Expert Systems with Applications 42 (2015) 873–884

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Hesitant fuzzy QUALIFLEX approach with a signed distance-based comparison method for multiple criteria decision analysis

Xiaolu Zhang [a], Zeshui Xu [b,*]

[a] School of Economics and Management, Southeast University, Nanjing 211189, China
[b] Business School, Sichuan University, Chengdu, Sichuan 610065, China

ARTICLE INFO

Article history:
Available online 7 September 2014

Keywords:
Hesitant fuzzy information
Multi-criteria decision-making
QUALIFLEX
Outranking method
Decision analysis

ABSTRACT

QUALIFLEX (QUALItative FLEXible multiple criteria method) is a very useful outranking method to deal simultaneously with the cardinal and ordinal information in decision making process. The purpose of this paper is to develop a hesitant fuzzy QUALIFLEX with a signed distance-based comparison method for handling multi-criteria decision-making problems in which both the assessments of alternatives on criteria and the weights of criteria are expressed by hesitant fuzzy elements (HFEs). We propose a novel concept of hesitancy index for the HFE to measure the degree of hesitancy of the decision-maker or the decision organization. By taking their hesitancy indices into account, we present a signed distance-based method to compare the magnitude of HFEs. Using the signed distance-based comparison approach, we define the concordance/discordance index, the weighted concordance/discordance index and the comprehensive concordance/discordance index. By investigating all possible permutations of alternatives with respect to the level of concordance/discordance of the complete preference order, the optimal ranking orders of alternatives can be obtained. An application study of the proposed method on green supplier selection is conducted. The study indicates that the proposed method does not require the complicated computation procedures but still yields a reasonable and credible solution.

1. Introduction

Multi-criteria decision-making (MCDM) is a usual human activity which helps making decisions mainly in terms of choosing, ranking or sorting the alternatives (Figueira, Greco, & Ehrgott, 2005). In the real-life world, there are lots of MCDM problems with imperfect, vague and imprecise information. To this end, Bellman and Zadeh (1970) first introduced the theory of fuzzy sets in the MCDM problems as an effective approach to deal with such vagueness and ambiguity in the decision making process, which is known as fuzzy MCDM. Afterwards, many extensions of fuzzy set, such as interval fuzzy set, intuitionistic fuzzy set (IFS), type-2 fuzzy set and fuzzy multiset, etc., have been proposed and used to deal with the uncertainty inherent in practical MCDM problems. Considering some real-life decision situations in which the decision makers (DMs) may hesitate among several values to assess an indicator, alternative, variable, etc., Torra (2010) further extended the fuzzy set to propose the concept of hesitant fuzzy set (HFS). The HFSs are characterized by a membership function represented by a set of possible values, which are able to express the hesitancy of human beings efficiently, especially when two or more sources of vagueness appear simultaneously. Torra (2010) discussed the relationships between HFS and IFS, HFS and type-2 fuzzy set, HFS and fuzzy multiset. He showed that the envelope of HFS is the IFS, all HFSs are type-2 fuzzy sets, and HFSs and fuzzy multisets have the same form, but their operations are different.

The hesitant fuzzy elements (HFEs) (Xia & Xu, 2011) are the basic elements of HFS. Xu and Xia (2011a) gave an example to illustrate the appropriateness of HFEs: a decision organization including several DMs is authorized to estimate the degree that an alternative should satisfy a criterion. Suppose that there are three cases: some DMs provide 0.3, some provide 0.5, and the others provide 0.6, and these three parts cannot persuade each other, and thus the degree that the alternative should satisfy the criterion can be represented by a HFE {0.3, 0.5, 0.6}. It is noted that the HFE {0.3, 0.5, 0.6} can describe the above situation more objectively than the crisp number 0.3 (or 0.5, or 0.6), or the interval number [0.3, 0.6], or the intuitionistic fuzzy number (0.3, 0.4), because the degrees that the alternative should satisfy the criterion are not the interval between 0.3 and 0.6, or the convex of 0.3 and 0.6, but just three possible values. Apparently, the use of hesitant fuzzy assessments makes the DMs' judgments more reliable and informative in decision-making.

* Corresponding author.
E-mail addresses: xiaolu_jy@163.com (X. Zhang), xuzeshui@263.net (Z. Xu).

http://dx.doi.org/10.1016/j.eswa.2014.08.056
0957-4174/

The MCDM with HFEs is called the hesitant fuzzy MCDM. For further applications of HFSs to decision making, many useful and valuable decision making methods have been proposed to solve the hesitant fuzzy MCDM problems (Rodríguez, Martínez, Torra, Xu, & Herrera, 2014). From the perspective of the sources of decision information, they can be roughly divided into two types. The first type is based on the hesitant fuzzy assessment information of alternatives with respect to each criterion provided by the DMs. For example, Xu and Zhang (2013) put forward a hesitant fuzzy TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) approach based on the maximizing deviation method to handle the hesitant fuzzy MCDM problems with incomplete weight information. Zhang and Wei (2013) and Liao and Xu (2013), respectively, extended the VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method for solving the MCDM problem with the decision making environment of HFEs. Motivated by the idea of traditional ELECTRE (ELimination Et Choix Traduisant la REalité) method, Wang, Wang, Zhang, and Chen (2013) proposed a hesitant fuzzy outranking approach for dealing with the hesitant fuzzy MCDM problems. Zhang and Xu (2014) proposed an interval programming method for multiple criteria group decision making (MCGDM) problems in which the ratings of alternatives are taken as HFEs and the pair-wise comparison judgments over alternative are represented by intervals. What's more, several decision methods based on different types of aggregation operators (Bedregal, Reiser, Bustince, Lopez-Molina, & Torra, 2014; Torres, Salas, & Astudillo, 2014; Wei, 2012; Xia & Xu, 2011) have also been developed. The second type is based on the hesitant preference relations provided by the DMs through pair-wise comparisons of alternatives. Zhu, Xu, and Xu (2013) proposed the concept of hesitant fuzzy preference relations and developed two hesitant fuzzy ranking methods to handle the decision making problems with hesitant fuzzy preference relations. Zhang and Wu (2014) proposed the concept of hesitant multiplicative preference relations and developed a consistency and consensus-based decision support model for group decision making with hesitant multiplicative preference relations.

It can be easily seen that most of these decision making methods consist of scoring or compromise models, only the literature (Wang et al., 2013) discusses the hesitant fuzzy outranking model, i.e., the hesitant fuzzy ELECTRE (HF-ELECTRE) method. However, the HF-ELECTRE method is the preferred method for MCDM problems with a large set of alternatives and few criteria (Hatami-Marbini & Tavana, 2011; Schinas, 2004). For the decision making problems where the number of criteria markedly exceeds the number of alternatives, the use of HF-ELECTRE method makes the decision making process very complex and may fail to yield the distinct ranking results of the alternatives. This sort of decision making problems arise in many practical situations, such as the selection of green suppliers in supply chain management in which a large number of decision indices (criteria) and the relative few potential green suppliers (alternatives) exist. Thus, it is necessary to develop a new outranking method in the context of HFEs to overcome such drawbacks.

The QUALIFLEX (qualitative flexible multiple criteria method) developed by Paelinck (1976, 1977, 1978), is one of the effective outranking methods to solve the MCDM problems, especially suitable to deal with the decision making problems where the number of criteria markedly exceeds the number of alternatives (Chen, Chang, & Lu, 2013). This QUALIFLEX method is based on the pairwise comparisons of alternatives with respect to each criterion under all possible permutations of the alternatives and identifies the optimal permutation that maximizes the value of concordance/discordance index (Martel & Matarazzo, 2005). The most characteristic of the QUALIFLEX method is the correct treatment of cardinal and ordinal information (Rebai, Aouni, & Martel, 2006). Recently, many useful extensions have been developed to enrich the QUALIFLEX method. For instance, Chen and Wang (2009) extended the Jacquet-Lagreze's permutation method (Guigou, 1974) by developing an interval-valued permutation method for solving the MCDM problems. To derive an optimal ranking for the given rankings and criteria weights, Griffith and Paelinck (2011) extended the QUALIFLEX to develop a qualitative regression method known as QUALIREG. Chen et al. (2013) proposed an extended QUALIFLEX method for handling the MCDM problems in the context of interval type-2 trapezoidal fuzzy numbers (IT2TrFNs) and applied it to a medical decision making problem. More recently, Chen (2013a) developed a QUALIFLEX-based method for MCGDM within a decision environment of interval-valued intuitionistic fuzzy numbers (IVIFNs). Depending on the likelihood of fuzzy preference relations between IVIFNs, Chen (2014) further put forward an IVIF-QUALIFLEX outranking method with a likelihood-based comparison approach for handling the IVIF MCDM problems. Note that all of the aforementioned QUALIFLEX methods and their extensions cannot be used to handle the hesitant fuzzy decision data. In this paper, we will employ the main structure of the QUALIFLEX method to develop a new outranking method to handle the MCDM problems in which both the assessments of alternatives on criteria and the weights of criteria are expressed by HFEs.

This paper makes several significant contributions to the existing literature on hesitant fuzzy decision making methods for MCDM problems: First, we propose a novel concept of the hesitancy index of a HFE to measure the degree of hesitancy of the DM or the decision organization. Second, by taking their hesitancy indices into account, we introduce two novel distance measures and a signed distance-based comparison method for HFEs. Third, based on the signed distance-based comparison method, we develop a hesitant fuzzy QUALIFLEX (HF-QUALIFLEX) method to solve the MCDM problems in which both the ratings of alternatives and the weights of criteria are denoted by HFEs. Finally, we modify the HF-ELECTRE method to conduct a comparative study.

The structure of this paper is organized as follows: Section 2 briefly reviews some concepts and operations of HFEs. Section 3 presents a concept of hesitancy index of HFEs, and two novel distance measures as well as novel comparison methods for HFEs. Section 4 proposes a HF-QUALIFLEX method for solving hesitant fuzzy MCDM problems. Section 5 employs a green supplier selection example to demonstrate the applicability and the implementation process of the proposed method. This section also provides a comparative analysis with the HF-ELECTRE method. Section 6 presents our conclusions.

2. Basic concepts of hesitant fuzzy elements

Hesitant fuzzy set was conceived by Torra (2010) to manage the decision situations in which the DMs hesitate among several possible values to assess an indicator, alternative, variable, etc. Its definition is introduced as below:

Definition 2.1 Torra, 2010. Let X be a reference set, a HFS Q on X is defined in terms of a function $h_Q(x)$ when applied to X returns a subset of [0, 1].

To be easily understood, Xia and Xu (2011) expressed the Q by a mathematical symbol:

$$Q = \{\langle x, h_Q(x)\rangle | x \in X\} \tag{2.1}$$

where $h_Q(x)$ is a set of some different values in [0, 1], representing the possible membership degrees of the element $x \in X$ to Q. Usually, $h_Q(x)$ is called a HFE denoted by $h = \{\gamma^{\lambda} | \lambda = 1, 2, \ldots, \#h\}$.