International Journal of Production Economics 188 (2017) 72–85

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Multi-objective optimization decision-making of quality dependent product recovery for sustainability

Kai Meng[a,b], Peihuang Lou[a,b], Xianghui Peng[c,*], Victor Prybutok[d]

[a] College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, Jiangsu, China
[b] Jiangsu Key Laboratory of Precision and Micro-Manufacturing Technology, Nanjing, Jiangsu, China
[c] Department of Management, College of Business and Public Administration, Eastern Washington University, Spokane, Washington, USA
[d] Department of Information Technology and Decision Sciences, College of Business, University of North Texas, Denton, Texas, USA

ARTICLE INFO

Keywords:
End-of-life product
Product recovery
Remanufacturing
Dismantling
Sustainability
Multi-objective optimization

ABSTRACT

The increasing external pressure to establish sustainable operations has forced firms to embrace approaches such as sustainable manufacturing through product recovery. To improve the performance of product recovery, we studied a decision-making problem involving the selection between end-of-life product remanufacturing and dismantling. A quality-dependent multi-objective optimization model was developed and validated to identify the optimal or near optimal product recovery solution that best balances the economic, environmental and societal performances of product recovery for sustainability. We also investigated how the quality level, recovery cost and retail price impact the product recovery decision under different decision makers' preferences. Experiments on a case of an automobile engine model demonstrated the multi-objective optimization model's effectiveness to achieve satisfactory recovery solution. The results also provide insights for product recovery practices, which can assist firms in adapting their practices to meet the challenges of sustainability.

1. Introduction

Sustainability is a global concern due to increasing sensitivity about environmental pollution and resource consumption. It is also a crucial issue to creating an environmental friendly business which is increasingly important to competitive position and for the future while not sacrificing current profits. In order to respond to this challenge, many companies worldwide have implemented sustainable manufacturing by strategically incorporating product recovery into their practices. The need for product recovery is driven by both external environmental regulations and internal sustainable operation requirements (Gunasekaran and Spalanzani, 2012; Mangun and Thurston, 2002). Product recovery is the reclamation of the value of end-of-life (EOL) products via collecting, reconditioning, reusing or recycling them. Product recovery is a promising way to achieve sustainability by reducing waste, saving cost, increasing profits, and creating jobs (TISRM, 2010; Ilgin and Gupta, 2010). In this paper, we study a product recovery decision-making problem to identify an optimal product recovery solution that optimizes the economic, environmental and societal performances of sustainability, while considering practice constraints, quality conditions of EOL products, cost functions and retail prices.

There are two main strategies for recovering the EOL product: remanufacturing the entire product or dismantling it into components (Ferguson et al., 2011; Johnson and McCarthy, 2014). Remanufacturing refers to restoring an EOL product to almost brand-new condition through a series of processes (Hatcher et al., 2011; Ijomah et al., 2007). Components that cannot feasibly be restored to good quality are replaced with new ones. The intent is for the quality of a remanufactured product to be as good as or even superior to that of the original product (Zhang et al., 2015a, 2015b). However, it is critical that its process cost and retail price are much lower than that of a new product. Many companies in the remanufacturing business provide a wide range of remanufactured products, e.g. Cummins engine, Caterpillar engineering equipment, Xerox printer, IBM laptop (Ongondo et al., 2011; Zhang et al., 2015a, 2015b). Dismantling aims to recover the components via reselling them after remanufacturing, directly reusing them as spare components, or material recycling - e.g. a personal computer can be dismantled to reuse or resell those reusable components such as memory and mother board (Ferguson et al., 2011). Similarly, the key components of an automobile engine, such as the crankshaft and block, can be reused to meet the demand for repair service or a secondary market. Both product recovery strategies are considered higher level product recov-

* Corresponding author.
E-mail addresses: nuaamk@126.com (K. Meng), mecphlou@nuaa.edu.cn (P. Lou), xpeng@ewu.edu (X. Peng), Victor.Prybutok@unt.edu (V. Prybutok).

http://dx.doi.org/10.1016/j.ijpe.2017.03.017
Received 1 October 2016; Received in revised form 15 February 2017; Accepted 22 March 2017
Available online 25 March 2017
0925-5273/ Published by Elsevier B.V.

ery compared to material recycling (Gerrard and Kandlikar, 2007). Product remanufacturing and dismantling potentially achieves better performances of sustainability because these strategies can save more energy and resources, and prevent the material extracting, processing and transporting (Go et al., 2012). However, firms should balance the two strategies to identify a solution that optimize the economic, environmental and societal performances while achieving sustainability. They also need to determine the level at which an EOL product should be disassembled and which recovery option should be assigned to each component. In order to push sustainability forward, we establish a multi-objective optimization decision-making model for assessing sustainable performances of product recovery options.

Sustainable performances are positively correlated with the quality condition of each EOL component because different quality levels will lead to different process cost, different energy consumption and different waste emission (Çorbacıoğlu and van der Laan, 2013; Nagalingam et al., 2013; Ng and Song, 2015). Unfortunately, EOL product quality varies significantly due to various usage conditions and patterns (Ferguson et al., 2009; Ondemir and Gupta, 2014a, b; Wan and Gonnuru, 2013). Therefore, a quality dependent product recovery decision-making model is the key to seeking the best solution by mirroring and capturing the "true" sustainable performances. However, there is still a lack of such models to balance remanufacturing and dismantling for product recovery from a perspective of sustainability.

The purpose of this paper is to fill this gap by developing and validating a multi-objective optimization decision-making model to select the optimal product recovery strategy that best meets the criteria of sustainability between remanufacturing and dismantling and to identify the best disassembly level and component recovery options. In this paper, the quality level of EOL components is obtained with the probability distribution function, which is estimated based on statistical models and usage data with the help of information tracking technologies (Fang et al., 2015; Ondemir and Gupta, 2014a, b). We assess the quality dependent sustainable performances of remanufacturing and dismantling for a case of an automobile engine model and demonstrate the effectiveness of our developed model. We also investigate how the quality level, cost function and retail price impact the sustainable performances and the final tradeoff decision. The results of the experiments show that the quality level has a significant impact on sustainable performances and component recovery options but a limited effect on the final tradeoff decision. However, for high quality EOL products, the high motivation of product reuse has a potential to decrease the benefit of remanufacturing. Cost-benefit performance is the key for the final tradeoff decision in most scenarios except those in which decision-makers pay more attention to environmental and societal performances. Firms can adopt or adapt our model to identify the optimal solution and then adjust their product recovery practices when using various inputs from industry cases.

The rest of the paper is organized as follows. In next section, we review the most related research to further position our work. Then, we develop the quality dependent multi-objective optimization decision-making model in Section 3. This is followed by solving the developed model based on Non-Dominated Sorting Genetic Algorithm II (NSGA-II) and Pareto optimal selection in Section 4. Experiments are presented in Section 5 in order to validate our model. Finally, Section 6 concludes the paper and discusses future research directions.

2. Literature review

There are numerous studies on optimization decision-making models for product recovery. In this literature review, we focus on the studies on optimization decision-making models for dismantling and remanufacturing in order to better define our work.

Remanufacturing and dismantling strategies both involve remanufacturing, reusing or recycling the EOL components. There are two major decisions for implementing two strategies. One is determining the optimal disassembly plan (i.e. disassembly level and sequence). The other is identifying the optimal recovery option for each component. Most of the existing research deal with the two sub-problems separately from quality independent optimization decision-making models. Kongar and Gupta (2006) and Go et al. (2012). used a genetic algorithm to optimize the disassembly sequence for component recovery. But they only considered the disassembly cost as the optimization objective. W.D. Li et al. (2013) investigated the selective disassembly planning problem of waste electrical and electronic equipment by proposing a multi-objective optimization model (MOOM) to consider the legislative and economic impacts. They considered three criteria for the components disassembled from the EOL product: potential recovery value, hazardousness removal, and weight removal. Rickli and Camelio (2013) also developed a MOOM for partial disassembly seeking a solution that best balances disassembly revenue, environmental impact and disassembly feasibility. These studies only focused on disassembly optimization under the prerequisite that recovery options were given. Shokohyar et al. (2014) established a decision-making model to optimize the service period and recovery options simultaneously. They modeled both economic and environmental impacts to help the manufacturers to implement sustainable product service system. The connotative assumption was that the disassembly plan was known. However, in most practices, decision makers need to determine both the disassembly plan and recovery strategies (Ma et al., 2011). Some studies integrated the two sub-problems by first identifying the best recovery strategies and then optimizing the disassembly plan (González and Adenso-Díaz, 2005; Lee et al., 2010, 2001). To find a global optimal solution, researchers suggested intelligent algorithms for solving this integrated problem. Hula et al. (2003) presented a multi-objective model and solved it by using NSGA-II to determine the best disassembly plan and recycling options. Both recycling profits and potential energy consumption were considered as optimization objectives. However, they only considered the scenario of component recycling without considering the scenarios of remanufacturing and dismantling for EOL products.

All the above studies were based on the assumption that sustainable performances of EOL product recovery are quality independent. Considering the importance of quality, some research established quality dependent decision-making models to optimize recovery decisions. Recovery profits or costs should be formulated as a function of quality to mirror the real EOL product condition and residual value. Wan and Gonnuru (2013) proposed a quality dependent model of disassembly planning for dismantling strategy. The quality of each EOL component was evaluated by a fuzzy logic model to enable the optimization model in order to determine the disassembly level and sequence according to the quality dependent profits. Rickli and Camelio (2014) used age distribution to characterize the quality of EOL component and then modeled the quality dependent recovery value to achieve flexible partial disassembly planning. Meng et al. (2016) developed a quality dependent profit maximization model to integrate disassembly planning and recovery option selection. Jun et al. (2007) proposed a quality dependent optimization model for product remanufacturing. They aimed to maximize the quality of a refurbished product and minimize recovery costs. They extended this model for the optimization of multiple EOL products remanufacturing (Jun et al., 2012). But sustainable performances were not discussed in these studies. Ondemir and Gupta (2014a, b) considered multiple objectives for dismantling - including recovery cost, financial profit, waste disposal and customers' satisfaction level - to formulate a goal programming model. Remaining useful life of EOL components was used as the quality measurement to implement a demand driven recovery decision-making model.

All of this research provided valuable models, approaches and insights into optimization decision-making on remanufacturing or dismantling. However, most of them focused on dismantling strategy