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# Integration of fuzzy AHP and interval type-2 fuzzy DEMATEL: An application to human resource management

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ABSTRACT

The fuzzy analytic hierarchy process (fuzzy AHP) and fuzzy decision making trial and evaluation laboratory (fuzzy DEMATEL) have been used to obtain weights for criteria and relationships among dimensions and criteria respectively. The two methods could be integrated since it serves different purposes. Previous research suggested that the weights of criteria and the relationships among dimensions and criteria were obtained with the utilization of triangular type-1 fuzzy sets. This study proposes the integration of fuzzy AHP and interval type-2 fuzzy DEMATEL (IT2 fuzzy DEMATEL) where the interval type-2 trapezoidal fuzzy numbers are used predominantly. This new integration model includes linguistic variables in interval type-2 fuzzy sets (IT2 FS) and expected value for normalizing upper and lower memberships of IT2 FS. The integration was made when the weights obtained from fuzzy AHP were multiplied with expected values of IT2 fuzzy DEMATEL. The proposed integration method was tested to a case of human resources management (HRM). The results show that the criterion of education is more critical than the other criteria since it is a cause and directly influence HRM. The case study results verify the feasibility of the proposed method that suggested the criteria of education as the most influential criteria in managing human resources.



## 1. Introduction

The multi-criteria decision making (MCDM) is widely used method to evaluate criteria that are typically multiple. The method is used to compare, rank and order several alternatives with respect to criteria. A typical MCDM problem involves a number of decision-makers (DMs) to provide qualitative and quantitative measurements for determining the performance of each alternative with respect to criteria and the relative importance of the evaluation criteria with respect to the overall judgments (Abdullah, Sunadia, & Imran, 2009). Many MCDM problems in the real world are judged or evaluated by a group of DMs. There are numerous MCDM approaches have been proposed thus far. Analytic hierarchy process (AHP), analytic network process (ANP), decision making trial and evaluation laboratory (DEMATEL), technique for order preference by similarity to ideal solution (TOPSIS), just to name a few. One of the most outstanding MCDM approaches is the AHP where decision is made by DMs based on pair-wise comparison among criteria and alternatives. In AHP, the linguistic scale of crisp value is used for defining pair-wise comparison. However, this method is not appropriate for human thinking process where fuzziness is present in handling uncertainty in linguistic judgment (Marbini & Tavana, 2011; Sen & Cinar, 2010; Shaw, Shankar, Yadav, & Thakur, 2012). Moreover, a crisp decision-making method as the AHP is not appropriate because many of the maintenance goals taken as criteria are non-monetary and difficult to be quantified (Wang, Chu, & Wu, 2007). For this reason, linguistic variables with fuzzy number preference scales are used to express the DMs' uncertainty. In addition, linguistic variables denote words or sentences of a natural language (Zadeh, 1975). Thus, the AHP is extended by incorporating the basic concepts of fuzzy sets theory. This method is popularly known as fuzzy AHP. The fuzzy AHP has been developed, in which the pair-wise comparisons in the judgment matrix are fuzzy numbers. The decisions are evaluated in a systematic manner through subjective ratings such as 'between three and five times less important' and 'approximately three times more important' (Yeap, Ignatius, & Ramayah, 2014). The DMs are given the authority to select linguistic variable that reflects their confidence. The fuzzy AHP applies fuzzy arithmetic and fuzzy aggregation operators in order to solve the hierarchical structure of problems. The calculation of fuzzy AHP is done as per normal AHP method for weighting the criteria of decision problems (Bozbura, Beskese, & Kahraman, 2007).

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Fuzzy AHP has been successfully applied in diverse applications. Many authors have developed many variations of fuzzy AHP for evaluating fuzziness of decision making problems (Bulut, Duru, Kececi, & Yoshida, 2012; Chou, Sun, & Yen, 2012; Csutora & Buckley, 2001; Laarhoeven & Pedrycz, 1983; Lee, 2009; Lee, Kang, & Wang, 2005; Saaty & Tran, 2007; Vahidnia, Alesheikh, & Alimohammadi, 2009; Yeap et al., 2014). Despite these variations, the ultimate aim of fuzzy AHP is to obtain relative weights of the criteria and rank the criteria accordingly. The relative weights are the output of the fuzzy AHP. However, some researchers often perceive the relative weights as potential input for other MCDM methods where integration with other methods could be established and applied in various knowledge domains. Jung (2011), for example, proposed fuzzy AHP-goal programming (GP) approach for integrated production-planning. In this research, the fuzzy AHP was utilized to generate the relative weight of each manufacturing partner and GP approach was applied to minimize the total cost. Shaw et al. (2012) presented the integration of fuzzy AHP method and fuzzy multi-objective linear programming to select the appropriate supplier in the supply chain. The fuzzy AHP was used at the first phase of the integration method to calculate the relative weights of the criteria and fuzzy multi-objective linear programming was used to obtain the optimum solution of the problem. In another related research, integration of fuzzy AHP and fuzzy TOPSIS was proposed by Patil and Kant (2013) to identify and rank the solutions of Knowledge Management (KM) adoption in supply chain. The empirical case study analysis of an Indian hydraulic valve manufacturing organization was conducted to illustrate the use of the proposed framework. In a human resource management decision, Chou et al. (2012) used an integration of fuzzy AHP and fuzzy DEMATEL method in human resource for science and technology (HRST). The research flow started with fuzzy AHP where the relative weights of different dimensions for the performance of HRST were obtained. The fuzzy DEMATEL method was subsequently used to capture the complex relationships between dimensions and criteria.

Likewise fuzzy AHP, fuzzy DEMATEL method is also one of the MCDM approaches. However, the two MCDM methods serve different purposes. Determining relative weights of criteria through pair-wise comparison judgement is the end result of fuzzy AHP. Unlike fuzzy AHP, fuzzy DEMATEL is the method that specifically tailored for causal relationship between criteria and dimensions. Fuzzy DEMATEL and DEMATEL method have been developed initially to visualize the causal relationship of sub-systems through a causal diagram (Gabus & Fontela, 1973). The two methods, according to the characteristics of objective affairs, can verify the interdependence among the criteria and confirm the relation that reflects the characteristics with an essential system and evolution trend (Chiu, Chen, Tzeng, & Shyu, 2006; Huang & Tzeng, 2007 and Tamura, Nagata, & Akazawa, 2002). The fuzzy DEMATEL is used to solve MCDM problems where fuzzy numbers are included in linguistic judgement. It is needed to build an extended crisp DEMATEL method by adopting linguistic variables (Lin & Wu, 2004). Preferences of DMs' are extended to fuzzy numbers using fuzzy linguistic scale so as to handle with ambiguity of human assessments. In other words, linguistic assessments are used instead of numerical values, in which all assessments of the criteria are evaluated by means of linguistic variables (Jassbi, Mohamadnejad, & Nasrollahzadeh, 2011). Fuzzy DEMATEL expresses the different degrees of influences or causalities in crisp DEMATEL with five linguistic terms of 'Very high', 'High', 'Low', 'Very low' and 'No' by adopting fuzzy numbers (Lin & Wu, 2004). Fuzzy direct influence matrix is constructed so as to avoid uncertainty and vagueness in crisp direct influence evaluations. Most of the existing fuzzy DEMATEL methods are built from linguistic variables based on type-1 fuzzy set (T1FS). Lin (2013), for example, utilized the T1FS and DEMATEL to construct a structural model for searching the cause and effect relationships among criteria in green supply chain management. Jassbi et al. (2011) investigated the Balanced Scorecard as the basis for a strategic management system by applying T1FS and DEMATEL method. Chang, Chang, and Wu (2011) applied fuzzy DEMATEL method to identify the influential factors for selecting suppliers using T1FS.

With the latest development of type-2 fuzzy sets (T2FS) and the concepts of interval type-2 fuzzy sets (IT2FS), causal relationship in the DEMATEL deserves to receive more comprehensive evaluation thanks to the flexibility of spaces representing uncertainties than they do with T1FS. T2FSs are characterized by fuzzy membership functions, as each element of this set is a fuzzy set in $[0,1]$, unlike a T1FS where the membership grade is a crisp number in $[0,1]$ (Mendel, 2001). The membership functions of T2FS are three-dimensional and include a footprint of uncertainty (FOU) which is the new third dimension of T2FS and provides additional degrees of freedom for directly modeling and handling uncertainties (Turksen, 2002). Currently, IT2FSs are widely used and have been successfully applied in perceptual computing (Mendel & Wu, 2010; Mendel et al., 2010), and control systems (Hagras, Doctor, Callaghan, & Lopez, 2007; Jammeh, Fleury, Wagner, Hagras, & Ghanbari, 2009; Wagner & Hagras, 2010; Wu & Mendel, 2011). Ozen and Garibaldi (2004) used the shape of type-2 fuzzy membership functions to model variation in human decision-making. In short, IT2FS has more flexibility in capturing uncertainties in the real world due to the fact that it is described by primary and secondary membership (Hu, Zhang, Chen, & Liu, 2013). Moreover, IT2FS can provide us with more degrees of freedom to represent the uncertainty and the vagueness of the real world (Zhang & Zhang, 2013). Therefore, it is impeccable to integrate the extra flexibility of IT2FS and the unique causal relationship of DEMATEL. So far, however, there has been little discussion about this integration. There was an attempt made by Hosseini and Tarokh (2013) to propose type-2 fuzzy set extension of DEMATEL and its application in perceptual computing decision making. However, this method has only depended on triangular fuzzy numbers and interval for defining linguistic or word. The present study attempts to make an extension of fuzzy DEMATEL where triangular fuzzy numbers are substituted with IT2 trapezoidal fuzzy numbers. The IT2 fuzzy DEMATEL is expected to visualize the structure of complex causal relationships using matrices or diagrams.

The pair-wise comparison evaluation of fuzzy AHP and the new IT2 fuzzy DEMATEL are the two MCDM methods that could be integrated to develop a new model. Previously, Chou et al. (2012) had developed the integration of fuzzy AHP and fuzzy DEMATEL. The fuzzy AHP was adopted to find weights of the criteria whereas the fuzzy DEMATEL was adopted to capture the complex relationship between dimensions and criteria. The two methods were used separately with two different purposes and there was no clear integration between the methods. The weights obtained from fuzzy AHP were meant for improving staff management in a short period and the relationships were used for improving in a long run. The fuzzy AHP used was totally unrelated to fuzzy DEMATEL and vice versa. They only divided the methods into short term period solution and long term period solution and their method was just the same as single approach of fuzzy AHP and fuzzy DEMATEL without having any integration between these two methods. Therefore, we attempt to merge the fuzzy AHP and the new IT2 fuzzy DEMATEL to become an integrated method. The two methods are now being aptly by introducing weight obtained from fuzzy AHP to IT2 fuzzy DEMATEL.

In the proposed integration method, IT2 trapezoidal fuzzy numbers are used instead of type-1 triangular fuzzy numbers. This move is made to align with IT2 trapezoidal fuzzy number that is used in fuzzy DEMATEL. Trapezoidal fuzzy number also can cap-