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Reverse channel decisions for a fuzzy closed-loop supply chain

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ABSTRACT

This article reports the results of a study that explores the decisions of reverse channel choice in a fuzzy closed-loop supply chain. Specifically, a manufacturer produces new products by using original components or by remanufacturing used products and wholesales the new products to the retailer who then sells them to the consumers. The used products are collected by the manufacturer or the retailer or a third party. The primary goal of this paper is to investigate the implications of three different used-product collection modes on the decisions of the manufacturer, the retailer, and the third party, and on their own profits in the expected value model. By using game theory and fuzzy theory, the firms optimal strategies are obtained.

1. Introduction

With the increased environmental consciousness, environmental concerns and stringent environmental laws, closed-loop supply chain management has received growing attention from both business and academic research throughout this decade [1]. A distribution system, which uses a combination of manufacturing and remanufacturing, is called closed-loop supply chain [2]. A closed-loop supply chain includes the forward supply chain and the reverse supply chain. The reverse supply chain can be defined as the logistics activities all the way from used products no longer required by the customer to products again usable in the market [3]. Costs derived from reverse-logistics activities in the US exceed $35 billion per year, remanufacturing is a $53 billion industry in the US [4]. Without a doubt, closed-loop supply chain has become a matter of strategic importance – an element that companies must consider in decision-making processes concerning the design and development of their supply chains [5].

One of the important management issues in remanufacturing industry is to effectively match demand and supply by dealing with the uncertainty of the quality and quantities of the collected products and the uncertainty of the market demand. Since the returned products are not pre-sorted in many cases and the information about their quality is usually limited to firms, the amount of remanufacturable parts which can be recovered from the returned products is subject to uncertainty [6].

Traditionally deterministic or probabilistic concepts have been used to model the various parameters among today's many studies published on the closed-loop supply chain [7–11]. In these studies, the input parameters are described as crisp values or having crisp probability distributions. Although these models provide some general understating of the behavior of closed-loop supply chain under different assumptions, they are not capable of perfectly representing real-life situations. For example, in many cases where there is little or no historical data available to the decision maker, perhaps due to recent changes in the closed-loop supply chain, probability distribution may simply not be available, or may not be easily or accurately estimated [12]. Moreover, in some cases, it may be impossible to collect data on the random variables of interests

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because of certain system or time constraints. Additionally, other critical closed-loop supply chain parameters, in particular the various costs that impact the system, are often ill-defined and may vary from time to time. All of these situations raise challenges for using traditional supply chain models in practice [13].

In the above situations, the uncertainty parameters can be approximately estimated by manager's judgements, intuitions and experience, and can be characterized as fuzzy variables [14], e.g. the phrase ''around x dollars'' to describe a cost that can be regarded as a fuzzy variable $\tilde{x}$. Therefore, the quantitative demand forecasts based on manager's judgements, intuitions and experience seem to be more appropriate, and fuzzy theory rather than probability theory should be applied to model these kinds of uncertainties [14]. Fuzzy theory provides a reasonable way to deal with the possibility and linguistic expressions. Zadeh [15] initialized the concept of a fuzzy set via membership function. From then on, many researchers such as Nahmias [16], Kaufmann and Gupta [17] made great contributions to this field. Recently, Liu [18], Liu and Liu [19] laid a new foundation for optimization problems in the fuzzy environment, in which the expected value was proposed to deal with optimization problems.

In recent supply chain studies, some researchers have already adopted fuzzy theory to depict uncertainties in supply chain models [20–23]. Zhao et al. [24] considered the pricing problem of substitutable products in a fuzzy supply chain. Chou et al. [22] proposed an improved solution procedure for a fuzzy EOQ model with fuzzy budget and storage capacity constraints. Giannoccaro et al. [25] presented a methodology to define a supply chain inventory management policy, which is based on the concept of echelon stock and fuzzy set theory. Wei and Zhao [26] considered the optimal pricing decision problem of a fuzzy closed-loop supply chain with retail competition. Xu and Zhai [27] considered a two-stage supply chain coordination problem with demand uncertainty by using fuzzy numbers to depict customer demand. Ebrahimnejad et al. [28] considered a construction project problem under multiple criteria in a fuzzy environment and proposed a new two-phase group decision making (GDM) approach. However, to our best knowledge, no research on the problem of reverse channel choice under fuzzy environment has been given.

In this paper, a fuzzy closed-loop supply chain model with one manufacturer, one retailer and one third party is presented, the fuzziness is associated with the consumer demand, the remanufacturing cost, and the collecting cost of the used product. In the forward supply chain, the manufacturer produces new products by using original components or by remanufacturing used products which are collected from end consumers, and wholesales the new products to the retailer who then sells them to the consumers. For the reverse supply chain, three different collecting modes are considered in this paper, namely, the manufacturer collecting used products directly from the customers, the manufacturer contracting the collection of used products to the retailer, and the manufacturer contracting the collection of used products to a third party. By using game theory and fuzzy theory, we investigate the implications of the three different used-product collection modes on the decisions of the manufacturer, the retailer, and the third party, and on their own expected profits in the expected value model. Moreover, some management insights are also given by using numerical studies.

The rest of the paper is organized as follows. Section 2 gives the preliminaries for this paper. Section 3 gives the problem description and notations, and Section 4 details our key analytical results. Numerical studies are given in Section 5. Concluding remarks are presented in Section 6.

2. Preliminaries

A possibility space is defined as a triplet $(\Theta, \mathcal{P}(\Theta), \mathrm{Pos})$, where Θ is a nonempty set, $\mathcal{P}(\Theta)$ the power set of Θ, and Pos a possibility measure. Each element in $\mathcal{P}(\Theta)$ is called an fuzzy event. For each event A, $\mathrm{Pos}\{A\}$ indicates the possibility that A will occur. Nahmias [16] gave the following three axioms.

Axiom 1. $\mathrm{Pos}\{\Theta\}$=1.

Axiom 2. $\mathrm{Pos}\{\phi\}$=0, where ϕ denotes the empty set.

Axiom 3. $\mathrm{Pos}\{\bigcup_{i=1}^{m} A_i\} = \sup_{1\leqslant i\leqslant m}\mathrm{Pos}\{A_i\}$ for any collection A_i in $\mathcal{P}(\Theta)$.

Besides the axioms mentioned above, there is another axiom given by Liu [29] to define the product possibility space.

Axiom 4. Let Θ_i be nonempty sets, on which Pos_i is possibility measure satisfying the first three axioms, $i = 1, 2, \ldots, n$, and $\Theta = \prod_{i=1}^{n}\Theta_i$. Then

$$\mathrm{Pos}\{A\} = \sup_{(\theta_1,\theta_2,\ldots,\theta_n)\in A} \mathrm{Pos}_1\{\theta_1\} \wedge \mathrm{Pos}_2\{\theta_2\} \wedge \cdots \wedge \mathrm{Pos}_n\{\theta_n\}$$

for each $A \in \mathcal{P}(\Theta)$. In that case we write $\mathrm{Pos} = \wedge_{i=1}^{n}\mathrm{Pos}_i$.

Lemma 1 (*Liu [29]). Suppose that $(\Theta_i, \mathcal{P}(\Theta_i), Pos_i)$ is a possibility space, $i = 1, 2, \ldots, n$. By Axiom 4, $(\prod_{i=1}^{n}\Theta_i, \mathcal{P}(\prod_{i=1}^{n}\Theta_i), \wedge_{i=1}^{n}Pos_i)$ is also a possibility space, which is called the product possibility space.*