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SPECIAL ISSUE “INTUITIONISTIC FUZZY THEORY AND ITS APPLICATION IN ECONOMY, TECHNOLOGY AND MANAGEMENT”

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1. Uncertainty theory and intuitionistic fuzzy sets

In the economic, technical and managerial decision-making of the decision makers' subjective participation, they can use standardized knowledge to normalize the decision thinking process so as to achieve their decision-making purposes by concerning the qualitative factors or a mix of qualitative and quantitative decision factors which played a decisive role in reflecting peoples' judgment and experience. Uncertainty theories, such as fuzzy sets (Zadeh 1965), interval-valued fuzzy sets (Zadeh 1965), grey sets (Deng 1998; Liu, Lin

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2006), intuitionistic fuzzy (Atanassov 1986), Vague (Gau, Buehrer 1993), neutrosophic sets (Smarandache 1999), the linguistic term sets and computing with words (CWW) (Zadeh 1975a, 1975b, 1975c; Herrera *et al.* 2008) etc. are the effective tools to solve the decision making problems with the qualitative and quantitative nature together in economic and management decision-making.

The knowledge representation by intuitionistic fuzzy set is a kind of intuitive behavior of human advanced thinking in essence. Such as the interval fuzzy knowledge, grey knowledge, and intuitionistic fuzzy knowledge, all of them were called intuitive knowledge by Dubois and Gottwald (2005). Intuitive knowledge development is a necessity of economic, technical and managerial decision making which coincides with the transition from the industrial society to the information society. In addition, the intuitive knowledge was developed from one to three dimensions (i.e. fuzzy numbers, intervals, three dimensional discrete points) in terms of data describing, and was developed from subjectivity to the combination of subjectivity and objectivity in considering preference expression, and it was also developed from rough to fine on simulating human decision making and behaviors.

2. Evolution of intuitive decision-making knowledge

The evolution of intuitive knowledge and the development of operational systems have approximately experienced 50 years.

(1) **Interval fuzzy knowledge.** In the periods of the third science and technology revolution, there is a urgent need to find a tool for identifying the qualitative problems with the emergence of all kinds of "man-machine control system". In 1965, Cybernetics expert, Professor Zadeh (1965) proposed fuzzy set theory, which opened up a new era of quantitative analysis for qualitative problems. As early as in 1966, Moore (1966) has put forward the concept of interval analysis, and he focused on the operational systems of interval numbers. However, these operational systems are still limited to algebraic arithmetic systems, and they are not reversible. This is also destined to make the interval operational theory not make a breakthrough in the conventional conditions.

In 1975, Zadeh (1975a, 1975b, 1975c) put forward a theory of interval fuzzy set which is an extension of fuzzy theory by generalizing the ordinary fuzzy membership to an uncertain interval. Fuzzy interval arithmetic can better express the People's decision preference, i.e., although objective things cannot be cognized accurately, at least, its subject range of membership can be defined. Interval fuzzy sets referenced interval operational systems and the operational results are expressed by the approximate numerical values, which are gradually accepted by researchers in the field of decision making.

(2) **Grey interval knowledge.** In 1982, "The Control Problem of Grey System" by Deng (1982) is published in North Holland in 1982, which marked the birth of the grey system theory, and stressed the object of the research "extension is clear and definite and the intension is not clear and definite". By the grey interval, the decision maker's preference is expressed. Since 1993, Huang *et al.* (1993) has laid very important theoretical foundation for the study of grey planning as well as has greatly promoted the development of the grey multi-objective and grey multi-attribute decision making theory which are based on the

optimization decision-making theory. In grey system, many scholars suggested that the decision interval were expressed by the linear parameters so as to avoid the limitations of interval operations. The domain of grey preference is defined in $(-\infty, +\infty)$ while fuzzy preference interval are limited to $[0,1]$, thus, the grey interval preference knowledge can emphasize more on the objectivity of data.

(3) Intuitionistic fuzzy knowledge. In 1986, Atanassov (1986) proposed the intuitionistic fuzzy sets which are the extensions of fuzzy sets, and then he further established the relationship between intuitionistic fuzzy sets and interval fuzzy sets in 1989 (Atanassov, Gargov 1989). Intuitionistic fuzzy sets can express the decision maker's preference by three discrete values i.e. membership degree, non-membership degree and hesitation degree, which are the discrete expressions of continuous interval fuzzy values.

In the field of group decision making, about People's reactions to the evidence or opinions, there are three kinds of situations in general, i.e., affirmation, negation and uncertainty, the People's behavior recognition process is similar to the thoughts of intuitionistic fuzzy sets. The normal operations cannot handle the intuitionistic fuzzy system, and new operational laws have been built (Atanassov 1986; Liu 2014; He *et al.* 2014). Further, the successful applications of the intuitionistic fuzzy sets theory in pattern recognition, clustering analysis, knowledge inference and other areas have greatly promoted the developments of unconventional operational systems in intuitionistic fuzzy systems.

(4) Knowledge of intuitionistic fuzzy theory extensions. Because of the complexity of objective things, the fuzziness of human thinking, as well as the limits of decision time, cost and the decision-maker's knowledge, there are still many limitations to express the decision information in the form of intuitionistic fuzzy sets. On the one hand, sometimes, it is difficult for people to express membership degree and non-membership degree by real numbers, so, there are a lot of researches about the extensions of intuitionistic fuzzy sets, for example, the membership degree and non-membership degree are extended to interval numbers (Atanassov, Gargov 1989), triangular fuzzy numbers (Zhang, Liu 2010), fuzzy numbers (Wang, Zhang 2009) and linguistic variables (Chen *et al.* 2015). Obviously, these extensions have improved the ability of intuitionistic fuzzy sets to express uncertain information. On the other hand, the decision makers can give the membership degree and non-membership degree of the intuitionistic fuzzy set only for a particular concept, in order to make the membership or non-membership belonged to some a special value and not to a concept, many researchers combined intuitionistic fuzzy sets with fuzzy numbers (Wang, Zhang 2009), linguistic variables (Wang, Li 2009; Liu 2013a) and uncertain linguistic variables (Liu, Jin 2012), and proposed intuitionistic trapezoidal fuzzy numbers, intuitionistic linguistic variables, intuitionistic uncertain linguistic variables and so on to indicate the degrees of membership and non-membership to some a fuzzy number, linguistic variable, uncertain linguistic variable. Clearly, these extensions, which fully considered the merits of intuitionistic fuzzy sets and fuzzy numbers or linguistic variables, uncertain linguistic variables, are of greater generality, and can easily express the complex realistic decision information.

3. The research progress of intuitionistic fuzzy sets in economy, technology and management decision-making field

In recent years, the intuitionistic fuzzy sets have attracted wide attentions, and have made important research progress in economy, technology and decision-making management fields (Mardani *et al.* 2015).

- (1) Research on the fundamental theory of intuitionistic fuzzy sets, include: the operational laws, information entropy, distances, similarity and comparison methods for intuitionistic fuzzy sets; aggregation function and aggregation operators for intuitionistic fuzzy information, such as generalized aggregation operator, Sugeno and Choquet integral operators, prioritized aggregation operators, power average operators, Bonferroni mean, dependent aggregation operators, density weighted average operators and so on (Zavadskas *et al.* 2014; Liu 2013a, 2013b; Liu, Yu 2013; Liu *et al.* 2014; Liu, Wang 2014).
- (2) Research on the decision making methods, mainly include: extensions of the traditional decision making methods to intuitionistic fuzzy sets, such as TOPSIS (Wang *et al.* 2015), VIKOR (Peng *et al.* 2015), ELECTRE (Liu, Zhang 2011; Ebrahimnejad *et al.* 2015; Hashemi *et al.* 2016), TODIM (Li *et al.* 2015), DEMATEL (Govindan *et al.* 2015), MOORA (Pérez-Domínguez *et al.* 2015), MULTIMOORA (Zavadskas *et al.* 2015), COPRAS (Hajiagha *et al.* 2013a), DEA (Hajiagha *et al.* 2013b; Liu *et al.* 2014) and so on are extended to intuitionistic fuzzy information, we can call these extensions the extended decision making methods; another decision making methods are based on the aggregation operators, and can provide the comprehensive values by aggregating the criteria information.
- (3) Research on intuitionistic fuzzy group decision-making, mainly include: the construction of aggregation rules for intuitionistic fuzzy information, the optimization modeling construct, conflict measure models of group members, group consistency analysis models and the optimal selection of the project etc.
- (4) Research on applications of intuitionistic fuzzy sets. There are a lot of applications in real decision making based on the intuitionistic fuzzy sets (Hajiagha *et al.* 2013a), such as scheme selection, performance evaluation, pattern recognition, computing with words, clustering analysis, knowledge inference, medical diagnosis and so on. These researches include information acquisition, optimization model construction, algorithm design, simulation and analogue test, system development, and they are also the extension of general multi-attribute decision-making methods (Hajiagha *et al.* 2015).

4. About the papers of this special issue

Now, we briefly summarize the contents of this special issue in which there are five new contributions on the theory of intuitionistic fuzzy sets and the methods of multiple attribute decision making or multiple attribute group decision making based on intuitionistic fuzzy sets. These contributions can be divided into three groups.

The first one includes two papers which provide some new theory for intuitionistic fuzzy set, such as novel score function and accuracy function, the spherical distance for intuitionistic fuzzy sets, and inclusion comparison possibility for interval-valued intuitionistic fuzzy sets. The second group only covers one paper introducing the fuzzy ELECTRE outranking method with interval-valued intuitionistic fuzzy sets. The third group only includes one paper presenting novel fuzzy MCDM models based on significant aggregation operators.

There are three papers in the first group which introduces some new theory of IFS.

- Wu *et al.* in “An approach for MADM problems with interval valued intuitionistic fuzzy sets based on nonlinear functions” propose the nonlinear score, accuracy and hesitation functions of IVIFNs based on the normal distribution. The advantage of these nonlinear functions is that they have an additional variance value, which can have more information to rank IVIFNs than Xu and Chen’s score function and Ye’s accuracy function. In addition, authors also develop a nonlinearly optimized model to obtain attribute weights by integrating these nonlinear functions, and they further present an MADM approach in which two cases are considered: the attribute weight information is known and particularly known.
- Gong *et al.* in “The spherical distance for Intuitionistic fuzzy sets and its application in decision analysis” propose the spherical distance between two IFSs. The advantage is that it relies not only on their relative differences but also their absolute values. Authors generalize the properties of spherical distance measures between IFSs, and develop an optimization spherical distance model with IFS preference in group decision making.
- In the paper entitled “An inclusion comparison approach for multiple criteria decision analysis based on interval-valued intuitionistic fuzzy sets”, by Chen, an inclusion comparison possibility defined on interval-valued intuitionistic fuzzy sets is proposed, and some important properties are investigated. Further, authors constructs a linear programming model (for consistent information) and an integrated, nonlinear programming model (for inconsistent information) to estimate the criterion weights and the optimal ranking order of the alternatives under an incomplete preference structure by considering the maximal comprehensive inclusion-based indices.

In addition, based on these new theories of IFS, authors propose the some decision making methods for MADM problems in which the attribute values take the form of IFS and attribute weight is known and particularly known.

There is one paper in the second group which introduces an extended ELECTRE outranking method for multiple criteria decision-making with interval-valued intuitionistic fuzzy sets.

- Chen in “An IVIF-ELECTRE outranking method for multiple criteria decision-making with interval-valued intuitionistic fuzzy sets” proposes an interval-valued intuitionistic fuzzy ELECTRE (IVIF-ELECTRE) method and applies it to multiple criteria decision analysis (MCDA) involving the multiple criteria evaluation/selection of alternatives. Author identifies inclusion comparison approach, concordance and discordance sets for each pair of alternatives, and determines the concordance

and discordance indices using an aggregate importance weight score function and a generalized distance measurement between weighted evaluative ratings, respectively. Based on the concordance and discordance dominance matrices, two IVIF-ELECTRE ranking procedures are developed for the partial and complete ranking of the alternatives.

There is one paper in the third group which introduces intuitionistic trapezoidal fuzzy prioritized OWA operator.

- Liu *et al.* in "A multi-criteria decision-making method based on intuitionistic trapezoidal fuzzy prioritized OWA operator" proposes intuitionistic trapezoidal fuzzy prioritized ordered weighted aggregation (ITFPOWA) operator, and develops an approach to the multi-criteria decision-making with intuitionistic trapezoidal fuzzy numbers. The advantage is that this method considers the prioritized relationship among decision-making attributes and the attribute values take the form of intuitionistic trapezoidal fuzzy information.

In the applications to real decision making problems, the five new contributions have also good performances.

The method proposed by Wu *et al.* in "An approach for MADM problems with interval valued intuitionistic fuzzy sets based on nonlinear functions" was applied to solve the environmental performance evaluation problems.

The method proposed by Gong *et al.* in "The spherical distance for Intuitionistic fuzzy sets and its application in decision analysis" was applied to group decision making, pattern recognition, and medical diagnosis.

The method proposed by Chen in "An inclusion comparison approach for multiple criteria decision analysis based on interval-valued intuitionistic fuzzy sets" was applied to select the most suitable bridge construction method for the Su-Hua Highway Alternative Route Plan at the Hualian and Taidong areas in Taiwan.

The method proposed by Chen in "An IVIF-ELECTRE outranking method for multiple criteria decision-making with interval-valued intuitionistic fuzzy sets" was applied to select a suitable watershed site.

The method proposed by Liu *et al.* in "A multi-criteria decision-making method based on intuitionistic trapezoidal fuzzy prioritized OWA operator" was applied to the recruitment of human resource managers.

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