Information Sciences 297 (2015) 293–315

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Multi-attribute group decision making using combined ranking value under interval type-2 fuzzy environment

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ARTICLE INFO

Article history:
Received 12 December 2013
Received in revised form 29 October 2014
Accepted 5 November 2014
Available online 26 November 2014

Keywords:
Multiple attribute group decision making
Interval type-2 fuzzy set
Interval type-2 fuzzy entropy
Combined ranking value
Least squares method

ABSTRACT

In this paper, we investigate a new method to handle multiple attribute group decision making (MAGDM) problems based on combined ranking value under interval type-2 fuzzy environment, in which all the attribute values provided by experts take the form of interval type-2 fuzzy sets (IT2FSs). We first introduce some basic concepts and related operational laws on IT2FSs. Then, we put forward three kinds of ranking value formulas to calculate the ranking value of IT2FSs based on arithmetic average (AA) operator, geometric average (GA) operator and harmonic average (HA) operator, respectively, and discuss some of its desirable properties. Based on these properties, we define the concept of combined ranking value and also further develop a new interval type-2 fuzzy entropy with trigonometric sine function to measure the uncertainty of the IT2FSs. By using the three types ranking value formulas and interval type-2 fuzzy entropy we proposed, a new approach based on the principle of combinatorial optimization with ranking-entropy and the least squares for determining attribute weight is given. Furthermore, a decision making procedure based on combined ranking value is given to select the best alternative(s). Finally, a simple practical example concerns that urban rail transit evaluation is provided to illustrate the practicality and effectiveness of the proposed method, and a comparative analysis is performed.

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1. Introduction

Fuzzy multiple attribute group decision making (MAGDM) is an important topic both in fuzzy sets (FSs) theory and its applications [1–4,6]. With a development of FSs theory and its application in the past few years, many approaches have been presented for handling MAGDM problems based on type-1 fuzzy sets (T1FSs) theory [5–13]. For example, Xu and Chen [5] developed a interactive approach for selecting a fuzzy MAGDM problem, the method can not only reflect the importance of the given arguments and the ordered positions of the arguments, but also relieve the influence of unfair arguments on the decision result. Hatami-Marbini and Tavana [6] investigated an extension of the ElECTRE-I method for solving MAGDM problems under fuzzy environment. Herrera et al. [7] established some decision models based on multiplicative preference relations for solving MAGDM problems, where several transformation functions are obtained to relate preference orderings and utility functions with multiplicative preference relations. Chiclana et al. [8] presented some induced ordered weighted averaging (IOWA) operators and applied them for solving MAGDM problems based on fuzzy preference relations. Herrera-Viedma et al. [9,10] constructed a consensus model for group decision making with incomplete fuzzy preference relations and

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http://dx.doi.org/10.1016/j.ins.2014.11.022
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multigranular linguistic preference relations. Cabrerizo et al. [11] proposed a consensus model for group decision making problems with unbalanced fuzzy linguistic information. Wang and Elhag [12] proposed a fuzzy TOPSIS based on α-cut level for MAGDM and then applied it for bridge risk assessment. Li and Yang [13] developed a linear programming technique for multi-dimensional analysis of preferences in multi-attribute group decision making under fuzzy environment. In addition, some authors also used T1FSs decision making theory successfully in granular computing [14,15], social network analysis [16], financial risk management [17], facility location selection [18,19] and some other domains [20–22].

However, due to the increasing complexity of social economic environment and the vagueness of the inherently subjective nature of human thinking, in many practical decision making situations, there are various limitations, such as a lack of information, uncertainty of the decision-making environment, and difficulties in information extraction, etc. Therefore, it is often difficult to determine the exact values of the membership degree under real-world decision environment. Meanwhile, with increasing system complexity and uncertainty, T1FSs are unable to handle such high complexity and uncertainty. To overcome the limitations of T1FSs theory, Zadeh [23] presented type-2 fuzzy sets (T2FSs) theory in 1975, which can be regarded as an extension of the concept of T1FSs that is characterized by two membership functions: primary membership function (PMF) and secondary membership function (SMF), with the additional dimension of membership function, T2FSs can deal with the fuzziness and uncertainty characteristics of fuzzy complex systems more accurately and effectively than the traditional T1FSs. In recent years, many works have been done and fruitful research results have been achieved in T2FSs [24–31]. In theoretical research, Mendel [24] further developed the fundamental theory and extended related operational laws of T2FSs. Karnik and Mendel [25] presented the approximation iterative algorithm for computing the centroid of the T2FSs, as well-known Karnik–Mendel(KM) algorithm, which was the most widely used method for type reduction of T2FSs. Wu and Mendel [28,29] studied uncertainty measures for IT2FSs and made a comparative study of ranking methods, similarity measures and uncertainty measures for IT2FSs. Zhai and Mendel [26] proposed the uncertainty measures based on a-plane representation for general T2FSs. Liu and Mendel [30,31] improved the type-2 reduction algorithm and obtain some good analytical properties. Greenfield et al. [32] studied the collapsing method of defuzzification of discretised interval type-2 fuzzy sets and further developed the sampling method defuzzification for T2FSs based on experimental evaluation. Greenfield and Chiclana [33,34] proposed a new efficient and accurate method for defuzzification of discretised IT2FSs and generalized type-2 fuzzy sets (GT2FSs). Chiclana and Zhou [35] developed a new type-reduction of GT2FSs based on Type-1 OWA approach.

Similar to the researches on interval type-2 fuzzy sets, some authors investigated the topic of interval-valued fuzzy sets (IVFSs) and obtained some meaningful conclusions mainly in decision making [36–41]. For example, Bustince et al. [42] developed an approach for multiple criteria decision making by means of interval-valued Choquet integrals. After that, Bustince et al. [43] introduced an algorithm to aggregate the preference relations provided by experts in multi-expert decision making problems based on penalty functions defined over a cartesian product of lattices. Barrenechea et al. [44] constructed of interval-valued fuzzy preference relations from ignorance functions and fuzzy preference relations and then application to decision making. Paternain et al. [45] proposed two generalizations of the weighted voting strategy to work with interval-valued preference relationship, and constructed a framework of an alternative to fuzzy methods in decision-making problems.

It is noted in the literatures [24,32,41] that the point of view that IT2FSs are mathematically equivalent to the previous well-known IVFSs is not entirely correct. Recently, Niewiadomski [46] presented a comparison analysis between the IT2FSs and IVFSs, the conclusion shows the fact that IVFSs and IT2FSs are not fully equivalent, although numerous similarities exist. For example, the cardinality of the IVFSs is an interval number, while the cardinality of the IT2FSs is a real number. Moreover, the ordering of the IVFSs is partial order, whereas the ordering of the IT2FSs is total order. As we know, how to fix a linear order, namely, an order allows to compare any two intervals is the most key problem of IVFSs (or IT2FSs). Recently, Bustince et al. [47] introduced the concept of an admissible order as a total order that extended the usual partial order between intervals and then put forward two aggregation functions to derive the admissible orders, by strictly mathematical analysis proved that the most existing total orders are special cases of the proposed admissible orders. Based on this work, Bustince et al. [48] further extended the admissible order by using linear transformations to study interval-valued Choquet integrals and the ordering method with IVFSs, and then applied to multiple criteria group decision making applications.

In applied research, several useful applications [49–51,53,58–73] have been considered in group decision making (GDM) problems under T2FSs environment, especially in the aspect of interval type-2 fuzzy MAGDM problems. For example, Chen et al. [49] developed an extended QUALIFLEX method for handling MAGDM based on interval type-2 fuzzy sets (IT2FSs) and gave a case study for medical decision making. Hu et al. [53] proposed an approach by using probability theory to integrate interval type-2 fuzzy information and applied it in decision making field. Chen and Lee [60] presented an new approach to solve fuzzy multiple attribute hierarchical group decision making (MAHGDM) problems based on arithmetic operations and fuzzy preference relations of IT2FSs, the time complexity of this method is low and it is more efficient than traditional methods. Chen and Lee [58,59] investigated an interval type-2 fuzzy TOPSIS method to handle fuzzy MAGDM problems based on IT2FSs information. Ngan [51] established the probabilistic linguistic framework with IT2FSs MAGDM problems, some arithmetic operations such as union and intersection between the interval type-2 fuzzy linguistic numbers were also be defined. Chen [50] developed a new linear assignment method based on signed distances for handling MAGDM problems with IT2FSs information and applied in the selection of landfill site. Wu and Mendel [61] proposed linguistic weighted average aggregation operator to handle multiple attribute hierarchical group decision making by using fuzzy preference relations under interval type-2 fuzzy environment. Wang et al. [62] investigated some optimization models for determining the attribute

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