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Dual hesitant fuzzy VIKOR method for multi-criteria group decision making based on fuzzy measure and new comparison method

Zhiliang Ren[a], Zeshui Xu[a,b,*], Hai Wang[a]

[a] School of Economics and Management, Southeast University, Nanjing, Jiangsu 211189, China
[b] School of Computer and Software, Nanjing University of Information Science and Technology, Nanjing 210044, China

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ABSTRACT

In the process of group decision making, dual hesitant fuzzy sets (DHFSs) are a very flexible tool for decision makers (DMs) to express their preferences for alternatives. Based on an extended VIKOR method, in this paper, we propose an approach for multi-criteria group decision making (MCGDM) with dual hesitant fuzzy information. To distinguish dual hesitant fuzzy elements (DHFEs) more efficiently, we propose a score function and a comparison method of DHFEs, and based on which we develop a new distance measure for DHFEs. After that, we use the fuzzy measures to characterize the interactive relationships among criteria, and then put forward a dual hesitant fuzzy VIKOR method for solving the MCGDM problems. Finally, we utilize a real example concerning the selection of a cooperative partner to illustrate the availability of the proposed method.

1. Introduction

In the process of decision making, it is very difficult to avoid the uncertainty of information due to the intrinsic complexity of natural objects and the limited ability of human beings. Zadeh [44] introduced fuzzy sets (FSs) to deal with vagueness and fuzziness in real decision making problems. Rodríguez et al. [22] put forward the hesitant fuzzy linguistic term set (HFLTS), which is an extension of the FS. Based on the HFLTSs, a multi-criteria decision making method was then presented by considering the pessimistic attitude and the optimistic attitude of the decision makers (DMs) [4]. By using the likelihood-based comparison relations and some aggregation operators of HFLTSs, Lee and Chen [11] proposed a fuzzy decision making method and a fuzzy group decision making method, respectively. In essence, most of the existing extensions of FSs can be regarded as tools for Granular Computing [20], which has been widely applied in the field of decision making. Granular Computing covers the concepts of intuitionistic fuzzy sets (IFSs) [37] and computing with words [38], and lots of studies have been done based on Granular Computing techniques [1,15]. Thus, in the future work, it is worth applying Granular Computing techniques to solve the MCGDM problems.

Recently, Zhu et al. [49] further extended the FS to the dual hesitant fuzzy set (DHFS), based on which the dual hesitant fuzzy power aggregation operators [32], the dual hesitant fuzzy interaction operators [39], and the dual hesitant fuzzy Archimedean t-conorm and t-norm [43] have been proposed to solve the uncertain decision making problems, where the

* Corresponding author.
E-mail addresses: ren_zhi_liang@126.com (Z. Ren), xuzeshui@263.net (Z. Xu), wanghai17@sina.com (H. Wang).

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DMs hesitate among several possible evaluation values involving the positive and negative aspects. Being a more flexible tool to express the DMs' preference information, DHFSs can encompass FSs [44], IFSs [2], hesitant fuzzy sets (HFSs) [26] and fuzzy multi-sets (FMSs) [45] as special cases. Zhu et al. [49] investigated some preliminary properties of DHFSs and discussed the relationships between DHFSs and other extended FSs mentioned above. In addition, they illustrated the application of DHFSs with an example of group forecasting. For the purpose of developing the theory of DHFSs, Zhu and Xu [50] proposed the typical DHFSs (T-DHFSs) and studied some special properties of T-DHFSs. After that, the distance and similarity measures [21,24], the correlation measures [29,42], the entropy measures [48], the aggregation operators [12,30,31,47], and the evaluation model [40] based on DHFSs have been developed to deal with the multi-criteria decision making (MCDM) problems. In the process of decision making, the DMs can express their preferences more flexible with DHFSs, and thus, the DHFS is a very effective tool to depict the DMs' preference information and has extensive applications in real life. However, the decision making techniques mentioned above have not considered the interactive relationships among criteria which could not be avoided in real decision making problems, such as student assessment, supplier selection, site selection and so on. Let us take into account some possible criteria like 'math' and 'physics' in student assessment. It is obvious that there is a positive correlation relationship between 'math' and 'physics', and so does 'politics' and 'history'. Thus, it is not reasonable to set the independence of criteria or set the priority of criteria in some practical applications. In order to model the interactive relationships among criteria, Sugeno [25] introduced the fuzzy measures, which have been used in many MCDM problems, such as the prediction of wood strength [8], and the multi-criteria evaluation in geographical information systems [9].

Opricovic and Tzeng [17,18] introduced the VIKOR method, in which the conflicting criteria are considered directly in the processes of decision making. Then, they made a comparison between the VIKOR method and other MCDM methods and showed some advantages of the VIKOR method [19]. Since then, a lot of extensions of the VIKOR method have been developed to solve real decision making problems, including the hesitant fuzzy VIKOR methods [13,46], the hesitant fuzzy linguistic VIKOR method [14], the VIKOR method with a mechanism to extract and deploy the objective weights based on Shannon entropy [23], and the MCDM model by combining the decision making trial and evaluation laboratory (DEMATEL) with the VIKOR method [28]. However, all these methods presume the independence or the gradability among criteria, which does not accord with the reality. To solve this issue, in this paper we utilize the fuzzy measures to develop a dual hesitant fuzzy VIKOR method to deal with the multi-criteria group decision making (MCGDM) problems with the interactive relationships among criteria.

The paper is organized as follows: some preliminaries of IFSs, HFSs, DHFSs, VIKOR method and fuzzy measures are introduced in Section 2. In Section 3, motivated by the improved objective approach [7] and the idea of prospect theory [10], we first define a score function to characterize the hesitation degree of a dual hesitant fuzzy element (DHFE). Then, based on the score function, we propose a comparison method to distinguish and rank the DHFEs. In addition, we give a distance measure for DHFEs based on the score function and the generalized dual hesitant normalized distance measure of DHFSs [24]. In Section 4, we develop a novel decision making method, which uses the fuzzy measures to characterize the interactive relationships among criteria in the MCGDM problems. A numerical example is given to illustrate our method in Section 5, and finally, we draw some conclusions in Section 6.

2. Preliminaries

In this section, we review some necessary concepts, such as IFSs, HFSs and DHFSs, and the classic VIKOR method and fuzzy measures.

2.1. IFSs, HFSs and DHFSs

Atanassov [2,3] defined the concept of intuitionistic fuzzy sets (IFSs) so as to express the DMs' preference information more exactly in the process of decision making.

Definition 2.1 [2,3]**.** Let $X=\{x_1, x_2, \ldots, x_n\}$ be a reference set, then an IFS A on X is an object having the form:

$$A = \{\langle x_i, \mu(x_i), \nu(x_i)\rangle | x_i \in X\}$$

where $\mu(x_i)$ and $\nu(x_i)$ are the membership function and the non-membership function on the interval [0,1], respectively, and satisfy $0 \le \mu(x_i)+\nu(x_i) \le 1$ for all $x_i \in X$. $\pi_A(x_i)=1-\mu(x_i)-\nu(x_i)$ is called the degree of uncertainty of x_i to A.

For convenience, Xu and Yager [34] called $\alpha=\langle\mu(x_i), \nu(x_i)\rangle$ an intuitionistic fuzzy number (IFN). To deal with the situations where the DMs are hesitant between several possible values in the process of decision making, Torra [26] introduced the concept of hesitant fuzzy set (HFS).

Definition 2.2 [26]**.** A HFS H on X is defined in terms of a function $h(x)$ that returns a subset of [0, 1] when it is applied to X.

Xia and Xu [33] gave the mathematical expression of the HFS as follows:

$$H = \{\langle x_i, h(x_i)\rangle | x_i \in X\}$$

where $h(x_i)$ is a set of several different values in the interval [0,1]. $h(x_i)$ is called a hesitant fuzzy element (HFE) of the HFS H.