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The multi-criteria group decision making methodology using type 2 fuzzy linguistic judgments

Kuo-Ping Chiao Q1
Department of Industrial Management and Enterprise Information, Aletheia University, Tamsui, New Taipei, Taiwan

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ABSTRACT

This paper develops an integrated methodology for multiple criteria and multiple experts decision making problems using type 2 fuzzy sets (T2FS) as the linguistic judgments. The experts or decision maker's opinions are in linguistics forms. The proposed approach is the extension of the analytic hierarchy process (AHP) method for multiple experts. The pairwise or relative comparisons of decision linguistic judgments are characterized by interval type 2 fuzzy sets (IT2FS). The integrated methodology consists of the following stages: 1. Construct IT2FS pairwise comparison matrix (PCM), 2. Elicit IT2FS weights and rates, 3. Normalize the IT2FS weights and rates, 4. Synthesize the IT2FS weights and rates, 5. Calculate the global IT2FS rates, 6. Determine the final decision priority. At the outset of the decision making the IT2FS PCM for a set of criteria is created. The quadratic programming models are constructed to elicit the absolute IT2FS weights of the criteria in the sense of minimizing the least squares logarithmic regression functions. A normalization procedure is introduced for the IT2FS vector to obtain the well-defined and normalized IT2FS weights. Two approaches, the linear programming model and the IT2 fuzzy weighted average (FWA), are developed to synthesize and aggregate the local rates and weights. Thus, the overall global IT2FS rates for the alternatives are obtained. The final decision then can be concluded by the priority of the overall IT2FS rates of the alternatives. The proposed approach is applied to New Product Development (NPD) project screening. NPD is largely uncertain, because of competition accompanied with modern technology and market changes. It always leads to failure of New Product Development. The final project screening decision is obtained from the overall global IT2FS rates of the projects with respect to the screening criteria. Q2

1. Introduction

Q3

Decision maker judgments including preference information are highly appropriate stated in linguistic terms. There are many approaches proposed for modeling the decision linguistic term sets. Zadeh defined the linguistic variable a variable whose values are words or sentences in a natural or artificial language in his three consecutive papers [97–99]. Recently, Morente-Molinera et al. [74] provided a systematic review of fuzzy linguistic modeling approaches for the last decade. The reviewed methods are classified into six categories based on different approaches. Cabrerizo et al. [9] found that linguistic term sets are sometimes not uniformly and symmetrically distributed and proposed a methodology which is able to manage the unbalanced fuzzy linguistic information. Montes et al. [73] presented a practical application in the housing market and developed a web tool using a 2-tuple linguistic fuzzy model with hesitant information.

Words mean different things to different people. The uncertainty of the relative importance among criteria can be further given by words. Zadeh [100] originated the phrase Computing With Words (CW or CWW) one that is a methodology for which the propositions are extracted from a human language. There are many various CWW approaches applying to decision making task with linguistic terms. To overcome the drawback "loss of information" while using linguistic information in CWW, Herrera and Martínez [41] firstly proposed a 2-tuple fuzzy linguistic representation model for CWW. Also, they claimed that such kind of model is more precise than the previous ones. Dong et al. [33] drew upon the generalized inverse operation to map an interval numerical scale to the linguistic 2-tuples and proposed an interval version of the 2-tuple linguistic representation model which connects the linguistic 2-tuples, intervals and IT2FSs in CWW. Later,

E-mail address: chiao@mail.au.edu.tw

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based on consistency of preference relations, Dong and Herrera-Viedma [29] proposed a consistency-driven methodology to set the 2-tuple linguistic term sets with linguistic preference relations. By extending the proportional 2-tuple fuzzy linguistic representation model [90], Dong et al. [32] developed a consensus model based on multi-granular unbalanced 2-tuple linguistic preference relations.

This paper is mainly concerning with developing a complete approach to multi-criteria group decision making (MCGDM) based on the AHP by extending the crisp judgments to IT2FS linguistic scales. The typical AHP consists of the following stages: 1. Construct pairwise comparison matrix (PCM), 2. Elicit criteria weights and alternative rates, 3. Normalize the weights and rates, 4. Synthesize the weights and rates, 5. Calculate the global rates for each alternative, 6. Determine the final decision priority. This paper develops at least one approach for each stage. That is the major contribution of this article. For example, we propose two approaches to synthesis or aggregate the IT2FS. One is the linear programming models, and the other is a direct extension of interval weighted average. At the outset of the aggregation studies, Yager [94] proposed the ordered weighted averaging (OWA) operator for aggregating criteria guided by quantifiers. The OWA operator providing a parametric class of averaging operators is for discrete and crisp quantifiers and arguments. Later, for extending the OWA operator applications Yager [95] developed the continuous OWA (C-OWA) operator by considering the arguments in a continuous interval rather than a finite set of values. Based on Zadeh's extension principle [97], Zhou et al. [101] was the first study that extends the OWA operator for T1FS quantifiers and arguments. For the T2FS linguistic quantifiers, Zhou et al. [101] also provided the procedure for obtaining the linguistic weights for the T1FS OWA operator. Later, Zhou et al. [102,103] proposed the T2FS OWA operator which is a direct approach to the aggregation of IT2FS. The centroid value is one of the defuzzification method used in the final stage of AHP for T1FS scales. However, the centroid of an IT2FS has no universal definition. Some of the systematic studies about IT2FS centroid are Karnik and Mendel [47], Mendel and Wu [70], and Mendel [69]. Greenfield et al. [37] proposed a defuzzification approach of IT2FS by introducing a collapsing method to convert IT2FS into T1FS representative embedded set. They claim that such approach is more accurate than Karnik and Mendel [47]. Chiclana and Zhou [19] developed a method to determine the centroid of the IT2FS by using T1FS OWA. Torshizi et al. [83] give a literature review for IT2FS type reduction studies.

The best mapping to the so-called "words" can be modeled by IT2FS [66]. To capture the word uncertainty, we need to collect the various opinions from experts and to map into an overall representative term. Some approaches were proposed for gathering experts information mapping into a T1FS as surveyed by Mendel [68], for example, polling [42,54], direct rating [12,94,75,85], reverse rating [94,85,84,86], interval estimation [21,34,104,25], and transition interval estimation [25]. However, Mendel [68] also pointed out that none of the methods transfers the uncertainties from a group of experts judgments into a T1FS because a T1FS does not have enough degrees of freedom. That is why we do need T2FS the one that has the potential to capture decision uncertainties. In addition to the scholarly publications, some excellent reviews about introducing the concept of T2FS are given by Mendel [62–64].

This paper develops a complete approach for solving the multi-criteria group decision making problems based on the analytical hierarchy process (AHP). AHP developed by Saaty [78,80] is an effective and popular approach to MCGDM. It has been widely applied to many fields such as logistics and supply chain management [50,45], manufacturing system and facility layout [35], resource allocation [82], economics and social sciences [81]. There are many authors published the reviews for the applications of AHP and fuzzy AHP (FAHP). Vaidya and Kumar [88] reviewed and critically analyzed AHP applications categorized according to the areas such as, personal, manufacturing, industry, social, education, etc. Instead of reporting the applications of AHP, Ishizaka and Labib [44] reviewed the methodological developments of AHP. They discussed the problem modeling, pairwise comparisons, judgment scales, derivation methods, consistency indexes, incomplete matrix, synthesis of the weights, sensitivity analysis and group decisions. Ho [43] reviewed the literature of the applications of the integrated AHP including mathematical programming, quality function deployment (QFD), meta-heuristics, SWOT analysis, and data envelopment analysis (DEA). Since 1980, critics have raised questions about the proper uses of AHP. Some heated topics are about the ranks of the alternatives. Upon changing the structure of the decision hierarchy, the ranking of some alternatives are changed and it is often referred to as rank reversal. Maleki and Zahir [60] specifically presented a comprehensive literature review to the research on AHP methodologies and rank reversals. However, AHP is still the most popular approach among the decision making tools, like ELECTRE, MacBeth, MAUT, PROMETHEE, SMART, TOPSIS, UTA (and its variants) [4,36]. It offers a comprehensive and rational framework for structuring the decision making problems. AHP is capable of evaluating quantitative and qualitative criteria and alternatives on the same preference scales for the tangible and intangible decision problems. The multiple dimensional scaling problems are transformed to the single dimensional scaling problem with AHP. The most critical stage while applying AHP is to elicit the absolute weight for each criterion or rate for each alternative from PCM. Many approaches have been developed in Literature. Bryson [6,7] developed the goal programming model. Laininen and Hämäläinen [52] proposed a method by robust regression.

In real world, most of the decision problems are under uncertain environment. The judgments might not be given as an exact relative scale. The criteria are characterized as possessing not only quantitative but also qualitative. In addition, some attributes of the alternative and criteria are intangible. For example, the performance or skill cannot be measured as numbers. It is highly appropriate using linguistic scales. The original Saaty's AHP model is of crisp opinions, which is too restrictive for experts to judge. The fuzzy version of the extension of Saaty's priority theory was proposed by de Graan [27] and Loostma [59]. Based on their fuzzy extension, Van Laarhoven and Pedrycz [89] formally presented a method to find the fuzzy priority vector from a fuzzy pairwise comparison matrix (FPCM) with the triangular fuzzy numbers (TFN) as the matrix elements. By proposing a normalization modification of the fuzzy priority vector from Loostma's LSMR algorithm, Boender et al. [5] pointed out that the normalized solution violates the first-order conditions, i.e. the applied normalization destroys optimality. Another approach to find the priority vector was based on the row and column geometric means (RCGM) which was studied by Crawford and Williams [1,26,49,87]. Buckley [8] was the first one to develop the fuzzy geometric mean method to find the fuzzy priority vector (weights). Actually, Buckley developed the interval geometric mean method for obtaining the interval priority vector for interval comparison matrix. His algorithm can be applied to any general fuzzy numbers and not just for TFN. However, the numerical evaluation process is tedious.

In this paper, a MCGDM integrated methodology with IT2FS extension of AHP is developed. The judgments in the context of linguistic comparison scales are represented by IT2FS characterized by trapezoidal and triangular T1FS. The original AHP scales proposed by Saaty are the crisp numbers, {1, 2, 3, 4, 5, 6, 7, 8, 9} as well as the reciprocals. They are to be relaxed for including more uncertain judgment information. For instance, one of the Saaty's crisp scale as in Table 1, "Weak importance of one over another" might have different meanings to different people. Because the word "slightly" in the explanation is actually a matter of linguistic term, it is not appropriate to be simply given the 3 out of the set of scales 1–9.