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Regret theory-based group decision-making with multidimensional preference and incomplete weight information

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ABSTRACT

In this paper, we study fuzzy multi-attribute group decision-making (FMAGDM) problems with multidimensional preference information in the form of pairwise alternatives and incomplete weight information. We develop a new group decision-making (GDM) method considering regret aversion of the decision-makers (DMs). Firstly, we define a fuzzy regret/rejoice function and a computational formula for the perceived utility of alternative decisions. We propose a perceived utility value-based group consistency index (which reflects the total consistency) and a group inconsistency index (which represents the total inconsistency) for pairwise rankings of alternatives based on regret theory and an a priori multidimensional preference order given by the DMs. Then, under the circumstances of an unknown fuzzy ideal solution, we set up a mathematical programming model to determine the optimal attribute weights and a defuzzified fuzzy ideal solution with the idea of the Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP). We compute the DMs' optimal comprehensive perceived utility values and obtain the ranking order of alternatives. Finally, we illustrate the application of the developed procedures with an air-fighter selection problem. The rationality and validity of the proposed method is demonstrated by comparing with two other GDM methods, including the fuzzy LINMAP (FLINMAP) method and the prospect theory-based GDM method.

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1. Introduction

Fuzzy multi-attribute group decision-making (FMAGDM) is the process of ranking feasible alternatives and selecting the best by considering multiple criteria (involving both quantitative and qualitative) and multiple expert opinions [1–2]. In recent years, several FMAGDM tools and approaches have been suggested for choosing the optimal probable options [3–14]. Especially, researches on FMAGDM with multidimensional preference information [15–20] as well as FMAGDM with incomplete weight information [21–25] have caused wide attention (see Section 4, "Related work", for details). The existing studies have made significant contributions to the development of rational decision theory in fuzzy environment.

However, researchers have found that it is difficult to explain many phenomena in real applications based on the hypotheses of rational decision-making. Some paradoxes (such as Allais's Paradox in 1953 and Ellsberg's Paradox in 1961) have led researchers to begin to explore people's actual decision-making processes [26]. Given that, based on the assumption of bounded rationality, behavioral scientists proposed some behavioral decision theories such as prospect theory (PT) [27], cumulative prospect theory (CPT) [28], regret theory (RT) [29–31], disappointment theory [32], and fairness theory [33]. The aim of these theories is to explain how individuals judge and choose between alternatives in their daily life. Considering loss aversion and other psychological decision-making behaviors, scholars have proposed some effective decision-making models or analysis methods. For example, Liu et al. [34] proposed a multi-attribute decision-making (MADM) method based on PT, to solve risk decision-making problems with interval probabilities. Wang et al. [35] developed an interval-valued intuitionistic fuzzy multi-criteria decision-making approach based on the prospect score function. Fan et al. [36] proposed a method based on PT for solving the MADM problem with aspiration-levels for the attributes. Liu et al. [37] suggested a risk decision analysis method based on CPT, to solve the risk decision-making problem for emergency responses. Nevertheless, PT and CPT applied to actual decision-making processes have some shortcomings and insufficiencies, as reported by Nwogugu [38]. Based on evidence from neurobiology, Nwogugu pointed out that the natural mental processes of human beings can result in decision-making patterns that differ from those predicted by and implicit to CPT and PT.

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Additionally, Nagarajan and Shechter [39] showed that PT (a prevalent framework for decision-making under uncertainty) cannot explain observations in behavioral operations literature regarding the news vendor problem. They also concluded the possible cause was that the newsvendor problem involved many chance outcomes in its explicit form. Thus, there is a need for more realistic decision models. To more simply and consistently depict intuitive judgments, Loomes et al. [29] and Bell [30] introduced regret and rejoice factors when calculating utility values. RT is an alternative behavioral decision theory that they independently presented in 1982. Regret captures differences between the performance of a chosen product or service and the performance of a rejected product or service [40]. The psychological behavior of regret aversion of decision-makers (DMs) in the decision-making process can be quantified [41]. Since then, RT has been extensively applied to problems such as asset pricing [42], investment choices [43], and material selection in a manufacturing environment [44].

Recently, a few scholars have tried to introduce RT to MADM process. For example, Huang et al. [45] considered the regret aversion perspective and developed a revised VIKOR model for dealing with MADM problems. This method includes two different kinds of regret (the discontent and choiceless utilities) to reflect the behavior of DMs. Zhang et al. [46] proposed a decision analysis method based on RT to solve a risky MADM problem, where the attribute values and probabilities of the states were both in interval form. Nevertheless, so far, there exist the following three deficiencies for RT-based MADM methods. (a) A single kind of decision-making information is only concerned when applying RT-based decision-making methods, but the actual decision-making process may involve multiple types of information, such as reference information, preference information or multidimensional preference information, and incomplete weight information. (b) Evaluation or attribute values are usually crisp numbers, but related work on how to calculate the regret/rejoice of decision-maker (DM) in fuzzy multi-attribute environment is not reported until now. (c) There is little focus on how to coordinate the conflict among several DMs when the DMs' regret aversion is taken into account in GDM environment. Note that regret aversion psychology is also typically implied when a DM compares pairwise alternatives in fuzzy multi-person decision-making environment. Therefore, for solving FMAGDM problems under the hypothesis of bounded rationality, (a) it is extremely important and essential to quantitatively express the regret aversion characteristics of the DMs in fuzzy uncertain environment, and (b) it is theoretically and practically significant to develop a new decision analysis method that the DMs' regret aversion is integrated into in GDM environment.

This paper aims to propose a GDM method based on RT to solve FMAGDM with multidimensional preference information in terms of pairwise alternatives and incomplete weight information. We use linguistic variables to assess alternatives to qualitative attributes using fuzzy ratings or scores, which correspond to some triangular fuzzy number (TFN). A fuzzy decision matrix can be constructed after extracting the DMs' fuzzy ratings. The DMs' regret aversion is integrated into the process of selecting alternatives, and then the DM's perceived utility function (based on RT) is defined using a kind of defuzzification method (i.e., Graded Mean Integration Representation (GMIR)). Our novel group consistency and inconsistency measure indices in combination with the perceived utility function. They are defined on the basis of the DMs' preferences given by incomplete preference information structures, that is, multidimensional preference information in terms of pairwise alternatives. In the case of partly known attribute weights and unknown fuzzy ideal solution (FIS), with the idea of Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP) we set up a new mathematical programming model based on the defined group total consistency and inconsistency measure indices to determine the attribute weights and defuzzified FIS values. Finally, we calculate the optimal comprehensive perceived utility of each alternative to determine the ranking order of all the alternatives. The main innovations of this paper are as follows. (a) We quantify the psychological behavior of the DMs in a fuzzy decision environment from the perspective of regret aversion, and show that the perceived utility function in a crisp decision environment is a special case of the fuzzy perceived utility function proposed in this paper. (b) We effectively aggregate three types of decision information using LINMAP and GMIR by considering the DMs' regret aversion, and our aggregation method can be extended to GDM problems with trapezoidal fuzzy numbers (TrFNs) and even generalized fuzzy numbers using the defuzzification method (i,e., GMIR).

The remainder of the paper is organized as follows. Section 2 reviews some related concepts and definitions. In Section 3, we describe FMAGDM problems with multidimensional preference information in terms of pairwise alternatives and incomplete weight information. Related work for problems investigated in this paper is summarized in Section 4. In Section 5, a new GDM method that considers regret aversion is proposed. The proposed method is illustrated using a real air-fighter plane selection example, and we compare some similar methods in Section 6. Section 7 ends the paper with some concluding remarks.

2. Preliminaries

2.1. Fuzzy numbers and linguistic variables

In this section, we give some basic definitions.

2.1.1. Fuzzy numbers and defuzzification

Let X be a universe set. A fuzzy subset F of X is defined by a membership function $\mu_F(x)$ that maps each element x in F to a real number in the interval [0, 1]. The value of $\mu_F(x)$ signifies the grade of membership of x in F. When $\mu_F(x)$ is larger, the degree of membership of the element $x \in X$ to the set $F \subseteq X$ is higher [47–48].

Definition 1. [47–48] Let F be a trapezoidal fuzzy number (TrFN), denoted as $F = (l, m_1, m_2, u)$, whose membership functions is given as follows:

$$\mu_F(x) = \begin{cases} (x-l)/(m_1-l), & l < x < m_1, \\ 1, & m_1 \le x \le m_2, \\ (u-x)/(u-m_2), & m_2 < x < u, \\ 0, & \text{otherwise}. \end{cases}.$$

The closed interval $[m_1, m_2]$ is the mode of F. l and u are the lower and upper limits of F. It is easily seen that a TrFN $F = (l, m_1, m_2, u)$ is reduced to a real number m if $l = m_1 = m_2 = u$. Conversely, a real number m can be written as a TrFN $F = (m, m, m, m)$. A TrFN $F = (l, m_1, m_2, u)$ is reduced to a TFN $F = (l, m, u)$ if $m_1 = m_2$.

Definition 2. [49–50] Let F be a TrFN, denoted as $F = (l, m_1, m_2, u)$. Under the extension principle of fuzzy numbers [51], the GMIR or the defuzzified value of a TrFN F is

$$P(F) = [\lambda(l + 2m_1) + (1-\lambda)(2m_2 + u)]/3,$$

where the value of λ depends on the preference of the DM. Typically, we choose $\lambda = 1/2$ so that it is not biased to the left or right. When $\lambda = 1/2$, $P(F) = (l + 2m_1 + 2m_2 + u)/6$. In particular, if $X = (l, m, u)$ is a TFN, then $P(X) = (l + 4m + u)/6$.

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