to prevent the value losses for time-sensitive products.

In this paper, we focus on a remanufacturing system for a type of short life cycle product with stochastic serviceable demand and stochastic returns. There are two return streams with different variabilities in the process of arrivals, namely we consider a hyper-exponential renewal process and a Poisson process. We use an economic framework and the M/M/1, H/M/1, and $H_2M/M/1$ queues to model the considered remanufacturing processes. We determine the admission decision threshold value that decides about the acceptance of returned products on the base of quality and processing time while maximizing the total expected profit. We show that the difference in variability in arrivals has a significant impact on the value of merging capacity. The proposed modeling aims to address the question: When does merging generate Pareto-improving benefits over the separated system?

The reminder of this paper is organized as follows. In Section 2, we survey the literature related to this paper. In Section 3, we give the description of the remanufacturing system under consideration. Section 4 is devoted to the problem formulation and the theoretical analysis of the queueing modeling. In Section 5, we conduct a numerical study to illustrate the theoretical results. The paper ends with concluding remarks and directions for future research.

2. Literature review

In the literature, hybrid production processes are modeled using capacitated and incapacitated models. The capacitated and incapacitated models both in manufacturing and remanufacturing processes are modeled as queuing networks with finite production rates [1,44,57,25].

Ching et al. [11] studied a Markovian queueing modeling for hybrid manufacturing/remanufacturing systems. They assumed that the arrival of returns follows a Poisson process and there is not any rejection of returns from the system. A matrix geometric method is applied to analyze the resulting queueing network. Inderfurth and van der Laan [34] studied a remanufacturing system and proposed a model where demands from customers can be satisfied by both new and recovered products. The recovered products were disposed or stocked in a dedicated inventory. Mahadevan et al. [47] used a similar modeling and proposed pull and push inventory policy for the remanufacturing system. Kiesmüller and van der Laan [42] considered dependent returned products and customer demands in the remanufacturing system. Karamouzian et al. [40] provided an analytical queueing analysis to obtain the best policy to accept returned products. Furthermore, a continuous genetic algorithm is implemented to solve the model, which happens to be a mixed integer non-linear mathematical program.

There is a rich literature that investigated production planning and control for remanufacturing, but only a few of these studies considered the quality of returned products. Returns are often assumed to have one single quality level [56,57,55,21,58,16]. Souza et al. [52] modeled the remanufacturing facility as a multi-class open queueing network where quality levels of returned products determine their classes. They dedicated special remanufacturing stations for different quality type returns. They examined the dispatching rules in remanufacturing stations in order to reduce flow times and improve the service level. Galbreth and Blackburn [19] considered a remanufacturing system with both deterministic demand and random demand under used product variability condition. In order to analyze remanufacturing and disposal decision, Aras et al. [4] emphasized on quality levels of returned product and constructed a continuous time Markov chain model and investigated quality based remanufacturing lead times and disposal cost. Takahashi et al. [53] used Markov analysis to study a remanufacturing system where recovered products are decomposed and classified into wasted to be disposed and materials and parts to be used in the processes for producing parts and products. Recently, Jin et al. [38] investigated the assembly strategies for product remanufacturing with variation in the quality level of returns. The author studied the optimal policy for the modular product reassembly within a remanufacturing setting where a firm receives returns with different quality levels and reassembles products of multiple classes to customer orders. Moreover, [39] modeled performance analysis of a remanufacturing system with warranty return admission.

Behret and Korugan [8] analyzed a hybrid manufacturing/remanufacturing system under general distributed processing times with different variances. Behret and Korugan [9]used simulation to analyze a hybrid system under uncertainties in the quality of remanufactured products, return rate and return times. Dobos and Richter [14] studied the quality of used products in an integrated production recycling system, and showed that it is better for the manufacturer to only buy back reusable products. Also, many applications and methods for analyzing the hybrid manufacturing system are discussed in [5–7,60,1,41].

Numerous recent trends motivate companies to merge their capacities which were previously dedicated to dissimilar demand processes. There are real case studies of such dissimilarity in demand processes. Gupta and Gerchak [30] provided several examples on the issue of operational synergies in a merger/acquisition between parties with different characteristics. Narus and Anderson [48] studied the case of Volvo heavy truck division distribution center which has separate distribution capacities to serve urgent and scheduled orders. It should be noted that the urgent orders have more variability than the scheduled ones. Eisenstein and Iyer [15] discussed the Chicago school system in which two separated distribution capacities and warehouses were used to serve demands with different levels of predict ability. Fisher [17] investigated two product types with different variabilities in demand: functional and innovative. The demand processes of functional products are less variable than the innovative products. Lee and Tang [45] studied modularization and part commonality term in manufacturing