Computers & Industrial Engineering 99 (2016) 124–136

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Optimal disposition decisions for a remanufacturing system considering time value of products

Mostafa Pazoki [a], Walid Abdul-Kader [b,*]

[a] Industrial and Manufacturing Systems Engineering, University of Windsor, Canada
[b] Mechanical, Automotive and Materials Engineering, University of Windsor, Canada

ARTICLE INFO

Article history:
Received 30 July 2015
Received in revised form 11 July 2016
Accepted 14 July 2016
Available online 16 July 2016

Keywords:
Remanufacturing
Time value of products
Mathematical model
Simulation

ABSTRACT

This paper studies disposition decisions of cores where the value of returns deteriorates over time. Mainly in disposition decisions, a remanufacturer is interested to determine how many units to remanufacture and to salvage. To address this research problem along with value deterioration of returns, a rough-cut mathematical model is developed by considering various parameters of interest such as selling price, salvage value and remanufacturing rate with the aim to maximize total profit. Due to uncertainty limitations, the model can provide decision-makers with relevant insights about disposition decisions. Simulation modeling techniques are used to validate the proposed model. Numerical examples are presented to demonstrate the applicability of the model and to show the negative relation between the deterioration rate and the total profit. However, the above-indicated parameters of selling price, salvage value and remanufacturing rate work the opposite way.

1. Introduction

Reverse logistics triggers the backward flow of materials in order to preserve the value of the used products and protect the environment. Potential profitability, environmental consideration and federal laws are the three main driving forces of remanufacturing. The total value of the remanufactured items in United States till 1998 was reported to worth $53 billion at the time of the study (Lund, 1998). In 2011 the total value of the remanufacture production went up to $43 billion, expecting to grow each year.[1]

Decision making levels in reverse logistics have been expanded from strategic to operational. In the literature of reverse logistics and remanufacturing, a variety of operational level assumptions and considerations are taken into account. One of the considerations studied in the literature is the deteriorated value of the returned product over the delay time. High-tech products such as computers are prone to lose their value due to delays from the time they are received till the time they are resold to the secondary market. The addressed delay, which is the time between receiving a returned product until it is remanufactured and resold in the secondary market, has several consequences. It deteriorates customers' willingness to pay, incurs holding cost and reduces the selling price of the products. The loss incurred by the delay may be as high as 1% per week for some products (Blackburn, Guide, Souza, & Van Wassenhove, 2004). Thus, the time value of products should be taken into account (Guide, Gunes, Souza, & Wassenhove, 2008; Voutsinas & Pappis, 2002, 2010). The IBM case addressed in Ferguson, Fleischmann, and Souza (2011) and the HP case studied in Guide et al. (2008) are two examples of this consideration. Generally, electronic devices such as laptops and cellphones can be categorized in this group of high-tech and short lifecycle products (Guide et al., 2008). The second approach is to consider work in process (WIP) cost for the remanufacturing line. The time interval in which the returned product is kept unfinished can be translated to WIP cost (Pazoki & Abdul-Kader, 2014). This approach has been considered in the scheduling context (Alidaee & Womer, 1999) where the value of products depends on the completion time (Janiak & Krysiak, 2007).

The remanufacturing process is not absolutely continuous for many industries. The machines have to be serviced on a regular basis to increase the utilization rate and decrease the defect rate. In addition, many remanufacturing systems are involved in manufacturing. Therefore, after manufacturing brand new products, the machines need to be cleaned and set up to start remanufacturing. Thus in the addressed firm, not only does the remanufacturing process have to be done in discrete periods of time, but also it must be started when the production line is available for such activities.

* Corresponding author.
E-mail addresses: pazoki@uwindsor.ca (M. Pazoki), kader@uwindsor.ca (W. Abdul-Kader).

[1] "Remanufactured goods: An overview of the U.S. and global industries, markets, and trades." US International Trade Commission, USITS publication, Oct 2012.

http://dx.doi.org/10.1016/j.cie.2016.07.015
0360-8352/

This situation, which to the best of our knowledge has been overlooked in the literature, is considered in this article.

The aim of this research work is to address the optimal disposition decision. The addressed assumptions of deteriorating value of returns and the discrete period assigned to remanufacturing are the two key considerations of this study. The quality conditions of returns are not identical and all unclassified arrivals are delivered to the system in bulk. This assumption is commonly considered in the scheduling context where the value of the product depends on the completion time and the goal is to maximize the total profit (Voutsinas & Pappis, 2002). A threshold is considered in this research as a boundary to accept or reject the categorized returns on the basis of the expected delay and the exponential value deterioration function. Considering the salvage value of a returned product and its expected deteriorated value, decisions would be made whether to remanufacture the product or to sell it immediately at its salvage value. This problem is classified as disposition problem in the literature. To tackle the addressed problem, a mathematical model is presented. The schematic view of the disposition decision is illustrated in Fig. 1.

As explained earlier, the remanufacturing process is performed in discrete periods of time. Throughout this article, the total available length of time for manufacturing and remanufacturing is called *production period*, and the time assigned for remanufacturing within a production period is called *operating period*. The portion of the production period in which remanufacturing is not performed is referred to as *idle time*. Returns are inspected, sorted and put in *classes* or *categories*. Note that the terms "class" and "category" are used interchangeably throughout this paper. *Remanufacturing rate* refers to the rate at which returns are remanufactured, and *remanufacturing time* is the time it takes to remanufacture a unit of product (inverse of remanufacturing rate).

This proposed work contributes to the literature in several terms. Firstly, to the best of our knowledge, no previous or published research work has considered the availability of unclassified returns at time zero together with disposition decisions and time value of the products. This consideration makes it possible to incorporate disposition decisions with tactical level decisions about inventory and pricing. Secondly, the operating periods and idle times are considered in this model. Dividing the total production period into operating period and idle time is adapted from real situations. If the company is fully involved in remanufacturing, the operating period is the time assigned to remanufacturing and the idle time is the time devoted to secondary tasks such as maintenance (Su & Xu, 2014). Otherwise if it is a hybrid (re)manufacturing system, the operating periods can be interpreted as the time assigned to remanufacturing task and the idle time would be the times assigned to manufacturing and maintenance tasks.

Thus, as a summary, this proposed research contributes to the literature by considering (in addition to the quantity to remanufacture and to salvage) the following points:

- Deterioration value for returns and time value of the products.
- Assuming availability of returns at time zero.
- Availability of discrete time intervals for remanufacturing.

Moreover, it is shown that although the mathematical model is generated on the basis of average process times, it could give good total revenue estimation for stochastic systems. Consequently, it is called a rough-cut model.

The remaining of the paper is organized as follows. The related research studies are discussed in Section 2. The research problem is defined and the mathematical model is presented in Section 3. A numerical example is given to show the relevance of the model. Given the rough-cut nature of the model in the absence of uncertainty considerations, the model is validated using simulation modeling techniques where a variety of probability distributions is used to represent the processing times. Sensitivity analysis together with accuracy of the model in general conditions is performed in Section 4. Finally, conclusion and recommendations for future research are presented.

2. Literature review

2.1. On the quality variability, marginal value of time and arrival/service times

Quality variability complicates remanufacturing planning (Guide, 2000). Many research studies have taken quality variability into account either as a continuous function (Denizel, Ferguson, & Souza, 2010; Galbreth & Blackburn, 2010) or a discrete function (Teunter & Flapper, 2011). Admission decision belongs to remanufacturing planning problem presented in 1970s where the remanufacturer decides on the quantity to remanufacture and quantity to salvage. Generally, remanufacturing has greater profit than recycling. However, since the value of high-tech products deteriorates over time and considering holding cost, it should be decided whether to salvage the product immediately or remanufacture it.

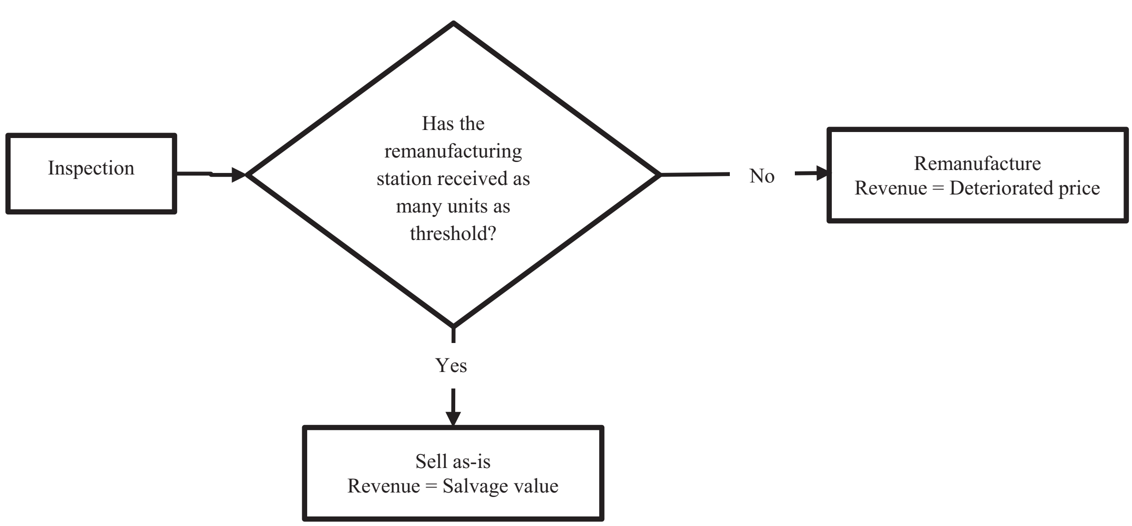

Fig. 1. Disposition decision and flow of materials.