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Information fusion for intuitionistic fuzzy decision making: An overview

Zeshui Xu *, Na Zhao

School of Economics and Management, Southeast University, Nanjing, Jiangsu 211189, China

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ABSTRACT

Intuitionistic fuzzy decision making is to find the suitable method for ranking alternatives based on the provided intuitionistic fuzzy information or some related attributes. To date, many studies have focused on intuitionistic fuzzy decision making problems and various decision making methodologies and approaches have been proposed. To provide a clear perspective on the information fusion for intuitionistic fuzzy decision making, this paper presents an overview on the existing intuitionistic fuzzy decision making theories and methods from the perspective of information fusion, involving the determination of attribute weights, the aggregation of intuitionistic fuzzy information and the ranking of alternatives. Some potential challenges in future research are meanwhile pointed out. In addition, we provide a survey of recent applications of the discussed theories and methods in various fields.

1. Introduction

Decision making is a fairly common activity in people's daily life, which can be seen as a process of ranking alternatives or selecting the best one(s) from multiple alternatives based on the provided decision information under the given environment. Due to the complexity of the socioeconomic system, most decision making problems involve multiple attributes/indices used to reflect the characteristics or performances of candidate alternatives, which we usually call multi-attribute decision making (MADM) problems. To date, much attention has been paid to MADM, and many fruitful research results have been achieved [1]. There are three major families of methods for MADM: (i) The utility theory based approaches, in which information fusion techniques are often adopted to synthesize the assessment values of each alternative under different attributes into an overall value, and then the alternatives are ranked by comparing the overall values. The weighted sum model based on some aggregation operators [2], the Analytic Hierarchy Process (AHP) method [3] and the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method [4] are three classical methods in this family. Besides, the method recently developed based upon penalty functions also belongs to this family [5,6]; (ii) The outranking approaches, which are used to identify whether the considered alternative is preferable, incomparable or indifferent to the others over the attributes. There are two main outranking approaches, which are the ELECTRE (Elimination et Choice Translating Reality) method [7] and the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method [8]; (iii) The interactive approach, which allows the decision maker to interact with the analyst or computer (i.e., man–machine interactive decision making) to update his/her preferences [9]. With the increasing complexity and uncertainty of socioeconomic environments and the sharp growth of the amount of knowledge and information, more and more real-life decision making problems cannot be effectively resolved by a single decision maker for a person's attention, knowledge and experience are limited. Accordingly, it is needed to gather multiple decision makers with different knowledge structures and experience to conduct a group decision making (GDM). Two processes are necessarily implemented to solve GDM problems: the consensus process and the selection process [10]. The former aims at reaching the maximum degree of agreement among the decision makers' opinions. The latter encompasses two phases: the aggregation of individual opinions into a collective opinion by using an information fusion technique and the exploitation of the collective opinion for ranking alternatives.

In decision making, uncertainty is ubiquitous since objective things are uncertain and complex, and the managing and modelling of uncertain information are vital for the acquisition of desirable solutions. The fuzzy set [11] has been found to be a useful tool to model people's imprecise decision information, and lots of fuzzy decision making methods have been put forward [10,12,13]. However, the fuzzy set only involves the membership degree, but neglects the hesitation and the indeterminacy often involved in decision making. For example, in a voting event, there is usually "abstention" in addition to "support" and "objection" [14]. In order

* Corresponding author. Tel.: +86 25 84483382.
E-mail addresses: xuzeshui@263.net (Z. Xu), zhaonawfxy@163.com (N. Zhao).

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to fully reflect the characteristics of affirmation, negation and hesitation of human cognitive performance, Atanassov [15] extended the fuzzy set to introduce the intuitionistic fuzzy set (IFS), which is characterized by a membership function, a non-membership function and a hesitancy (indeterminacy) function.

As the IFS can express human's imprecise cognitions from the aspects of affirmation, negation and hesitation, it has been widely used to describe the imprecise, vague or uncertain preferences of the decision makers in decision making process. Xu [16] defined intuitionistic fuzzy numbers (IFNs) (also called intuitionistic fuzzy values (IFVs) [17,18]) as the basic components of an IFS, and developed a decision making method to help a manufacturing company to search the best global supplier. In this example, the IFN (u_{ij}, v_{ij}) was adopted to evaluate the global supplier A_i, where u_{ij} indicates the degree that the supplier A_i satisfies the attribute C_j, v_{ij} indicates the degree that the supplier A_i does not satisfy the attribute C_j, and $1-u_{ij}-v_{ij}$ indicates the hesitancy degree that the supplier A_i satisfies the attribute C_j. Hernandez and Uddameri [19] applied the IFNs to the evaluation of agriculture best management practices in the coastal semi-arid area of South Texas. In this case study, they used the IFN (ρ_i, σ_i) to evaluate the importance of the attribute C_i, where ρ_i and σ_i denote the degrees of membership and non-membership of the attribute C_i to the fuzzy concept "importance", respectively. Wan and Dong [20] developed a novel mathematical programming method for hybrid multi-criteria group decision making, in which the criteria values are expressed by IFNs, interval-valued intuitionistic fuzzy numbers, trapezoidal fuzzy numbers, linguistic variables, interval numbers and real numbers. Liu et al. [21] constructed a partial binary tree DEA-DA cyclic classification model for the decision makers in complex multi-attribute large group interval-valued intuitionistic fuzzy decision making problems. To depict the preferences of the decision makers for each pair of alternatives comprehensively, Xu [22] gave a simple notion of intuitionistic fuzzy preference relations (IFPRs) in which the basic elements are IFNs (u_{ij}, v_{ij}) $(i,j=1,2,\ldots,n)$ and applied them to evaluate the agroecological regions in Hubei Province, China. Here, u_{ij} denotes the certainty degree to which the agroecological region A_i is preferred to the agroecological region A_j, v_{ij} denotes the certainty degree to which A_i is non-preferred to A_j, and $1-u_{ij}-v_{ij}$ is interpreted as the hesitancy degree to which A_i is preferred to A_j. Paternain et al. [23] presented a construction method of IFPRs from fuzzy preference relations and proposed two novel decision making algorithms by generalizing the weighted voting strategy.

Up to now, a large number of studies have been done on the intuitionistic fuzzy decision making and a variety of decision making methodologies and approaches have been proposed [14,24,25]. Since the fusion and processing of intuitionistic fuzzy information are very critical for intuitionistic fuzzy decision making, in this paper, we shall summarize and analyze the current approaches to intuitionistic fuzzy decision making from the perspective of information fusion, involving the determination of attribute weights, the aggregation of intuitionistic fuzzy information and the ranking of alternatives. Furthermore, we shall introduce in depth their recent applications in different fields. Towards these objectives, we set out the remainder of the paper as follows: In Section 2, we briefly introduce some relevant knowledge about intuitionistic fuzzy decision making. Section 3 provides a review of the approaches to derive attribute weights from the intuitionistic fuzzy decision information or from both the intuitionistic fuzzy decision information and the partially known weight information. In Section 4, we first survey the orders of IFNs, which are vital for the ordered aggregation of intuitionistic fuzzy information, and then survey the aggregation operators of intuitionistic fuzzy information in different situations. In Section 5, we review four main approaches for ranking alternatives within the intuitionistic fuzzy decision contexts. Section 6 lists the recent applications of the discussed approaches in various fields. In the last section, we present some conclusions.

2. Intuitionistic fuzzy decision making

In 1986, Atanassov [15] introduced the intuitionistic fuzzy set (IFS) to comprehensively portray the uncertainty of human beings when providing judgments over the objects.

Definition 1 [15]. Let X be a fixed set, then an intuitionistic fuzzy set (IFS) I on X is defined as:

$$I = \{\langle x, u_I(x), v_I(x)\rangle |\ x \in X\}$$

where the functions $u_I : X \to [0,1]$ and $v_I : X \to [0,1]$ ascertain the membership degree $u_I(x)$ and the non-membership degree $v_I(x)$ of the element $x \in X$ to the set I, respectively, with the condition: $u_I(x) + v_I(x) \leqslant 1$.

Usually, $\pi_I(x) = 1 - u_I(x) - v_I(x)$ is called the indeterminacy degree or the hesitancy degree of x to I [17]. $\alpha = (u_\alpha, v_\alpha)$ is called an intuitionistic fuzzy number (IFN) (also called intuitionistic fuzzy value (IFV) [18]) whose physical interpretation can be presented as follows: For instance, if $(u_\alpha, v_\alpha) = (0.5, 0.2)$, then it can be interpreted as "in a presidential election, the vote for a candidate is 50% in favor, 20% against, and 30% abstentions". From the perspective of a voting, the membership degree of an IFS can represent the approval percentage, the non-membership degree can stand for the rejection percentage, and the hesitancy degree, reflecting the percentage of voters who are not sure about whether the candidate is competent as the president, can be regarded as abstention.

During the decision making process, the decision maker is usually required to provide his/her preferences for each pair of alternatives, and then construct a preference relation. Based on the IFNs, Xu [22] defined an intuitionistic fuzzy preference relation (IFPR) on the set $X = \{x_1, x_2, \ldots, x_n\}$ as $\widetilde{A} = (\widetilde{a}_{ij})_{n\times n}$, where $\widetilde{a}_{ij} = (u_{ij}, v_{ij})$ is an IFN, for all $i,j = 1,2,\ldots,n$, and u_{ij} denotes the certainty degree to which the object x_i is preferred to the object x_j, v_{ij} denotes the certainty degree to which x_i is non-preferred to x_j, and $1-u_{ij}-v_{ij}$ is interpreted as the indeterminacy degree or hesitancy degree to which x_i is preferred to x_j. Furthermore, u_{ij} and v_{ij} satisfy the conditions: $u_{ji} = v_{ij}$, $v_{ji} = u_{ij}$, $u_{ii} = v_{ii} = 0.5$, for all $i,j = 1,2,\ldots,n$.

It is obvious that the IFN is very useful in modeling the uncertainty and vagueness of objective things for it allocates to each element in a universe a membership degree, a non-membership degree and a hesitancy degree. Accordingly, more and more researchers have been applying IFNs to describe the imprecise or uncertain decision information and dealing with the uncertainty and vagueness in decision making under different situations. According to the distinct forms of the decision information, the current intuitionistic fuzzy decision making can be roughly divided into two types: The first type is based on the intuitionistic fuzzy assessment information provided by the decision makers, which is expressed by IFNs. The second type is based on the IFPRs provided by the decision makers through pair-wise comparisons of alternatives. In this paper, we mainly focus our attention on the first type for we may refer to the review [26] for the second one.

Firstly, we pay attention to the most common intuitionistic fuzzy MADM (IF-MADM) problems, which can be mathematically described as follows: In a MADM problem, let $A = \{A_1, A_2, \ldots, A_n\}$ be a discrete set of n alternatives, $C = \{C_1, C_2, \ldots, C_m\}$ be the discussion universe containing m attributes, and $w = (w_1, w_2, \ldots, w_m)^T$ be the weight vector of the attributes, where w_j denotes the importance degree of the attribute C_j. If the assessment of each