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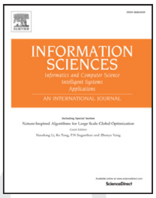

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A fixed-charge transportation problem in two-stage supply chain network in Gaussian type-2 fuzzy environments

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ABSTRACT

This paper presents two mathematical models representing imprecise capacitated fixed-charge transportation problems for a two-stage supply chain network in Gaussian fuzzy type-2 environment. It is a two-stage transportation process from a manufacturing center to m potential distribution centers (DCs) and then from DCs to business centers of n retailers with particular demands. Retailers are situated at some distances apart. Here unit transportation costs, fixed charges, availabilities, and demands are imprecise and represented by Gaussian type-2 fuzzy numbers. The proposed models are formulated as profit maximization problems in such a way that some DCs are selected in order to satisfy the demands at all retailers. The type-2 fuzziness has been removed by using generalized credibility measure developed with the help of CV-based reduction method and hence the models are reduced to chance constrained programming problems with different credibility labels. The deterministic models are then solved using both genetic algorithm (GA) based on Roulette wheel selection, arithmetic crossover with uniform mutation and modified particle swarm optimization (PSO), where the position of each particle is adjusted according to its own experience and that of its neighbors. Finally models are illustrated with some numerical data. Some sensitivity analyses on the proposed models are presented.

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1. Introduction

Supply chains (SCs) are generally complex. A SC is characterized by numerous activities spread over multiple functions and organizations (cf. [2,27]). The SC is a worldwide network comprised of suppliers, factories, warehouses, distribution centers, and retailers. In a SC, raw materials are acquired, transformed, and delivered to customers (cf. [9,24]). It has evolved very rapidly since 1990s showing an exponential growth in the literature [3].

A transportation problem (TP) is often associated with additional costs (termed as fixed charges) besides transportation cost. The fixed charge transportation problem was first proposed by Hirsch and Dantzig [12]. This problem considers two types of costs, say direct cost and fixed charge. The fixed charge costs may be due to permit fees, toll charges, etc. Since the introduction of TPs by Hitchcock [11], there have been lots of developments in this area by several researchers. Chanas et al. [4] formulated and solved TPs with fuzzy supply and demand values. Recently, Fegad et al. [7] found optimal solutions to TPs using interval and

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triangular membership functions. Kaur and Kumar [13] provided a new technique to solve TPs with transportation costs (TCs) as generalized trapezoidal fuzzy numbers. All the above investigations assumed the fuzzy parameters/variables to be of type-1 fuzzy set (T1FS). In decision making problems like transportation, the available data/possible values of the system parameters cannot be always exactly determined and known. There are several reasons for that like lack of input information, multiple sources of data, fluctuating nature of parameter values, noise in data, bad statistical analysis, uncertainty in judgment, etc. For example, transportation cost depends upon fuel price, labor charges, tax charges, etc., each of which fluctuates from time to time. So it is not easy to predict the exact transportation cost of a route for a certain time period. Generally possible values of parameters are given by the experts in approximate intervals, linguistic terms, etc. For instance, unit transportation cost for a route is “about 10$”, say between 8$ and 10$, the supply of a source is “around 35–38 units”, etc. Also each of the point in a given interval may not have the same importance or possibility. For a large data set of a certain parameter collected from previous experiments, generally all the points are not equally possible. Such types of linguistic information, approximate intervals and non-equipossible data set can be expressed by type-2 fuzzy sets (T2FSs) where membership degree of each point cannot be exactly determined. The three dimensional nature of a T2FS gives an extra degree of freedom to represent uncertainty over the ordinary fuzzy set. Also In case of computing with wards, a word does not have the same meaning to different people. Mendel [35,36] explained that a sensible way to model a word is to use T2 FS, more precisely using interval T2 FS. Also Mendel [35] explained using Popper’s Falsificationism that modelling a word using type-1 fuzzy set is not scientifically correct. As explained above, in some case this membership function also becomes uncertain and it is represented by another fuzzy function. These functions may be triangular, trapezoidal, etc. In real-life uncertain data, it is more appropriate to represent the impreciseness by Gaussian type-2 fuzzy numbers. Such a fuzzy set is called type-2 fuzzy set (T2FS). Due to fuzziness in membership function, the computational complexity is very high to deal with T2FS. For a T2FS, normally complete defuzzification process consists of two parts – type reduction and defuzzification proper. Type reduction is a procedure by which a T2FS is converted to the corresponding type-1 FS(i.e. ordinary fuzzy set), known as type reduced set (TRS). Karmik and Mendel [14] proposed a centroid type reduction method to reduce interval T2FS to T1FS. But it is very difficult to apply this method to a generalized T2FS. Some researchers (cf. [5,19,29,34], etc.) developed type reduction strategies for continuous generalized T2FS. Coupland [6] proposed a geometric defuzzification method for T2FSs by converting a T2FS into a geometric T2FS. Recently, Qin et al. [22] introduced three kinds of reduction methods called optimistic critical value (CV), pessimistic CV and CV reduction (critical values) of regular fuzzy variables. In transportation, transportation parameters such as unit transportation costs, fixed charges, resources and demands are sometimes uncertain. Furthermore, those uncertainties are evaluated by the opinions of experts or insufficient/ambiguous data. In this evaluation, in some cases, grades of these uncertainties are again uncertain and represented by another fuzzy function. Hence the above fuzzy transportation parameters are represented by type-2 fuzzy function. Figueroa and Hernandez [8] first considered a TP with interval type-2 fuzzy demands and supplies. Recently Kundu et al. [16] have solved fixed charge transportation problem (FCTP) with type-2 fuzzy parameters. They introduced an interval approximation method of continuous type-2 fuzzy variables. Abdullah and Najib [1] have developed a new type-2 fuzzy set of linguistic variables for the fuzzy analytic hierarchy process. But they did not consider the variables as Gaussian type-2 type. It requires a different reduction method for reduction to type-1 fuzzy set (T1FS) and then a different defuzzification method. Recently, intelligent fuzzy system draws attention as a new tool for decision making problems under fuzzy environments (cf. [31–33]).

There are mainly two methods available in literature regarding construction of type-2 fuzzy sets. The first kind is the fuzzistics approach [11–14] which utilizes one kind of uncertainty measures of interval type-2 fuzzy set (IT2FS) system-centroid to determine the parameters of IT2Fss to ensure that the identified IT2FS model can fit measured data in some sense. On the other is the interval approaches in [15] with its enhanced approach in [16]. The interval approaches adopt the statistics methods to realize the IT2Fs modelling. Miller et al. [39] introduced a method using interval valued survey responses from multiple experts on multiple occasions to produce type-2 fuzzy sets. More precisely if more than one expert gives the values of a system parameter on several occasions by interval numbers then a type-2 fuzzy set can be constructed representing all of the expert’s opinions for all surveys [39]. There are some methodologies also, such as the interval approach [34], the person membership function approaches [37] and the interval end-points approach [38] available in literature to obtain mathematical models for IT2 FS for words. Pagola et al. [40] introduced a method of construction of an interval type-2 fuzzy set from several membership functions. In this paper, we present the construction of general T2FSs following Miller et al. [39].

Recently, genetic algorithms (GAs) are used as optimization for decision making problems. GAs [10,25] are adaptive computational procedures modelled on the mechanics of natural genetic systems. They exploit the historical information to speculate on new offspring with expected improved performance. These are executed iteratively on a set of coded solutions (called population) with three operators – selection/reproduction, crossover and mutation. One set of these three operators are known as a generation in the parlance of GA. Since a GA works simultaneously on a set of solutions, it has very little chance to get struck at local optimum. Here, the resolution of the possible search space is increased by operating on potential solutions and not on the solutions themselves. Further, this search space needs not to be continuous. Recently, GAs have been applied in different areas like travelling salesman, scheduling, numerical optimization, etc. (cf. [21,25] and other).

Particle swarm optimization (PSO) is a heuristic optimization technique based on swarm intelligent. PSO is inspired by the behavior of bird flocking (cf. [15]). Like GA, a PSO normally starts with a set of solutions (called swarm) of the decision making problem under consideration. Individual solutions are called particles and food is analogous to optimal solution. The particles are flown through a multi-dimensional search space, where the position of each particle is adjusted according to its own experience and that of its neighbors. Many studies have been made to improve PSO algorithm in continuous optimization (cf. [17,20,23,26]).

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