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A preference degree for intuitionistic fuzzy values and application to multi-attribute group decision making

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ABSTRACT

This paper proposes a novel preference degree algorithm to rank intuitionistic fuzzy values (IFVs) and applies it to multi-attribute group decision making (MAGDM) with IFVs. First, the concept of preference degree of IFVs is defined according to the geometrical representation of IFVs. Some useful properties of the defined preference degree are discussed. Combining the preference degree with the hesitation margin of IFVs, a novel preference degree algorithm is designed to rank a series of IFVs. In MAGDM problems with IFVs, the attribute weights would be usually diverse for different decision makers (DMs). To derive the attribute weights for each DM objectively, a multi-objective programming model is constructed and transformed into a linear program to resolve. Then, the consensus indices are calculated from three levels based on the individual fuzzy reciprocal preference relations and the collective one. To determine DMs' weights, a linear goal programming model is established by maximizing the consensus index of group of DMs. Using the intuitionistic fuzzy weighted average operator, the individual comprehensive values of alternatives are obtained and further integrated into the collective comprehensive values of alternatives. The ranking order of alternatives is generated by the designed preference degree algorithm. At length, the validity of the proposed method is illustrated with a construction organization selection example.

1. Introduction

Multi-attribute group decision making (MAGDM) refers to the problem of selecting an alternative from a finite set of alternatives or ranking them based on the assessment of alternatives on multiple attributes provided by several decision makers (DMs) [37,38,40,43]. Generally, uncertainties are unavoidable due to the increasing complexity of practical decision making problems, but quite challenging to modeling by numerical techniques [52]. In this case, fuzzy set, initiated by Zadeh [57], is an effective tool to characterize uncertainty, imprecision and vagueness. The fuzzy decision making is a classical method of granular computing, which is a new concept and computing paradigm of information processing [10,12,18,20,21,33]. The granularities in human reasoning and concept formation are always ambiguous [4,19,28,32,36,44,55]. The fuzzy based computing with words is an important part of granular computing research [3,16,27]. To make up the drawback of single membership of fuzzy set, Atanassov [1] further extended fuzzy set to propose the concept of intuitionistic fuzzy set (IFS). In

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a famous monograph [31], Pedrycz points out that the idea of IFS has contributed massively to decision making methods where IFSs evaluate the membership degree (positive), non-membership degree (negative) and intuitionistic index (hesitation margin). Thus, compared with fuzzy sets, IFSs are more flexible in characterizing uncertainty and fuzziness [40,41].

At present, there are many research findings on IFSs, such as distance or similarity measures [5,9,34], aggregation operators [6,15,23,25,49,54], decision making methods [24,30,37,41,42,51,53] and ranking methods [2,11,13,14,29,35,48,59]. Especially, based on the 1318 references, Yu and Liao [56] comprehensively made a scientometric review on IFS studies. Up to now, the comparison of intuitionistic fuzzy values (IFVs) is still a hot topic for intuitionistic fuzzy theory. Bustince et al. [7] claimed that an order should allow to compare any possible two intervals arising in the valuation of alternatives and then introduced the concept of an admissible order as a total order which extends the usual partial order between intervals to a linear order. Bustince et al. [8] further studied the admissible orders generated by aggregation functions and admissible orders preserved by linear transformations. Many existing ranking methods are the particular instances of these admissible orders. Thus, the admissible order is logical and comprehensive, which can be as a judgment standard of whether the ranking method is reasonable. Similarly, the order of IFVs not only should meet the partial order, but also could be linear, i.e., could distinguish different IFVs. Atanassov [2] defined the partial order of IFVs (Hereafter, called Atanassov's partial order). Although Atanassov's partial order cannot rank all IFVs, it is a foundation of other ranking methods. If a ranking method violates Atanassov's partial order, it is illogical and should not be applied to decision making. Motivated by Bustince et al. [7,8], Liao and Xu [22] proposed the concept of admissible order of IFVs which is linear and refines Atanassov's partial order of IFVs. The admissible order of IFVs is more strict and reasonable than Atanassov's partial order. That is to say, a reasonable ranking method of IFVs should satisfy admissible order. Some works have done on the topic of ranking IFVs, which can be roughly divided into three classes.

The first class is based on score function or accuracy function of IFV. For example, Chen and Tan [11] proposed the score function of IFV by using the membership degree minus its non-membership degree. The bigger the score function of IFV, the larger the IFV. Given that only using the score function cannot compare many IFVs, Hong and Choi [14] presented the accuracy function of IFV, which is obtained through the membership degree plus its non-membership degree. Then combining the score function with the accuracy function, Xu [48] gave an algorithm to obtain the order relation of IFVs. Inspired by Technique for Order Preference by Similarity to an Ideal Solution, Zhang and Xu [59] proposed the ranking method for IFVs by similarity measure and accuracy degree.

The second class is to apply the information measure to rank IFVs. Considering the amount of information as well as the reliability of information of IFVs, Szmidt and Kacprzyk [35] defined a ranking measure to rank IFVs. Xu and Liao [50] applied the ranking measure in [35] to rank intuitionistic fuzzy weights in the intuitionistic fuzzy analytic hierarchy process. However, using such a ranking measure in [35] could violate Atanassov's partial order in some situations. To avoid this limitation, Ouyang and Pedrycz [30] proposed a lexicographical order for ranking IFVs by combining Atanassov's partial order with the ranking measure in [35]. Based on the geometrical representation of IFSs, Guo [13] developed a technique for ranking IFVs and further extended it to the attitudinal-based technique considering DM's attitude. Nguyen [29] introduced a knowledge-based measure to evaluate the quantity of information of IFV by which IFVs are compared.

The third class is possibility based methods for ranking IFVs. Wei and Tang [45] transformed IFVs into intervals and proposed a possibility degree to compare IFVs, which can be regarded as the likelihood of intervals defined by Wang et al. [46]. Li [17] presented another form of possibility degree of IFVs, which is equivalent to the concept of possibility degree defined in [45].

Although all the above ranking methods can be employed to rank IFVs in decision making, they have some limitations as follows:

(1) In methods [11,13,14,29,30,35,48,59], the comparison results of IFVs are directly generated by the order relations. They did not consider the preference degree when comparing IFVs. In particular, if two IFVs cannot be ranked by Atanassov's partial order, it is illogical to say that an IFV is absolutely preferred to another. In other words, the order of such two IFVs should contain a degree to which one IFV is preferred or non-preferred to another.
(2) Methods [13,17,29,35,45] violate Atanassov's partial order, which may lead to some unreasonable or counterintuitive results under some circumstances (see Section 2.2 for more details).
(3) Zhang et al. [58] pointed that the likelihood of intervals in [46] only takes the endpoints of the intervals into consideration but ignores the probability distribution of the intervals. Thus, the likelihood method may fail to provide reasonable results under some situations. The possibility degrees of IFVs [17,42] are simply derived by the likelihood of intervals through transforming IFVs into intervals. In analogy with likelihood of interval, using such possibility degrees to compare IFVs also can lead to some counterintuitive results (see Section 2.2 for more details).

To overcome these limitations, this paper defines a new preference degree of IFVs according to the geometrical representation of IFS. The preference degree of IFVs can measure the possibility of which one IFV is greater than another. Combining the preference degree with the hesitation margin of IFVs, a new preference degree algorithm is designed to rank IFVs and applied to MAGDM with IFVs. To derive the attribute weights for each decision maker (DM), a multi-objective programming model is constructed for each DM and transformed into a linear program to resolve. Using attribute weights for each DM, the individual comprehensive values of alternatives are integrated by intuitionistic fuzzy weighted average (IFWA) operator. Subsequently, based on the individual fuzzy reciprocal preference relations of alternatives and the collective one, the consensus indices are respectively defined at three levels: DM with respect to pair of alternatives, DM and group of DMs. To