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Multi-criteria decision-making based on hesitant fuzzy linguistic term sets: An outranking approach

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A B S T R A C T

Hesitant fuzzy linguistic term sets (HFLTSs) are introduced to express the hesitance existing in linguistic evaluation as clearly as possible. However, most existing methods using HFLTSs simply rely on the labels or intervals of linguistic terms, which may lead to information distortion and/or loss. To avoid this problem, linguistic scale functions are employed in this paper to conduct the transformation between qualitative information and quantitative data. Moreover, the directional Hausdorff distance, which uses HFLTSs, is also proposed and the dominance relations are subsequently defined using this distance. An outranking approach, similar to the ELECTRE method, is constructed for ranking alternatives in multi-criteria decision-making (MCDM) problems, and the approach is demonstrated using a numerical example related to supply chain management. Because of the inherent features of the directional Hausdorff distance and the defined dominance relations, this approach can effectively and efficiently overcome the hidden drawbacks that may hamper the use of HFLTSs. Finally, the accuracy and effectiveness of the proposed approach is further tested through sensitivity and comparative analyses.

1. Introduction

The modeling and solving of multi-criteria decision-making (MCDM) problems under uncertain conditions has been a challenging topic in recent decades. However, the introduction of fuzzy sets to this task [1] has been very constructive, and various extensions of fuzzy sets have emerged to express the fuzziness and vagueness of information as clearly as possible. These extensions include type-2 fuzzy sets [2,3], type-n fuzzy sets [3], fuzzy multisets [4], intuitionistic fuzzy sets (IFSs) [5], interval-valued fuzzy sets (IVFSs) [5], interval-valued intuitionistic fuzzy sets (IVIFSs) [6], hesitant fuzzy sets (HFSs) [7], and neutrosophic sets (NSs) [8], which mainly differ from each other by their descriptions of the membership degree and/or the non-membership degree of an element, and can properly depict quantitative information characterized by uncertainty. Nevertheless, assessing the alternatives using the linguistic expression is relatively convenient and preferred in reality, and, therefore, the related linguistic approaches are also essential. The fuzzy linguistic approach [3,9,10] was proposed during the 1970s, and has since received popular recognition. As such, linguistic approaches have been widely applied in a number of fields such as new product development [11], supply chain management (SCM) [12,13], emergency management evaluation [14], service quality evaluation [15], and performance evaluation [16]. Furthermore, extensions and improvements have been introduced, including a linguistic model based on discrete fuzzy numbers [17], type-2 fuzzy sets [18–20], the linguistic 2-tuple model [21–24], and extended 2-tuple fuzzy linguistic models [25]. Nevertheless, these linguistic models have a limited capability for describing fuzzy and vague information.

Rodríguez et al. [26], from the basis of the fuzzy linguistic approach [3,9], proposed hesitant fuzzy linguistic term sets (HFLTSs), which were based upon HFSs. In practice, the assessment of decision makers usually fluctuates between several possible linguistic values, and, as a result, a definite answer is not always provided. The primary characteristic of HFLTSs is that the approach can cope with such hesitance where more than a single linguistic term may be required for assessing a linguistic variable.

Several MCDM methods using HFLTSs have been introduced, but the methods retain certain deficiencies in their fundamental operations, which may degrade their credibility. These are outlined below.

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(1) Envelope-based approach. Firstly, in the MCDM model proposed by Rodríguez et al. [26], the linguistic intervals were calculated by means of aggregation operators, and used to obtain the final results. Moreover, this model has been applied in group decision-making [27]. Secondly, the HFLTS envelopes are the basic linguistic intervals defined by Rodríguez et al. [26]. These have been applied in document classification [28] and also integrated into a technique for order of preference by similarity to ideal solution (TOPSIS) model [29]. Thirdly, Zhang et al. [30] defined the aggregation operators of HFLTSs, and then compared the envelopes of the aggregated results to rank the alternatives. Fourthly, the 0-cut of the HFLTSs, which represents a revision of the HFLTS envelopes, was used for the fuzzy decision-making method [31]. Fifthly, Wang et al. [32] defined the dominance relations of HFLTSs, and established an outranking method to accommodate hesitant fuzzy linguistic information. The dominance relations being developed partially depend on the HFLTS envelopes. In these methods/models, the linguistic terms were transformed into intervals, and the operations mainly relied upon the labels of the linguistic variables. However, such designs ignored the fact that the linguistic term set is not a simple array with equal distances between neighbors.

(2) Fuzzy envelope. The fuzzy envelope of an HFLTS [33] was constructed using a fuzzy membership function, which was aggregated using the given HFLTSs and the ordered weighted averaging (OWA) operator [34], and then combined with a fuzzy TOPSIS model [35–37] to solve MCDM problems. To a certain extent, the fuzzy envelope can retain the vagueness of comparative linguistic expressions. Nevertheless, determining the parameters of the fuzzy membership function and OWA weights is fairly complicated, and the requisite calculations are considerable for an MCDM problem in the context of HFLTSs, which, for example, may contain four alternatives, four criteria, and seven linguistic terms that are used for assessment. Nevertheless, while the different levels of importance of the linguistic terms of HFLTSs was recognized in the design of fuzzy envelopes, the approach continued to ignore the possibility of different distances between adjacent linguistic terms.

(3) Derivatives of HFLTSs. Based on a convex combination of HFLTSs and the possibility degree formulae, Wei et al. [38] proposed the corresponding aggregation operators and introduced some MCDM methods. The necessary calculations also frequently involved the labels of the linguistic variables. However, the results calculated using these operators may vary because of different orders of operations or operands, which will be illustrated in Section 2.

(4) Distance measures for HFLTSs. Liao et al. [39] proposed distance and similarity measures of HFLTSs, and also considered their extensions in a continuous case; moreover, they developed the TOPSIS method using a relative distance measure. Zhu and Xu [40] developed hesitant fuzzy linguistic preference relations (HFLPRs), which consisted of HFLTSs. The distance between two HFLTSs was defined in [40], which is equivalent to the Hamming distance given in [39]. However, similar to the rules on the extension of HFSs that were defined by Xu and Xia [41,42], the normalization of HFLTSs was necessary in [39,40] because two HFLTSs must be of the same length to guarantee a correct ranking. Such an addition mainly relies on the subjectivity of decision makers, but the determination of risk preference is an intractable task indeed.

(5) To extend HFLTSs, hesitant fuzzy linguistic sets (HFLSs) have been defined on the basis of a continuous linguistic term set [43]. Although inconsecutive values are allowed in a hesitant fuzzy linguistic element (HFLE) [43], such an extension has certain limitations and the proposed aggregation operators involve complicated calculations, which will be discussed in detail in Section 2.

Due to the described limitations of the existing methods using HFLTSs, the directional Hausdorff distance is proposed in this paper. This distance can effectively accommodate HFLTSs, and is therefore further integrated into the outranking approach. The calculation involving intervals and labels is not adopted by this distance. Although cloud models have been shown to be capable of describing the inherent relation between randomness and fuzziness, and, therefore, have been successfully applied to linguistic decision making to transform linguistic variables into quantitative data [44–46], the parameters being involved, i.e., expected value, entropy, and hyper entropy, still cannot reveal various semantics. To carefully and comprehensively process the mapping from the linguistic terms to numerical data, the linguistic scale functions [47] are employed in this paper to conduct the related transformation. In this way, the original essence of vague evaluations can be properly retained and the accuracy and reliability of final results can be further increased.

In addition, a relation model is chosen in this paper because function models (e.g., TOPSIS and VIKOR) mainly rely on various distance measures, and different results may arise based on different operators and methods. ELECTRE, originally proposed by Benayoun and Roy [48,49], is a popular relation model by means of which the relevant alternatives can generally be ranked based on the defined outranking relations. ELECTRE and its extensions have been widely studied [48–51] and applied in various MCDM problems [52–58]. In this paper, an outranking approach to solving MCDM problems is developed, which is based upon the features of the directional Hausdorff distance and the elicitation of the ELECTRE methods used by Devi and Yadav [59] and Figueira et al. [60]. This approach will be further tested and compared with some of the above described methods employing HFLTSs.

The remainder of this paper is organized as follows. Section 2 contains the definitions of HFLTSs and HFLSs, and related discussion, as well as the definition of linguistic scale functions. In Section 3, the directional Hausdorff distance and dominance relations are developed together with some properties and propositions. In Section 4, using the proven proposal, an outranking approach to solving MCDM problems in the context of HFLTSs is constructed. Section 5 includes an illustrative example relevant to SCM, and the proposed approach is also validated through sensitivity and comparative analyses. The final conclusions and proposals for future work are summarized in Section 6.

2. Preliminaries

In this section, the definitions and some basic operations of HFLTSs are briefly reviewed, and the effectiveness of other existing methods/models using HFLTSs is discussed with the use of relevant examples. The definitions of HFLSs and their related operations are also discussed. Moreover, the linguistic scale functions are reviewed.

2.1. Hesitant fuzzy linguistic term sets

Assuming $S = \{s_i | i = 0, 1, 2, \ldots, 2g, g \in \mathbb{N}\}$ is a linguistic term set with odd cardinality, where s_i denotes a possible value for a linguistic variable, the following must be satisfied [61,62]:

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