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Heterogeneous multiple criteria group decision making with incomplete weight information: A deviation modeling approach

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ABSTRACT

Multiple criteria group decision making (MCGDM) problems with multiple formats of decision information, which are called heterogeneous MCGDM problems, have broad applications in the fields of natural science, social science, economy and management, etc. It is quite common that in heterogeneous MCGDM problems both the weights of the decision makers/experts and the criteria are partially known or completely unknown, but few studies focus on this issue. The purpose of this paper is to develop a deviation modeling method to deal with the heterogeneous MCGDM problems with incomplete weight information in which the decision information is expressed as real numbers, interval numbers, linguistic variables, intuitionistic fuzzy numbers, hesitant fuzzy elements and hesitant fuzzy linguistic term sets. There are three key issues being addressed in this approach, the first one is to construct a maximizing deviation optimal model in order to determine the optimal weights of criteria for each expert. Borrowing the idea of TOPSIS, the second one is to calculate the relative closeness indices of the alternatives for each expert. The third one is to establish a minimizing deviation optimal model based on the idea that the opinion of the individual expert should be consistent with that of the group to the greatest extent, which is used to determine the weights of experts and identify the optimal alternative. The proposed approach is applied to solve the practical decision making problem concerned with the selection of Strategic Freight Forwarder of China Southern Airlines, and a comparison analysis with a similar approach is conducted to demonstrate the advantages of the proposed method.

1. Introduction

In group decision making (GDM) problems with multiple conflicting criteria (or called multiple criteria group decision making (MCGDM) problems), the alternatives are usually evaluated according to the different criteria by using diverse information formats, due to the varying nature of such criteria, i.e., either quantitative or qualitative nature. The formats of evaluation information of the alternatives with respect to the criteria provided by experts/decision-makers depend on the nature of the criteria:

- When the criteria of the alternatives are measured by their quantitative nature, then they may be evaluated by taking the forms of real numbers, interval numbers [1], fuzzy numbers [2], intuitionistic fuzzy sets (IFSs) [3], interval-valued IFSs (IVIFSs) [4], hesitant fuzzy sets (HFSs) [5], type-2 fuzzy sets [6], type-n fuzzy sets [7] and fuzzy multisets [8], etc.
- When the criteria of the alternatives are quite qualitative, then they are usually evaluated by taking the forms of the 2-tuple linguistic sets [9–12], the symbolic linguistic sets [13,14], the hesitant fuzzy linguistic term sets (HFLTSs) [15] and the proportional 2-tuple linguistic sets [16,17], etc.

In general, the MCGDM problems with multiple formats of criteria values (such as real numbers, interval numbers, and linguistic variables) are simply called the heterogeneous MCGDM problems. This sort of MCGDM problems has broad applications in the fields of natural science, social science, economy, management and military affairs, etc., but it is difficult for calculation due to the multiformity of criteria values [18,19]. To this end, many useful and valuable methods have been proposed to solve such a type of heterogeneous decision making problems, which can be roughly divided into the following two categories.

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The first type of methods to deal with heterogeneous decision making problems is the methods based on the distances to the ideal solution. By investigating a heterogeneous MCGDM problem whose decision information takes the forms of linguistic variables, triangular fuzzy numbers (TFNs), interval numbers and real numbers, Li et al. [20] developed a systematical approach (we call it Li's method) in which it computes the distances to the ideal solution and the objects are ranked according to the proposed relative closeness degrees. Unifying the heterogeneous information into TFNs, Zhang and Lu [21] developed a method (Zhang's method) in which it calculates the distances between the alternatives and both the positive and negative ideal solutions and a closeness coefficient is obtained to rank the alternatives. Ma et al. [22] developed a fuzzy MCGDM process model based on distances to the ideal solution to deal with the heterogeneous information including real numbers, Boolean values and linguistic variables, and meanwhile presented a decision support system (called Decider) to implement this model. Wan and Li [23] presented an intuitionistic fuzzy programming method based on the distances to the ideal solution for solving the heterogeneous MCGDM problems with intuitionistic fuzzy truth degree whose decision data is expressed in real numbers, interval numbers, trapezoidal fuzzy numbers (TrFNs) and intuitionistic fuzzy numbers (IFNs).

The second type of methods to deal with heterogeneous decision making problems is the methods by unifying heterogeneous information into 2-tuple linguistic variables. For example, Herrera et al. [24] proposed a method (Herrera's method) that converts all the heterogeneous information into the 2-tuple linguistic information for solving the heterogeneous GDM problems whose decision information is expressed as real numbers, interval numbers, linguistic variables. To handle the heterogeneous information (real numbers, interval numbers and linguistic variables) in engineering evaluation processes, Martínez et al. [25] defined different fuzzy functions which may transform these heterogeneous information into a common format (i.e., 2-tuple linguistic set). Additionally, Espinilla et al. [26] conducted a comparison study among Herrera's method [24], Li's method [20] and Zhang's method [21], and further applied them to the evaluation of sustainable energy policies.

It is common that in the heterogeneous MCGDM problems both the weights of the experts and the criteria are partially known or completely unknown, but the aforementioned methods fail to solve this issue. Moreover, with the increasing complexity of real-world decision making problem, the experts often hesitate among several values to provide their assessments in the evaluation process. For instance, when the decision criteria are quite quantitative because of their nature, the HFSs proposed by Torra [5] are usually used for the experts to express their preferences provoked by hesitation. While the decision criteria are quite qualitative, the HFLTSs introduced by Rodríguez et al. [15] are employed for the experts to represent their assessments. Considering the fact that hesitant situations are very common in different real-world problems [27], it is essential to research the heterogeneous MCGDM problems with incomplete weight information in which the decision data may contain hesitant fuzzy elements (HFEs) and HFLTSs.

The purpose of this paper is to develop an effective decision method to deal with the heterogeneous MCGDM problems with incomplete weight information in which the decision information is expressed as real numbers, interval numbers, IFNs, HFEs, linguistic variables and HFLTSs. It is easy to find that there exist three major difficulties and challenges for solving such a heterogeneous MCGDM problem: (1) How to effectively manage the heterogeneous decision information. It is usually difficult to unify them into one form because different forms of criteria values have different meanings and expression ways. (2) How to derive objectively the weights of the experts and the criteria. These weights play an important role in the practical decision making process, but it is difficult for the managers and the experts to provide them precisely. (3) How to determine the final ranking of the alternatives. Although several MCGDM methods have been developed to rank the alternatives, few of them can be used to deal with the decision making problems with multiple forms of decision data, especially including the hesitant fuzzy decision data, such as HFEs and HFLTSs.

Bearing this fact in mind, this paper develops a deviation modeling method to deal with the heterogeneous MCGDM problems with incomplete weight information. This approach first normalizes all the heterogeneous information in order to ensure the compatibility of all criteria; then a maximizing deviation model is constructed to determine the optimal weights of criteria for each expert. Afterwards, the distances of the alternatives to the ideal solutions for each criterion and each expert are calculated by using different distance measures [28–30], respectively, and further the relative closeness indices of the alternatives for each expert are obtained. At length, a minimizing deviation model is proposed to determine the weights of experts and identify the optimal alternative. To do so, the structure of this paper is organized as follows: Section 2 briefly reviews some concepts and distance measures of linguistic variables, TrFNs, IFNs, HFEs and HFLTSs. Section 3 presents a heterogeneous MCGDM problem with incomplete weight information and introduces the normalized method of criteria values. Section 4 develops a deviation modeling method to solve the aforementioned heterogeneous MCGDM problems. Section 5 employs the practical decision making problem concerned with the selection of Strategic Freight Forwarder of China Southern Airlines to demonstrate the implementation process of the proposed method. Section 6 presents our conclusions.

2. Basic concepts and distance measures

Due to the fact that our proposal is based on the linguistic variables, TrFNs, IFNs, HFEs and HFLTSs, in this section we review their main concepts and distance measures.

2.1. Linguistic variables and fuzzy numbers

The linguistic variables proposed by Zadeh [2] are established by the linguistic descriptors and their semantics, which are often used to express experts' preferences in qualitative situations. There are different ways to choose the linguistic descriptors and to define their semantics [13–15,31,32]. The linguistic term set based on the ordered structure approach [14] can be defined as follows:

Definition 2.1 [14]. Let $S = \{s_i | i = 0, 1, \ldots, q\}$ be a finite and totally ordered discrete label set. Any label, s_i, represents a possible value for a linguistic variable, and it must have the following characteristics: (1) the set S is ordered, i.e., $s_i \geqslant s_j$, if $i \geqslant j$; (2) there exists a negation operator: $Neg(s_i) = s_j$, such that $j = q - i$; and (3) there exist a maximization operator and a minimization operator: $Max(s_i, s_j) = s_i$ and $Min(s_i, s_j) = s_j$ if $i \geqslant j$.

For example, a linguistic term set S with seven-point rating scales could be:

$$S = \{s_0 : \textit{definitely low}, s_1 : \textit{very low}, s_2 : \textit{low}, s_3 : \textit{medium}, s_4 : \textit{high}, s_5 : \textit{very high}, s_6 : \textit{definitely high}\}$$

Due to the fact that the linguistic terms provided by the experts are the approximate assessments, several authors [33,34] pointed out that the trapezoidal fuzzy membership functions are good enough to capture and represent the uncertainty and vagueness of such linguistic assessments [35].