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A hybrid approach for performance evaluation and optimized selection of recoverable end-of-life products in the reverse supply chain

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ABSTRACT

Performance evaluation and selection of end-of-life products have emerged as crucial issues for firms looking to adopt a product recovery strategy to achieve environmental responsibility while still meeting profit goals within the reverse supply chain. However, there is still a lack of a comprehensive methodology to address the issues because of the variety of decision factors involved and the inherent uncertainties associated with them. This research proposes and investigates a multiphase hybrid approach to identify the recoverable products that best meet the criteria set (such as technical feasibility, economic benefit, and environmental effect). The proposed method simultaneously considers multiple and conflicting goals, practical constraints, and information uncertainty. First, fuzzy logic and probability theory are utilized to estimate the quality condition of used products and subsequently conduct the cost-benefit analysis based on the product life-cycle information. Then, the modified preference ranking organization method for enrichment evaluations is used as a multi-criteria decision-making tool to quantify and aggregate the linguistic evaluation items into recovery preference factors. Further, all the qualitative and quantitative data are incorporated in a goal programming model to achieve a compromise and satisfied solution. We present a numerical example to illustrate the effectiveness and superiority of the proposed approach. The results indicate that the proposed approach can provide strong and flexible support for product recovery decision-making within the reverse supply chain.

1. Introduction

Significant increases in the consumption of natural resources and energy have brought pressure to develop sustainability. Recently, many countries have implemented strategies to achieve environmentally conscious manufacturing and end-of-life (EOL) product recovery (Ilgin & Gupta, 2010a). Stringent regulations of government or third parties and the green awareness of consumers are forcing manufacturers to deal with EOL products in a more environmentally-friendly manner (Guide, Jayaraman, Srivastava, & Benton, 2000). There is a strong need for researchers and practitioners to develop methods to optimize the reverse supply chain (RSC) in order to promote sustainable manufacturing through efficient and effective product recovery management (Pochampally & Gupta, 2012; Xanthopoulos & Iakovou, 2009).

To ensure the successful implementation of RSC management, how to evaluate the performance of EOL products and then how to select the best ones for product recovery are crucial for RSC decision makers. First, deciding what EOL products to collect and further product recovery is the prerequisite step in a RSC management system. Only when the recoverable products have been determined, the RSC management decision makers can further identify the RSC facilities (such as collection centers, demand centers, recovery firms) and design the networks (Pochampally & Gupta, 2008; Ilgin & Gupta, 2010a; Lambert, Riopel, & Abdul-Kader, 2011; Pochampally & Gupta, 2012). Second, deciding what EOL product to collect and further product recovery is also an essential gatekeeping for successful EOL product operations while effectively controlling costs (Lambert et al., 2011). Although product recovery is a promising strategy for saving resources and energy, reducing environment burden, and reclaiming the remaining value of EOL products, it also accrues costs related to sorting returns, testing products, disassembly, reprocessing and disposal. The EOL product processing firms, especially the product recovery

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firms need to select the products that are financially, environmentally, legally, and technologically feasible for recovery (Goodall, Rosamond, & Harding, 2014; Xanthopoulos & Iakovou, 2009). However, due to the inherent uncertainties in product returns, market demand, product conditions and information availability (Guide et al., 2000), it is very difficult to simply make a performance evaluation and selection of EOL products. In addition, the variation of decision-makers' drivers makes it impractical to pre-determine EOL products that can best meet multiple criteria (such as technical feasibility, economic benefit, environmental effect, cost constraint). All these reasons lead to a significant research topic on the issues about performance evaluation and optimized selection of EOL products.

After a thorough literature review, we found there are several gaps in the existing research. First, there is no prior study about how to select a set of EOL products under constraints to achieve optimized solution, while most prior studies investigated the recoverability of a specific type of product or how to select the best product for recovery. Second, a few prior studies provide a comprehensive model that combines multi-criteria evaluation and optimized selection by considering information vagueness, preference flexibility and trade-offs between goals and constraints. Third, most prior research assumed that the quality conditions and economic aspects of EOL products were given. They didn't provide details for estimating the EOL product-condition-dependent recovery value and cost.

However, in practice, most recovery firms receive a wide range of EOL products with different models rather than one type of model (Guide et al., 2000). The recovery firms want to reprocess more high value-added EOL products to maximize the benefits from product recovery. Besides, a method for estimating the EOL product-condition-dependent performance is critical for optimized selection of EOL products because EOL product condition can result in a large variation among product recovery options (Behret & Korugan, 2009; Ondemir & Gupta, 2014; Remery, Mascle, & Agard, 2012; Tripathi, Agrawal, Pandey, Shankar, & Tiwari, 2009; Ziout, Azab, & Atwan, 2014). There is still a lack of a comprehensive and effective approach that simultaneously considers multiple drivers, practical constraints, and EOL product uncertainties.

The objective of this research is to address the existing research gap and to contribute to the body of knowledge in academia. This work proposed a hybrid three-phase approach for evaluation and selection of EOL products by using both qualitative and quantitative methods. The proposed approach utilizes the fuzzy model and multi-criteria decision-making technique for performance evaluation and then looks for an optimized solution using a goal programming model. This research is the first study that develops a novel hybrid approach for evaluation and selection of EOL products by simultaneously considering multiple drivers, practical constraints, and EOL product uncertainties. Utilizing the numerical example, we also compare the results from the proposed approach with the results from prior developed approaches. The numerical example demonstrates the effectiveness of the proposed hybrid approach for the product recovery firms about RSC management decision making. The comparisons support its superiority over others. The insights obtained from this study also contribute to improving EOL product recovery practices for industry practitioners.

The rest of this paper is organized as follows. Section 2 reviews the most relevant literature for identifying the gaps of existing research. Section 3 presents the overall framework of the proposed hybrid approach. Section 4 elaborates the details of the proposed approach in three phases. We conduct a numerical experiment and discuss the results in Section 5. Finally, we conclude this paper and direct the future research in Section 6.

2. Literature review

This study proposes a novel hybrid approach for the evaluation and selection of EOL products by simultaneously considering multiple drivers, practical constraints, and EOL product uncertainties. To identify the gaps of existing research and investigate the superiority of the proposed approach, we narrow down the literature review to the most relevant studies that apply different research methodologies into EOL product recovery.

Cost-benefit analysis (CBA) is the most commonly used method for selection of EOL products (Ilgin & Gupta, 2010a) since recovery firms always pay considerable attention to the economy of EOL product operations. A cost-benefit function is constructed based on the financial value obtained by EOL product recovery. This function can be expressed in terms of the difference of recovery benefits and costs in a deterministic analysis model (Veerakamolmal & Gupta, 1999), or defined as the ratio of recovery benefits to recovery costs (Pochampally & Gupta, 2008). However, CBA is more suitable for the decision scenario where the evaluation criteria were expressed in terms of numerical items (Ilgin & Gupta, 2010a). Moreover, due to the absence of various decision factors, decision-making solely based on financial analysis may lead to inadequate or sub-optimized solutions (Yang, Ong, & Nee, 2014).

Therefore, multi-criteria analysis is considered appropriate for assessing the comprehensive performance of EOL products. The comprehensive index, which is a normalized and aggregate representation of all the aspects of recovery performance, was widely used (Lee, Lu, & Song, 2014). Kuo (2010) proposed a combined approach of Case Based Reasoning and Analytic Hierarchy Process (AHP) to calculate a recyclability index for recovery decision. Iakovou et al. (2009) developed a multi-criteria scoring method for optimized selection by assessing and ranking all EOL components with five criteria: residual value, environmental burden, weight, quantity of the particular component and ease of disassembly. Du, Cao, Liu, Li, and Chen (2012) proposed an integrated method for evaluating the re-manufacturability of used machine tool by analyzing the technology feasibility, economic feasibility and environmental benefits. Lee et al. (2014) captured the knowledge from the EOL stage to calculate the EOL product index by quantitatively evaluating various factors relevant to product recovery, disassembly, and disposal. Nagalingam, Kuik, and Amer (2013) developed a novel framework for performance measurement of EOL products using the design for six sigma methodology, in which recovery cost, manufacturing lead-time, waste disposal and quality characteristic were investigated and modeled. These multi-criteria analysis based approaches provide more comprehensive measures for EOL product performance assessment. However, they are limited to deal with the problem of optimized selection with various constraints.

To handle with various constraints, Xanthopoulos and Iakovou (2009) proposed an approach that combined multi-criteria evaluation and goal programming. To construct the optimizing goals, the researchers need to respectively determine the aspiration value of each criterion and the rating of each component for each criterion. Although Pareto/ABC was suggested, it would be still difficult to objectively identify the aspiration value and ratings for each qualitative criterion, especially for strategic planning at the product level where much EOL product information can be uncertain and vague.

This study utilizes both qualitative and quantitative methods to develop a hybrid three-phase approach for evaluation and selection of EOL products. We introduce the fuzzy logic inference into CBA model to identify the product-condition-dependent recovery value and cost. The fuzzy inference CBA model incorporates lifecycle information of EOL products into the economic analysis and