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Approaches to group decision making with intuitionistic fuzzy preference relations based on multiplicative consistency

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ABSTRACT

The intuitionistic fuzzy preference relation (IFPR) was introduced by Xu to efficiently deal with situations in which the decision makers (DMs) exhibit the characteristics of affirmation, negation and hesitation for the preference degrees over paired comparisons of alternatives. In this paper, two new approaches to group decision making (GDM) are proposed to derive the normalized intuitionistic fuzzy priority weights from IFPRs based on the order consistency and the multiplicative consistency. First, the concepts of order consistency and weak transitivity for IFPRs are introduced, and followed by a discussion of their desirable properties. Then, in order to convert the normalized intuitionistic fuzzy priority weights into multiplicative consistent IFPR, a transformation approach is investigated. Two linear optimization models are further developed to derive the normalized intuitionistic fuzzy weight vector for both individual and group IFPRs with the principle of minimizing the deviations between any provided IFPR and the converted multiplicative consistent IFPR, and the optimal deviation values obtained from the models enable us to improve the multiplicative consistency of IFPRs. Finally, based on the order consistency and the multiplicative consistency, two new algorithms for GDM are presented. Several numerical examples are provided, and comparative analyses with existing approaches are performed to demonstrate that the proposed methods are both valid and practical to deal with group decision making problems.
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1. Introduction

Making a decision means that there is a set of alternatives to be selected, and in such a case decision makers (DMs) rank these alternatives from the best to the worst and choose the one that fits with DMs desired goal. In group decision making (GDM) problems, DMs are usually required to provide their exact preference over a set of alternatives by the pairwise comparison method to express their preference information, and construct preference relation judgement matrices [1–3].

However, it may be difficult for DMs to express their preference information with a crisp number in many multi-attribute GDM problems due to that (1) the DM may not possess a precise or sufficient level of knowledge of the problem; and (2) the DM is unable to discriminate explicitly the degree to which one alternative are better than others [4,5]. In these situations, DMs may prefer imprecise judgment information in a pairwise comparison matrix. To characterize this fuzziness and uncertainty, there are different uncertain preference relations have been proposed, such as multiplicative preference relation (MPR) [6–9], fuzzy preference relation (FPR) [10–14], fuzzy interval preference relation (FIPR) [15,16], triangular fuzzy preference relation (TFPR) [17], trapezoid fuzzy preference relation (TDFPR) [18] and linguistic preference relations (LPR) [19–21]. Xu [22] presented a comprehensive survey of preference relations, and briefly discussed their properties and introduced some new preference relations. In order to deal with the GDM problems with additive reciprocal FPRs, Zhu and Xu [23] developed a new fuzzy linear programming method, and introduced an effective index to measure the DM's effect in the GDM problems, and then they proposed a new method to determine the DMs' weights. Saaty and Vargas [24] presented the concept of interval MPRs and developed a method to generate priority weights from interval MPRs. Herrera et al. [25] investigated an aggregation operator to combine interval FPRs with numerical preference relation and LPR. The incomplete LPRs and improved LPRs were defined by Xu [21], and then he developed an approach to GDM. Zhang et al. [26] introduced the concept of distribution LPRs, whose elements are linguistic distribution assessments, and analyzed the consensus measures for GDM based on distribution LPRs.

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Owing to traditional fuzzy sets (FSs), put forward by Zadeh [27], cannot express all the information in some uncertainty situation. Therefore, Atanassov [28,29] introduced the concept of intuitionistic fuzzy sets (IFSs), which is the generalization of the FSs. In IFSs, the data information is expressed by means of 2-tuples, and each 2-tuple is characterized by the degree of membership and non-membership. The introduction of IFSs proved to be very meaningful and practical, and has been found to be highly useful to deal with vagueness [30]. Xu [31] first defined the concepts of IFPR, consistent IFPR, incomplete IFPR and acceptable IFPR, and studied their desirable properties. Then, he developed several approaches to GDM from the IFPRs and incomplete IFPRs, respectively, and applied score function and accuracy function for ranking and selection of alternatives. Xu [32] studied the aggregation of intuitionistic multiplicative preference information and applied them to decision making. Due to an inconsistent preference relation may lead to unreasonable conclusions, then for various types of preference relations, an important research topic is to check their consistency. Based on the additive consistency and the order consistency, Lee [33] presented a method for GDM with incomplete FPRs, and then established the consistent matrix which satisfies the additive consistency and the order consistency. To overcome the drawbacks of Lee's method [33], Chen et al. [34] constructed a modified consistent matrix, and discussed some properties of the modified consistent matrix. They further proposed a new method for GDM using incomplete FPRs. Since an IFPR can be transformed into an interval fuzzy preference relation, Hülya [35] presented some optimization models for minimizing the deviations from additive consistency, and applied the optimal deviation values obtained from the model results to improve the consistency of considered preference relations. Liu et al. [36] explored the GDM problems with incomplete additive consistent FPRs, and discussed some properties of additive consistent FPRs. In order to avoid the operational difficulty in coping with the IFSs, the relation between the IFPR and the FIPR was established by Gong et al. [37], and they proposed some least squares methods and several goal programming approaches of the inconsistent IFPRs for deriving the priority weight vector. Lan et al. [38] investigated the relationship between the multiplicative consistent interval fuzzy preference relation and the additive consistent interval fuzzy preference relation, and then proposed a new method to derive interval weights. Based on the additive consistent IFPRs, Wang [39] developed linear goal programming models to derive intuitionistic fuzzy weight vector from IFPRs.

Viedma et al. [40] presented that the additive consistent FPRs are equivalent to the consistency property of MPR proposed by Saaty. However, if we used the additive consistency to estimate the missing information of FPRs, it is conflicted with the fuzzy scale. i.e., the estimating values of some unknown elements of FPRs do not belong to interval [0, 1].

For example, suppose that $r_{13} = 0.9$ and $r_{43} = 0.3$, then by using the additive consistency in Eq. (17) of [22], we have $r_{14} = r_{13} - r_{43} + 0.5 = 0.9 - 0.3 + 0.5 = 1.1 > 1$, it is obvious unreasonable. Thus, the additive consistency is an improper property of FPRs [41] in some degree. However, the multiplicative consistency does not have this limitation [41,42].

As the IFPRs can be transformed into FIPRs, Hülya [35] developed optimization models to derive the priority weights from multiplicative consistent IFPRs. Based on the membership and non-membership degrees of IFPRs, Liao and Xu [41] proposed a formula to construct a multiplicative consistent IFPR, and then some fractional programming models have been proposed to derive the priority weights of the IFPR.

Based on the IFSs, Xu [31] introduced IFPRs which can effectively use the advantages of IFSs to handle imprecision. As a new tool used for expressing preference information in GDM, IFPRs can cope with uncertainty situation where the preference information is set up with the degree of membership and non-membership. In GDM with IFPRs, just as the fuzzy preference relations, deriving the priority weight vector and studying the consistency of IFPRs are the important issues. Gong et al. [43] investigated some goal programming models for deriving the priority vector of the IFPR by analyzing the relation between the fuzzy interval preference relation and the IFPR.

However, due to the fact that the definition of multiplicative consistent IFPRs proposed by Gong et al. [43] is not based on IFPRs directly, we need to transfer the original IFPR given by DM into its corresponding fuzzy interval preference relation, thus, it seems to be an indirect computation process and the derived weights may not represent the original intuitionistic fuzzy preference information adequately. To circumvent this issue, it is natural and logical to expect that the priority weights should be directly derived by the original IFPRs. In addition, how to generate the complete multiplicative consistent IFPR according to the acceptable one is an important research topic for GDM. At present, there are few techniques about these issues. Therefore, it is necessary and meaningful to discuss some issues on deriving the priority weight vector directly by the original IFPRs based on multiplicative consistency and improving the multiplicative consistency of a group IFPRs.

In this paper, we employ membership and non-membership degrees to define multiplicative consistent IFPRs. Two linear optimization models are established to generate normalized intuitionistic fuzzy weight vector for both individual and group IFPRs with the principle of minimizing the deviations between the provided IFPR and the multiplicative consistent IFPR. The optimal deviation values obtained from the model results enable us to improve the multiplicative consistency of given IFPRs. To do this, the rest of the paper is organized as follows. In Section 2, we briefly review some basic concepts, including FPRs, IFSs and IFPRs. Section 3 defines order consistent IFPR, and some properties of multiplicative consistent IFPRs are discussed. In Section 4, two linear optimization models are established to derive normalized intuitionistic fuzzy weight vector for both individual and group IFPRs, and investigate a method to improve the multiplicative consistency of given IFPRs. Section 5 provides two numerical examples to illustrate the validity and applicability of the proposed methods. Finally, we end the paper by summarizing the main conclusions in Section 6.

2. Preliminaries

In this section, we furnish a brief review on some basic concepts, including FPRs, IFSs and IFPRs.

For a decision making problem, let $X = \{x_1, x_2, \dots, x_n\}$ be a finite set of alternatives. For convenience, suppose that $w = (w_1, w_2, \dots, w_n)^T$ be the normalized crisp vector of priority weights, where w_i reflects the importance degree of the alternative x_i, and $w_i > 0, i = 1, 2, \dots, n, \sum_{i=1}^{n} w_i = 1$. In the process of decision making, a DM generally needs to provide preference information for each pair of alternatives, and then constructs a FPR.

Definition 2.1. [10]. A reciprocal fuzzy preference relation R on X is characterized by a compassion matrix $R = (r_{ij})_{n \times n} \subset X \times X$ with

$$0 \le r_{ij} \le 1,\ r_{ij} + r_{ji} = 1,\ r_{ii} = 0.5,\ i, j = 1, 2, \dots, n, \tag{1}$$

where r_{ij} represents a fuzzy preference degree of the alternative x_i over alternative x_j.

If $r_{ij} = 0.5$, then it denotes that there is no difference between alternative x_i and alternative x_j; if $r_{ij} > 0.5$, then it denotes that alternative x_i is preferred to alternative x_j; the larger r_{ij}, the greater the preference degree of the alternative x_i over x_j; if $r_{ij} = 1$, then it denotes that alternative x_i absolutely preferred to alternative x_j.

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