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A novel robust fuzzy stochastic programming for closed loop supply chain network design under hybrid uncertainty

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Abstract

In today's business environments, the high importance of economic benefits and environmental impacts of using scrapped products has caused most companies to move to designing the closed loop supply chain network. This paper considers the closed loop supply chain network design problem under hybrid uncertainty, while there are two sources of uncertainty for most parameters, thus require fortifying of the robustness of the decision. The first source is that some uncertain parameters may be based on the future scenarios which are considered according to the probability of their occurrence. The second source is that the values of these parameters in each scenario are usually imprecise and can be specified by possibilistic distributions. In this case, the best robust decision has some additional properties in terms of mean value and variability of the objective function. We introduced two types of the variability named scenario variability and possibilistic variability. Possibility theory is used to choose a solution in such a problem and a novel robust fuzzy stochastic programming approach is proposed that has significant advantages. The performance of the proposed model is also compared with that of other models in term of the mean cost and variability by simulation.

Keywords: Robust fuzzy stochastic programming; Possibilistic mean absolute deviation; Credibility measure; Closed-loop supply chain network design, hybrid uncertainty

1. Introduction

A closed loop supply chain network (CLSCN) is an integrated system which includes both the forward and reverse supply chains, simultaneously. The CLSCN design is one of the infrastructure issues including decision making on the number, location, capacity, coordination of facilities, the flows through the network, purchasing and production values, and inventory holding in order to optimize the entire supply chain operations [6]. In the recent decade, the increasing importance of economic benefits and environmental impacts of using scrapped products has encouraged most companies to focus on the CLSCN design [52,39,47]. In fact, they have an interest in performing the CLSCN

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activities such as recovering, recycling, remanufacturing and disposing operations [16]. Since the integrated design of forward and reverse supply chain is a critical factor in reducing the costs, improving service level, and responding to environmental issues, most researchers (e.g., [61,49,66,16,22]) have recently focused on the CLSCN design problem.

In a practical decision-making environment, the CLSCN design problem is subject to many types of uncertainty including random and fuzzy (epistemic) uncertainties [43,46,6,56]. In the classical supply chain design problem, it is assumed that capacity, demand and costs are precisely known. It is obvious that this assumption is not realistic in practice. In most real environments we often try to describe a supply chain design problem whose parameters are not known a priori. While producing a solution we must take into account this uncertainty and consider that more than one possible realization may occur in the problem. We can rather define a range of possible values or sometimes probability or possibility distributions for handling the uncertainty. In uncertainty based programming approaches a set of possible realizations, called a *scenario set*, is provided. There are two approaches for defining this set. In the first one, called *discrete uncertainty representation*, we explicitly specify a set of all possible realizations with their corresponding probabilities for each parameter. In the second approach, called *interval uncertainty representation*, we define an interval of possible values for every parameter and limit it within a probability or possibility distribution function. Here scenario set is defined as the Cartesian product of all these intervals [29]. The discrete representation of uncertainty allows us to model a *disruption* (*structural*) *uncertainty* that is the one connected with some unpredictable events that have a global and main influence on the considered system. For instance, in a supply chain problem, several discrete scenarios for demand may be connected with the appearance of a new competitor, changes of customer usage patterns and economic crises and fluctuations. On the other hand, using the interval uncertainty representation we can handle an *operational* (*local*) *uncertainty*, corresponded with an imprecise nature of parameters in the supply chain problem. This type of risk is caused by uncertainties such as uncertain demands, supply, production and shipping costs, capacity, and lead time [54,6].

As the body of recent literature about CLSCN design problem shows, most developed mathematical programming models are the models under uncertainty. In the area of the supply chain network design, these programming models are ranged from stochastic (e.g., [1,50,66]), fuzzy (e.g., [55,45]) and robust (e.g., [46,22]) models to robust possibilistic (e.g., [48,7]) and robust stochastic (e.g., [40,21]) models. In the area of fuzzy mathematical programming, there are two different issues including flexibility or fuzziness in constraints and epistemic uncertainty in data, which are handled by flexible programming (e.g., [60,45]) and possibilistic programming (e.g., [34,55,47]), respectively. However, in some approaches, these two issues have been jointly considered in a coherent sense [8,43]. On the other hand, programming approaches under uncertainty involve a variety of modeling philosophy including minimization of expected (or mean) cost, minimization of cost deviations and minimization of maximum cost (worst case approach or minmax one). Some authors have used possibility theory to model the epistemic and fuzzy uncertainty including Dubois and Prade [11], Lai and Hwang [33], Liu and Iwamura [34], Inuiguchi and Ramik [26], Dubois et al. [15] and Jimenez et al. [27]. One of the main disadvantages of the possibilistic programming models either based on mean value [9] or expected value [27] is that they only address mean or expected values of the objective function in developing possibilistic programming models. In fact, despite of the wide investigation of risk issue in stochastic environments in different areas [40,21], risk and deviations control of objective function under the fuzzy conditions have been neglected and all decisions are made under average condition of realization of the uncertain parameters [64].

For addressing the risk issue in the stochastic programming, Mulvey et al. [40] proposed a flexible robust optimization approach for scenario-based stochastic programming models called *robust stochastic programming*. The programming approach, later developed by Yu and Li [58] and Leung et al. [38], has been widely applied in designing the supply chain networks (e.g., [6,44]). In the area of the possibilistic programming, Pishvaee et al. [48] developed a new approach called *robust possibilistic programming*. Also, Zhang et al. [64,63] produced the portfolio selection models based on the lower and upper possibilistic means and possibilistic variances of objective function. In formulation of Zhang and Zhang [65], absolute deviation is defined as a constraint and its upper bound is determined by decision maker's (DM) preferences. Indeed, in their formulation risk of possibilistic objective function is not included in the objective function for optimization. Babazade et al. [7] also proposed a new formulation of possibilistic programming method which is able to minimize the deviation (risk) values beside the total mean of the problem with epistemic uncertainty. In the robust stochastic and robust possibilistic models, it has been tried to minimize the expected value of the objective function and the deviation over and under the expected optimal value under stochastic and possibilistic environments, respectively.