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Closed-loop supply chain network design under a fuzzy environment

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ABSTRACT

Designing a logistic network is a strategic and critical problem that provides an optimal platform for the effective and efficient supply chain management. In this research, we address the application of fuzzy sets to design a multi-product, multi-period, closed-loop supply chain network. The presented supply chain includes three objective functions: maximization of profit, minimization of delivery time, and maximization of quality. In the context of fuzzy mathematical programming, the paper jointly considers fuzzy/flexible constraints for fuzziness, fuzzy coefficients for lack of knowledge, and fuzzy goal of decision maker(s). According to fuzzy components considered, a fuzzy optimization approach is adopted to convert the proposed fuzzy multi-objective mixed-integer linear program into an equivalent auxiliary crisp model to obtain the relevant solutions. Finally, the numerical experiments are given to demonstrate the significance of the proposed model as well as the solution approach.

1. Introduction

In today's world, enterprises have to handle the growing markets and the increasing customer expectations to survive in an ever-increasing competitive environment. In this regard, supply chain management (SCM) is one of the important research areas that has attracted the attention of enterprise managers and academic communities. One of the critical planning activities in SCM is to design the supply chain network. Supply chain network design (SCND) is an infrastructure problem in SCM having a long-lasting effect on activities at the tactical/operational level. Moreover, growing attention has been recently given to reverse logistics in SCM because of the prevention of primary resource use, pollution reduction, waste management, environmental concern, social responsibility, government directives (e.g. the European Union WEEE Directive), and customer pressures. More details about this issue can be found in Pokharel and Mutha [23] and Tseng et al. [29].

Successful supply chain management requires considering the various performance measures. While profitability tries to reduce the costs and the number of facilities, responsiveness causes a contrary effect. A high number of facilities can reduce the lead time to deliver a product to the final customer for firm, resulted in a competitive advantage in the market. Moreover, many organizations emphasize quality as a tool reputation to compete in business over their lifetime. It creates a reputation of high quality as representing future market share for new customers and maintaining market share for existing customers over the long run. In this regard, Six Sigma (6σ) is a one popular method to quantify quality, which is usually represented as a defect rate parts per million (PPM) [35].

From the practical point of view, when a SCND problem is addressed, and the corresponding expert is questioned regarding the details of the model parameters such as cost and demand, in many circumstances the answers given have a vague nature. For example, it is said that the cost is "about 32" or the demand is "not much more than 650". A useful tool to model these situations is the use of the concept of fuzzy numbers, since it permits numerical treatment of these types of qualitative descriptions, and that is a natural expression of the habitual form of communication between human beings [3,7]. For the applications of fuzzy theory in the study of supply chain, readers can refer to Wang et al. [31,32].

Based on the considerations described above, this paper presents a multi-objective model for designing a multi-product, multi-echelon, closed-loop logistic network over a multi-period horizon in a fuzzy environment. The model considers three objective functions: profit maximization, time minimization, and quality maximization. Moreover, in the context of fuzzy mathematical programming, two different issues can be considered: fuzzy/flexible constraints for fuzziness, and fuzzy coefficients for lack of knowledge [6]. The model proposed in this paper considers both the possible lack of knowledge in data and existing fuzziness. In other words, the main contributions of this paper can summarized as follows:

- Presenting a novel closed-loop supply chain design model integrating the forward flows and the reverse flows in the presence a multi-echelon, multi-product, and multi-period network.

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- Achieving the applicability and effectiveness of the fuzzy modeling approach for the proposed SCND model, contemplated the different sources of uncertainty as flexible constraints, fuzzy coefficients, and fuzzy goals of decision maker(s).

The structure of this paper is as follows. Section 2 reviews the state-of-the-art from the existing literature in the SCND area. In Section 3, we present a multi-objective model for multi-period, multi-product, closed-loop SCND with fuzziness in the parameters, constraints, and decision maker (DM)'s goals. The solution methodology of the proposed model is explained in Section 4. Section 5 presents a numerical example and discusses the computational results. Finally, we give the conclusions of this paper in Section 6.

2. Literature review

Many researchers have attempted to design and optimize the SCND problem. These studies comprise the diverse models ranging from simple linear deterministic problems to complex non-linear non-deterministic ones. Melo et al. [18] have provided the state-of-the-art of existing studies in the logistic network design. Here we focus on the studies associated with the closed-loop supply chain, and inquire into the most relevant and recent models as: deterministic, stochastic, and fuzziness.

In general, the focus of studies is on a deterministic approach and single objective, i.e. minimizing costs or maximizing profit. Fleischmann et al. [10] considered a reverse logistic design model that optimizes the forward flow together with the return flow without considering the capacity limit. Ko and Evans [13] developed a dynamic integrated forward/reverse network considering the third party logistic (3PL) service provider and used a Genetic Algorithm (GA) to solve their model. Üster et al. [30] presented a multi-product close-loop SCND model solved by the Bender decomposition method. They considered the production and reproduction separately and assumed a single sourcing for the customers. Aras et al. [1] presented a non-linear recovery logistic network design and proposed a Tabu search solution procedure to specify the locations of collection centers and the suitable price of returned products. Min and Ko [19] proposed a dynamic design of a reverse logistic network and presented a GA to solve the problem including the location and allocation for 3PLs. A bi-objective integrated forward/reverse supply chain design model was suggested by Pishvaee et al. [21], in which the cost minimization and the responsiveness maximization of a logistic network was considered as objectives of the model. They developed an efficient multi-objective memetic algorithm by applying three different local searches in order to find the set of non-dominated solutions.

Furthermore, several studies take into account closed-loop SCND models with stochastic parameters. Salema et al. [26] extended Fleischmann's model to a capacitated multi-product reverse logistic network with uncertainty on demands and returns used at an Iberian company. Lee and Dong [15] proposed a dynamic reverse logistic network under demand uncertainty. A solution approach integrating a proposed sampling method with a Simulating Annealing (SA) algorithm was extended to gain solutions. El-Sayed et al. [8] presented a multi-period multi-echelon forward-reverse logistic network design model under demand and return uncertainty where the objective of their model is to maximize the profit of the supply chain. Ramezani et al. [24] introduced a multi-objective stochastic model to design a forward/reverse supply chain network under an uncertain environment. The performance of the chain was evaluated through three measures: profit, customer responsiveness, and quality of suppliers. The Pareto optimal solutions along with the relevant financial risk were computed to illustrate tradeoffs of objectives that give a proper insight for having a better decision making. Ramezani et al. [25] presented a supply chain design for a multi-product closed-loop network in an uncertain environment. A robust optimization approach was adopted to cope with the uncertainty of demand and the return rate described by a finite set of possible scenarios. Moreover, to obtain robust solutions with better time, the scenario relaxation algorithm was used for the proposed model.

Moreover, a number of papers consider fuzziness in these models. Pishvaee and Torabi [22] presented a possibilistic programming approach for the closed-loop supply chain network design. The objective of the model was to minimize the total costs and maximize the total delivery tardiness. Fallah-Tafti et al. [9] proposed a multi-objective model for a closed-loop supply chain network design with uncertain parameters, such as cost coefficients and customer demands. They presented an interactive possibilistic approach based on the well-known STEP method to solve the multi-objective mixed-integer linear programming model.

As summarized above, a few researchers address closed-loop SCND in a fuzzy environment. Moreover, these researches have used fuzziness in parameters and did not consider fuzziness associated to the flexible constraints. Instead, this paper considers incomplete or imprecise information in data and the flexibility of

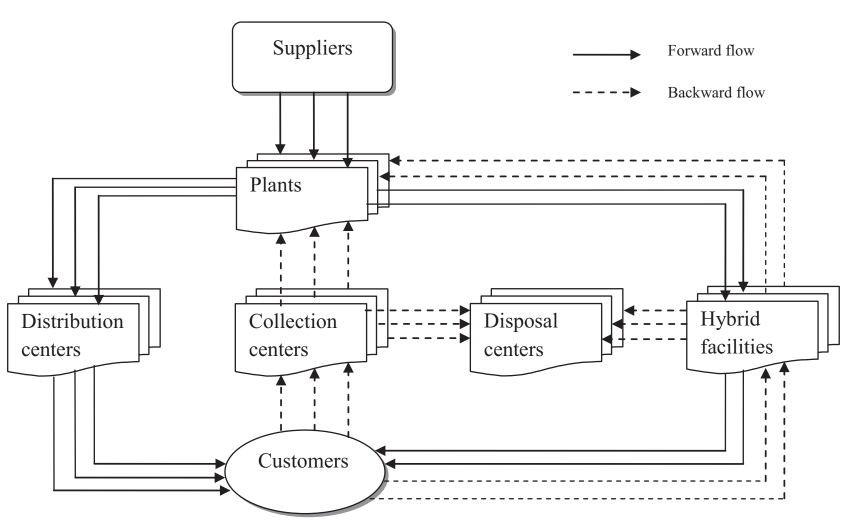

Fig. 1. Structure of the proposed closed-loop logistic network.