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Optimization of product refurbishment in closed-loop supply chain using multi-period model integrated with fuzzy controller under uncertainties

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ABSTRACT

Nowadays, product refurbishment is one of the most profitable and environmental benefit processes, drawing more and more attention from both product manufacturers and customers. This paper structures and optimizes the process of product refurbishment, considering inventories and uncertainties. A multi-period model is established. To deal with the uncertainties, an innovative fuzzy controller embedded with a quality indicator is proposed. Numerical experiments have been carried out to test and demonstrate the optimization quality of the proposed method. The results of numerical experiments proved the effectiveness of the proposed fuzzy controller, that can deal with the uncertainties of supply and demand in an efficient way.

1. Introduction

Product recovery is one of the most popular research fields in Closed Loop Supply Chain (CLSC). The processes of product recovery include product recycling, remanufacturing, refurbishment, reuse, resell, etc. Among these processes, product refurbishment is one of the most profitable and environmental benefit processes, drawing more and more attention from both product manufacturers and customers. In fact, many electronic products manufacturers have implemented product collection and refurbishment programs.

Many electronic producers have implemented product collection and refurbishment programs. TakingApple for example, this company has taken the lead in introducing refurbished products into the market, called “apple certified refurbished products”. These certified refurbished products, including many versions of ipad and macbook, are available on the Apple website. Another example is one of the most popular electronic products companies in China, MEIZU. This company also has implemented a similar refurbishment plan, especially in cell phone products. Due to strong quality guarantees and relatively low prices, the market for certified refurbished products is growing fast nowadays.

The process of products refurbishment starts from the collection of returned products. In the collection center, companies have to make decisions of collect or not for each returned products. Additionally, if customers trade in their used products for brand new ones, companies also have to decide the trade in allowance. The simulation network in this research provides decision supports for these decisions, considering each returned product’s quality and the inventory level. It helps companies minimize the total inventory costs and maximize customer profitability simultaneously.

In the process of product refurbishment, one of the important and complicatedproblems is the uncertainty of both the demand and supply. The supplies here mean the returned products. How to settle the uncertainty of both the input and output? One of the most difficult problems in dealing with the uncertainties of both supply and demand lies on the attributes of the returned products. The uncertainty in returned products is not only on the quantity but also the quality. This means that the uncertainty of supply further distributes both the quantity and quality, which makes the decision much more difficult. This paper aims to find answers to these research questions. The contributions of this paper are as follows.

(1) This paper structures and optimizes the process of product refurbishment, considering inventories and uncertainties with multi-periods. In the literature, few research studies have focused on the process of returned products refurbishment in CLSC.
(2) A novel fuzzy controller embedded with a quality indicator is proposed. Numerical experiments have proven the effectiveness of the proposed fuzzy controller, that can deal with the uncertainties of supply and demand in an efficient way. Additionally, the quality indicator enhances the ability of the proposed fuzzy controller in dealing with uncertainties in both quantity and quality.
(3) The simulation network implemented in this research provides decision supports for companies, considering both returned products quality and inventory level, minimizing the total inventory costs.

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This paper is structured as follows. Section 1 is the introduction. Section 2 discusses the related literature of product refurbishment in CLSC, and reveals its importance. Section 3 introduces the main topic. Section 4 formulates the mathematical model. Section 5 is the methodology part, and explains the proposed fuzzy controller embedded with the quality indicator. In order to prove the effectiveness of the proposed method, Section 6 demonstrates numerical examples. Section 7 concludes this research and puts forward some future research directions.

2. Literature review

In general, a CLSC network is comprised of multiple customers, parts, products, suppliers, remanufacturing subcontractors, and refurbishing sites. To accelerate the recovery of end of life products, so as to reduce the environmental pollution, the network of product recovery within closed-loop supply chain needs better planning. Since effective optimization design of product recovery network leads to efficiency and profitable business operation, thereby attracts more practitioners, it is significant to develop a closed-loop supply chain model considering product recovery. Correspondingly, the analysis of uncertainties became necessary. However, few of the work to date focused on the product recovery issues in closed-loop supply chain.

Product recovery is interpreted as a superior concept that involves concepts such as remanufacturing, refurbishment, reuse and material recycling [1]. Remanufacturing is the process of rebuilding a product, during which the product is disassembled, defective components are replaced and the product is reassembled, tested and inspected to ensure it meets newly manufactured product standards [2]. Refurbishment is the process in which a product or component is cleaned and repaired in order to make a resell [1]. Reuse is the additional use of a component, part or product after it has been removed from a clearly defined service cycle [3]. While material recycling is the process in which the structure of a product is destroyed in order to recapture its materials [1]. Among these processes, product refurbishment is one of the most profitable and environmentally beneficial processes, drawing more and more attention from both product producers and customers.

Jorjani et al. [4] formulated a piece-wise linear concave program to find the optimal disassembly strategy for electronic equipment. Tsai and Hung [5] focused on the treatment and recycling process of the system. They proposed a two-stage decision framework which includes treatment stage and recycling stage. Although supplier selection was added to this framework, it was not optimization of the whole closed-loop supply chain network.

A three-stage model considering evaluation, network configuration, and selection and order allocation was developed by Amin et al [6]. In the first stage, a new Quality Function Deployment (QFD) model was proposed together with fuzzy set theory to assess the relationship between customer requirements, part requirements, and process requirements. In the second stage, a stochastic mixed-integer nonlinear programming model was used to configure the closed-loop supply chain network. In the third stage, suppliers, remanufacturing subcontractors, and refurbishing sites were selected and order allocation determined. The strategic level decisions concerned the amount of goods flowing in the forward and reverse chains, while the tactical level decisions related to balancing the disassembly lines in the reverse chain. In order to evaluate the effects of randomness with respect to recovery, processing and demand volumes on the design decisions, a stochastic model was developed by Chouinard *et al.* [7] for designing logistics networks with consideration of reverse logistics.

The review of product recovery shows that product refurbishment is a rising and important research area, especially considering electrical and electronic products. Davis [8] identified three sources of uncertainty in supply chain network, including demand, manufacturing process and supply uncertainty. Subsequently, Simangunsong et al. [9] split demand uncertainty into customer demand, demand amplification and inaccurate forecasts. In 1998, Mason-Jones and Towill [10] added control uncertainty as another uncertainty source in supply chain.

Uncertainty in supply is a result of the faults or delays in the suppliers' deliveries. Uncertainty in the manufacturing process is caused by poorly reliable production process. As for the demand uncertainty, it is the most important among the three according to Davis [8]. Demand uncertainty is usually presented as a volatility demand or as inexact forecasting demands. In the product recovery system within closed-loop supply chain, all of these sources of uncertainties are exist and more complicated especially for the supply uncertainty, because of the difference between the supply in product manufacturing system and the supply in product recovery system. In product recovery system, the supply is from customers who prefer to return their used products to the collection centre. This supply is uncertain in each returned product quality, returned products quantity and also return lead time. So the analysis of uncertainty in product recovery system is more complicated than in product manufacturing system within closed-loop supply chain.

Moreover, product return processes are also significantly affected by the high degree of uncertainty in terms of the quality, quantity and time of products being returned from the market [11]. The quantity of returned products is volatile and the time of returns is also unpredictable. Both of these factors will affect the operational planning of the recovery processes. As for the quality of returned products, the various abrasion may affect the working procedure in the product recovery process. Hence the research considering uncertainty in terms of quality and quantity of returned products in product recovery becomes significant. While in the literature, few research inspected in this field of product recovery.

Jindal and Sangwan [12] established a fuzzy Mixed Integer Linear Programming model to optimize a multi-product, multi-facility capacitated CLSC uncertainty. Ozceylan and Paksoy [13] investigated the strategic and tactical decisions in CLSC. A fuzzy multi-objective Mixed Integer Non-linear Programming model was established, and several fuzzy interactive programming approaches were applied to solve this model. The results of computational experiments showed that the proposed model and approaches can effectively be used in practical CLSC problems. Nakandala et al. [14] investigated the total cost of the inventory system, and found that the change in stochastic demand during the lead time is the major factor that affects the total inventory costs.

Zhou et al. [15] developed a multiproduct CLSC network equilibrium modelunder a stochastic environment. To tackle the uncertainty associated with the quantity of returned products, a stochastic programming model for waste stream acquisition systems was proposed by Behdad et al. [16]. Nie et al. [17] developed a three closed-loop supply chain model and conducted a comparison for three models in the light of the retail price, demand, return rate, and the profits received by the supply chain members.

Pochampally and Gupta [18] developed a three-stage fuzzy logic approach dealing with the uncertainties in reverse logistics. Illustrative examples have been implemented. Ganga and Carpinetti [19] established a supply chain performance model based on fuzzy logic to predict supply chain performance. They found that the adoption of fuzzy logic in a prediction model contributes a lot in the decision making of managing supply chain performance. Prakash and Deshmukh [20] proposed a heuristic based on artificial immune system (AIS), a fuzzy logic controller was incorporated in it. A benchmarking experiment taken from literature review showed the efficiency of the incorporated fuzzy controller. Kumar et al. [21] established four multi-input single-output (MISO) Mamdani fuzzy inferencesystems for supplier evaluation. This method, considering the extent of the production cost that involves raw material costs, can be very helpful to companies for making decisions about supplier evaluation.

Marzieh Zarinbal [22] proposed a flexible fuzzy reinforcement learning algorithm, in which the value function is approximated by a fuzzy rule-based system. The proposed algorithm has a separate module for tuning the structure of the fuzzy rules. Moreover, the parameters of the