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Fuzzy multi-objective procurement/production planning decision problems for recoverable manufacturing systems

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ABSTRACT

In actual lot-sizing production-to-order problems for recoverable remanufacturing systems, input data or parameters are often imprecise or fuzzy. This study develops a novel fuzzy multi-objective linear programming (FMOLP) model with a piecewise linear membership function to solve integrated, procurement/production, planning decision problems with fuzzy environments and deal with multi-component, multi-vendor, multi-source and multi-machines under recoverable remanufacturing systems. The initial FMOLP model developed in this study attempts to simultaneously minimize total costs and total lead times in relation to supplier capacity, lead time, lot release, machine yield and customer demand. The proposed FMOLP model provides a systematic framework that facilitates a fuzzy decision-making process, enabling a decision maker to interactively adjust search direction during the solution procedure to obtain the preferred satisfactory solution. To test the model's adequacy, an actual implementation of several scenarios was conducted using remanufacturing production systems. The analytical results presented in this study can help decision managers better understand systematic analysis and the potential for improving cost-effectiveness and lead time in terms of recoverable remanufacturing planning.

1. Introduction

Problems with scarcity and waste generation have become more and more serious. Countries around the world have begun to take environmental topics such as reverse logistics, recycling and reuse and remanufacturing of products more seriously. Reverse logistics allow for user-end recycling of obsolete products. These products can be taken apart, cleaned and restored in a repetitive cycle of reuse and remanufacture. For instance, Hewlett-Packard employs user-end recycling to recover empty toner cartridges which are then made ready for repeat usage [32]. Demand for customization is gradually increasing, given that recycled parts may no longer meet customer demand for new products. To fulfill a particular customer's demand, a number of new parts and recycled parts may need to be released through reverse manufacturing systems. At the same time, the possibility of creating value-added products using new parts along with recycled parts and remanufacturing methods must be taken into account [39].

During the remanufacturing process, costs and lead times of new and recycled parts actually exhibit a trade-off relationship. When using new parts, purchasing costs are higher and the lead time for purchasing these parts is shorter. Relatively speaking, purchasing costs for recyclable parts are lower, but lead times are longer because the recyclable parts must be disassembled, repaired and refurbished. Thus, when companies consider differences in costs and lead times they tend to compromise by simultaneously considering new parts and remanufactured and recycled parts. Decision makers must simultaneously consider multiple factors, such as lowest total cost and lowest total lead time. However the majority of research related to this topic has tended to focus on a single objective.

In an actual lot-sizing production-to-order problem for recoverable remanufacturing systems, input data or parameters such as purchasing/production costs, supplier capacity, lead time and objective function are often imprecise or fuzzy. This may be due to information being incomplete, unavailable or unobtainable. These factors lead to an objective function with fuzziness. For instance, the objective function of annual production costs may be $0.5 million, or the annual lead time may be 14 days. This imprecision results in the need for a set of fuzzy multi-objective models to produce a set of compromise solutions. Therefore, this study applies a novel FMOLP model to solve the lot-sizing problems of recoverable remanufacturing and consider multi-components, multi-sources (new parts/recoverable parts), multi-vendors (new

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parts/recoverable parts vendor) and multi-machines (remanufacturing/reassembling machines) with yield rates for each machine. The proposed FMOLP model simultaneously optimizes total production costs and total lead times in terms of customer demand, machine capacity, lot release and bills of material (BOM) for recoverable product constraints. The model, therefore, aims to simultaneously achieve the targets of low-cost and low-lead-time. The original FMOLP model simultaneously minimizes total production costs and lead times with reference to multiple components, multiple sources, multiple vendors and multiple machines.

The remainder of this paper is organized as follows. Section 2 presents a literature review; Section 3 formulates the fuzzy multi-objective recoverable remanufacturing planning decisions model; Section 4 utilizes a remanufacturing toner cartridge case, which is used to assess the feasibility of the proposed model, and Section 5 gives conclusions.

2. Literature review

2.1. Recoverable manufacturing/remanufacturing

Recoverable manufacturing systems minimize the environmental impact of industry by reusing materials, reducing energy use and reducing the need to put industrial products in landfills [26,69]. Koh et al. [35] proposed a model to analyze an inventory system of recycled products and newly purchased products for procurement as well as for the optimal inventory level of recoverable items. Bhattacharya et al. [10] examined the problem of determining optimal retail order quantities, both from a manufacturer who makes new products and from a remanufacturer using used and unsold products. Jayaraman [31] proposed an analytical approach toward production planning and controls for closed-loop supply chains of product recovery and reuse. This approach consists of a linear programming (LP) model, calling remanufacturing, aggregate production planning, for aggregate production planning and control. Kim et al. [34] proposed a general framework for remanufacturing systems and a mathematical model for maximizing total cost savings when making decisions about quantity in a reverse logistics environment. Using a mathematical model, Choi et al. [21] studied an inventory system where the stationary demand can be satisfied by recovered products and newly purchased products. Li et al. [39] analyzed a version of the capacitated dynamic lot-sizing problem with substitutions and return products. They developed the capacitated multi-period two-product production-planning model that takes into consideration both remanufacturing and substitution and determines relative quantity levels for manufacturing/remanufacturing. Chung and Wee [22] analyzed the impact of the green product design, the new technology evolution and remanufacturing on production-inventory policy and develop an integrated deteriorating inventory model with a green-component life-cycle value design for remanufacturing in semi-closed supply chains.

Zhou and Wang [70] designed a reversed logistics network model that simultaneously takes into account repairing and remanufacturing options. Bao et al. [6] investigated the bimodality properties of disassembly/purchasing lead time distribution in a remanufacturing system. They propose a minimum relative entropy method for estimating the impact of bimodal distribution on system performance. Pishvaee et al. [51] developed a stochastic programming model for solving a single period, single product, multi-stage integrated forward and reverse logistics network design problem in uncertain environments. Behret and Korugan [8] analyzed a hybrid system with both remanufacturing and manufacturing operations that allows for different quality levels of return flows. They propose a multi-stage inventory control model that references uncertainties in the quality of remanufactured products, return rates and times for returned products. Konstantaras et al. [36] developed an inventory system that consists of a combination of inspection and sorting and recovery (remanufactured) and ordering of new parts for recoverable products in a reverse logistics environment. Ahiska and King [1] proposed an inventory optimization model for a single-product recoverable manufacturing system for either the regular manufacture of new parts or the remanufacturing of returned items using a Markovian decision making process. Ahiska and King [2] analyzed the inventory control problem of a single-product recoverable manufacturing system for an entire product life cycle.

Piñeyro and Viera [50] investigated the lot-sizing problem using different demand streams for new and remanufactured parts. They provide a mathematical model for solving the problem and develop a Tabu-search-based method for finding a near optimal solution. Konstantaras and Skouri [37] examined a production-remanufacturing inventory system that develops two inventory models which consider both shortage cases and no shortage cases for a single product recovery system with variable setup numbers. Chung and Wee [23] developed an integrated production-inventory deteriorating model that considers the greening operation process and life-cycles in a green supply chain inventory control system. Teunter et al. [55] studied problems and decision making in relation to acquisition and remanufacturing and take uncertainty, multiple quality and multinomial quality distribution for an acquired lot into consideration when determining optimal acquisition decisions. Feng and Viswanathan [25] investigated a deterministic model of product recovery in a manufacturing system. They propose two lot-sizing policies and develop two heuristics for the problem. Amin and Zhang [3] designed a multi-objective mixed-integer LP model to optimize the closed loop supply chain network. The model includes disassembly, refurbishing and disposal sites. The objective of network configuration is to determine the optimal number of products and parts in each section of the network. Rickli and Camelio [52] developed a genetic algorithm approach to optimize multi-objective partial disassembly sequences based on disassembly operational costs, recovery reprocessing costs, revenues, and environmental impacts. Chen [20] designed two dynamic decision models that consider deteriorating effects, as well as manufacturing and remanufacturing costs and competition intensity for remanufacturing closed loop supply chains with a co-opetitive strategy in e-markets.

2.2. Remanufacturing and planning decisions-related literature

Guide Jr. et al. [27] analyzed the impact of lead time variation on the process of release of components from the disassembly station to the remanufacturing station in a recoverable manufacturing environment. This work developed a simulation mode due to the dynamic nature of scheduling disassembly. It aims to provide foundations for the development of a complete production planning and control system for recoverable manufacturing. Laan et al. [38] analyzed the influence of lead-time duration and lead-time variability on total expected costs in production/inventory systems with manufacturing and remanufacturing operations. They apply simple push- and pull-strategies to implement and actually use in practice. Kiesmüller [33] investigated a single product recovery system for linear cost structure, a finite planning horizon, dynamic demand and return rates. Using the optimal control policy can be quite helpful, especially for production planning. Tang et al. [53] examined a disassembly remanufacturing system and develop models to determine the planned lead time in production planning and control of remanufacturing. Lieckens and Vandaele [47] utilized a mixed integer nonlinear programming (MINLP) model to solve the reverse logistics network problem with stochastic lead