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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; Mendel, 2007). 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

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used in fuzzy DEMATEL. Trapezoidal fuzzy number also can capture more generic class of fuzzy numbers where more linear membership functions can be created. The weights obtained from fuzzy AHP are used as multiplying factor to the expected values of IT2 fuzzy DEMATEL. The multiplications of weights and expected values are strongly being manipulated to construct the causal diagram that eventually provides a decision. The created multiplication operation is the main contribution in the integrated method apart from the introduction of trapezoidal fuzzy numbers in fuzzy AHP and the introduction of IT2 trapezoidal fuzzy numbers in DEMATEL. Specifically, this paper aims to develop an integration of fuzzy AHP and IT2 fuzzy DEMATEL and its application to a case of human resource management (HRM). The remainder of this paper is organized as follows. In Section 2, we describe the basic concepts of trapezoidal fuzzy numbers and IT2FS in MCDM method. The integration of fuzzy AHP and IT2 fuzzy DEMATEL framework is developed in Section 3. In Section 4, selection of criteria in a HRM problem is presented to demonstrate the feasibility of the integration method. Finally, this paper concludes in Section 5.

2. Preliminaries

This section introduces the basic definitions relating to trapezoidal fuzzy numbers, basic concepts of IT2FS and arithmetic operations between trapezoidal IT2 FS.

2.1. Trapezoidal fuzzy numbers

A trapezoidal fuzzy number can be defined as $\tilde{m} = (a, b, c, d)$ where the membership functions $\mu_{\tilde{m}}$ of $\tilde{m}$ is given by:

$$\mu_{\tilde{m}} = \begin{cases} \frac{x-a}{b-a} & (a \leqslant x \leqslant b) \\ 1 & (b \leqslant x \leqslant c) \\ \frac{d-x}{d-c} & (c \leqslant x \leqslant d) \end{cases} \quad (1)$$

where $[b, c]$ is called a mode interval of $\tilde{m}$, a and b are called lower and upper limits of $\tilde{m}$, respectively (Soheil & Kaveh, 2010).

Let $\widetilde{A}$ and $\widetilde{B}$ be two positive trapezoidal fuzzy numbers parameterized by (a_1, a_2, a_3, a_4) and (b_1, b_2, b_3, b_4), then the operational laws of these two trapezoidal fuzzy numbers are given as follows (Soheil & Kaveh, 2010):

$$\tilde{A} \oplus \widetilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \quad (2)$$

$$\widetilde{A} - \widetilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3, a_4 - b_4) \quad (3)$$

$$\widetilde{A} \otimes \widetilde{B} = (a_1 \times b_1, a_2 \times b_2, a_3 \otimes b_3, a_4 \times b_4) \quad (4)$$

$$(\widetilde{A})^{-1} = \left(\frac{1}{a_4}, \frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right) \quad (5)$$

2.2. Interval type-2 fuzzy set

Let $\widetilde{A}$ be a type-1 trapezoidal fuzzy set, $\widetilde{A} = (a_1, a_2, a_3, a_4; H_1(A), H_2(A))$ as shown in Fig. 1, where $H_1(\widetilde{A})$ denotes the membership value of the element a_2, $H_2(\widetilde{A})$ denotes the membership value of the element a_3, $0 \leqslant H_1(A) \leqslant 1$ and $0 \leqslant H_2(A) \leqslant 1$. If $a_2 = a_3$, then the type-1 fuzzy set A becomes a triangular type-1 fuzzy set.

In the following, brief review on some definitions of type-2 fuzzy sets and IT2 FS are retrieved from Mendel, John, and Liu (2006).

Definition 2.1. A type-2 fuzzy set $\tilde{\tilde{A}}$ in the universe of discourse X can be represented by a type-2 membership function $\mu_{\tilde{\tilde{A}}}$ shown as follows;

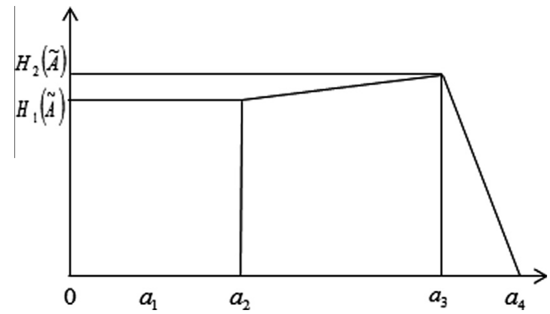

Fig. 1. A type-1 trapezoidal fuzzy set.

$$\tilde{\tilde{A}} = \left\{ (x, u), \mu_{\tilde{\tilde{A}}}(x, u) \middle| \forall x \in X, \forall u \in J_x \subseteq [0, 1], 0 \leqslant \mu_{\tilde{\tilde{A}}}(x, u) \leqslant 1 \right\} \quad (6)$$

where J_x denotes an interval in $[0, 1]$. The type-2 fuzzy set $\tilde{\tilde{A}}$ also can be represented as follows:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_x} \mu_{\tilde{\tilde{A}}}(x, u)/(x, u) \quad (7)$$

where $J_x \subseteq [0, 1]$ and $\int\int$ denotes the union over all admissible x and u.

Definition 2.2. Let $\tilde{\tilde{A}}$ be a type-2 fuzzy set in the universe of discourse X represented by the type-2 membership function $\mu_{\tilde{\tilde{A}}}$. If all $\mu_{\tilde{\tilde{A}}}(x, u) = 1$, then $\tilde{\tilde{A}}$ is called IT2 FS. An IT2FS $\tilde{\tilde{A}}$ can be regarded as a special case of type-2 fuzzy set, shown as follows:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_x} 1/(x, u), \quad (8)$$

where $J_x \subseteq [0, 1]$.

Definition 2.3. The upper membership function (UMF) and the lower membership function (LMF) of an IT2FS are type-1 membership function, respectively.

The reference points are used in the universe of discourse and the heights of the UMF and LMF of IT2 FS to characterize IT2 FS. Fig. 2 shows trapezoidal IT2 FS where upper and lower fuzzy numbers are clearly drawn.

Let $\tilde{\tilde{A}}_i = (\widetilde{A}_i^U, \widetilde{A}_i^L) = ((a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\widetilde{A}_i^U), H_2(\widetilde{A}_i^U)), (a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L; H_1(\widetilde{A}_i^L), H_2(\widetilde{A}_i^L)))$ where $H_j(\widetilde{A}_i^U)$ denotes the membership value of the element $a_{i(j+1)}^U$ in the upper trapezoidal membership function $\widetilde{A}_i^U, 1 \leqslant j \leqslant 2, H_j(\widetilde{A}_i^L)$ denotes the membership value of the element

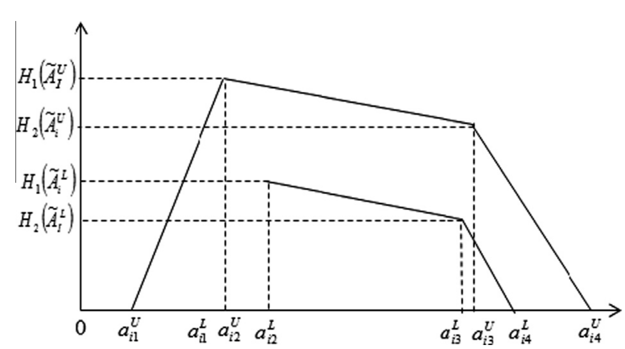

Fig. 2. The upper trapezoidal membership function $\widetilde{A}_i^U$ and the lower trapezoidal membership function $\widetilde{A}_i^L$ of IT2 FS $\tilde{\tilde{A}}_i$.

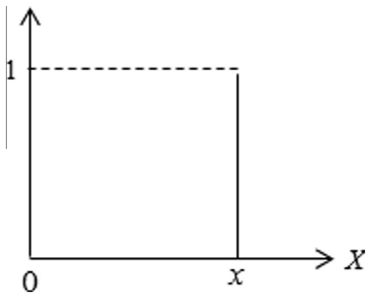

Fig. 3. A crisp value x.

$a^L_{i(j+1)}$ in the lower trapezoidal membership function $\widetilde{A}^L_i, 1 \leqslant j \leqslant 2, H_1(\widetilde{A}^U_i) \in [0,1], H_2(\widetilde{A}^U_i) \in [0,1], H_1(\widetilde{A}^L_i) \in [0,1], H_2(\widetilde{A}^L_i) \in [0,1]$ and $1 \leqslant i \leqslant n$.

Let $\widetilde{\widetilde{A}}$ be an IT2FS $\widetilde{\widetilde{A}} = (\widetilde{A}^U, \widetilde{A}^L)$ in the universe of discourse X.

If $\widetilde{A}^U = \widetilde{A}^L$, then IT2FS $\widetilde{A}$ becomes a type-1 fuzzy set. Let $\widetilde{A}$ be a type-1 fuzzy set, where $\widetilde{A} = (a_1, a_2, a_3, a_4; H_1(\widetilde{A}), H_2(\widetilde{A}))$.

Then, the type-1 fuzzy $\widetilde{A}$ also can be extended into the interval type-2 fuzzy set representation, for example $\widetilde{\widetilde{A}} = ((a_1, a_2, a_3, a_4; H_1(\widetilde{A}), H_2(\widetilde{A}))(a_1, a_2, a_3, a_4; H_1(\widetilde{A}), H_2(\widetilde{A})))$.

Let x be a crisp value. Then the IT2FS representation of the crisp value x is $(x, x, x, x; 1, 1)$ as shown in Fig. 3.

2.3. Arithmetic operations in trapezoidal interval type-2 fuzzy sets

The reviews of arithmetic operations between trapezoidal IT2FS are described in Chen and Lee (2010):

Definition 2.4. Suppose that A_1 and A_2 are two trapezoidal interval type-2 fuzzy numbers:

$$A_1 = \left(A^U_1, A^L_1\right) = \left(\left(a^U_{11}, a^U_{12}, a^U_{13}, a^U_{14}; H_1(A^U_1), H_2(A^U_1)\right), \left(a^L_{11}, a^L_{12}, a^L_{13}, a^L_{14}; H_1(A^L_1), H_2(A^L_1)\right)\right)$$

$$A_2 = \left(A^U_2, A^L_2\right) = \left(\left(a^U_{21}, a^U_{22}, a^U_{23}, a^U_{24}; H_1(A^U_2), H_2(A^U_2)\right), \left(a^L_{21}, a^L_{22}, a^L_{23}, a^L_{24}; H_1(A^L_2), H_2(A^L_2)\right)\right)$$

The arithmetic operational rules are shown as follows:

(1) $$A_1 + A_2 = (A^U_1, A^L_1) + (A^U_2, A^L_2) = ((a^U_{11} + a^U_{21}, a^U_{12} + a^U_{22}, a^U_{13} + a^U_{23}, a^U_{14} + a^U_{24}; \min(H_1(A^U_1), H_2(A^U_2)), \min(H_2(A^U_1), H_2(A^U_2)))), (a^L_{11} + a^L_{21}, a^L_{12} + a^L_{22}, a^L_{13} + a^L_{23}, a^L_{14} + a^L_{24}; \min(H_1(A^L_1), H_2(A^L_2)), \min(H_2(A^L_1), H_2(A^L_2))) \tag{9}$$

(2) $$A_1 - A_2 = (A^U_1, A^L_1) - (A^U_2, A^L_2) = ((a^U_{11} - a^U_{24}, a^U_{12} - a^U_{23}, a^U_{13} - a^U_{22}, a^U_{14} - a^U_{21}; \min(H_1(A^U_1), H_1(A^U_2)), \min(H_2(A^U_1), H_2(A^U_2))), (a^L_{11} - a^L_{24}, a^L_{12} - a^L_{23}, a^L_{13} - a^L_{22}, a^L_{14} - a^L_{21}; \min(H_1(A^L_1), H_1(A^L_2)), \min(H_2(A^L_1), H_2(A^L_2))) \tag{10}$$

(3) $$A_1 \times A_2 = (A^U_1, A^L_1) \times (A^U_2, A^L_2) = ((a^U_{11} \times a^U_{21}, a^U_{12} \times a^U_{22}, a^U_{13} \times a^U_{23}, a^U_{14} \times a^U_{24}; \min(H_1(A^U_1), H_1(A^U_2)), \min(H_2(A^U_1), H_2(A^U_2))), (a^L_{11} \times a^L_{21}, a^L_{12} \times a^L_{22}, a^L_{13} \times a^L_{23}, a^L_{14} \times a^L_{24}; \min(H_1(A^L_1), H_1(A^L_2)), \min(H_2(A^L_1), H_2(A^L_2))) \tag{11}$$

(4) $$kA_1 = \left(\left(ka^U_{11}, ka^U_{12}, ka^U_{13}, ka^U_{14}; H_1(A^U_1), H_2(A^U_1)\right), \left(ka^L_{11}, ka^L_{12}, ka^L_{13}, ka^L_{14}; H_1(A^L_1), H_2(A^L_1)\right)\right)$$

(5) $$\frac{1}{k}A_1 = \left(\left(\frac{1}{k}a^U_{11}, \frac{1}{k}a^U_{12}, \frac{1}{k}a^U_{13}, \frac{1}{k}a^U_{14}; H_1(A^U_1), H_2(A^U_1)\right), \left(\frac{1}{k}a^L_{11}, \frac{1}{k}a^L_{12}, \frac{1}{k}a^L_{13}, \frac{1}{k}a^L_{14}; H_1(A^L_1), H_2(A^L_1)\right)\right)$$

These preliminaries are being used in defining new IT2 fuzzy DEMATEL and also in constructing the integration method of fuzzy AHP and IT2 fuzzy DEMATEL.

3. The proposed integration method

The intended integration method is basically hybridizing the two methods where the output from the first method is used as a multiplying factor to the computational steps of the second method. The integration of fuzzy AHP and IT2 fuzzy DEMATEL is constructed without losing the generality of the fuzzy AHP and fuzzy DEMATEL. The proposed IT2 fuzzy DEMATEL and the proposed integration are sequentially presented in the following subsection.

3.1. The IT2 fuzzy DEMATEL

The IT2 fuzzy DEMATEL is an innovation of the traditional DEMATEL method where the aims of the both methods are remained; to visualize the causal relationship of sub-systems through a causal diagram. Our proposed work is the new fuzzy DEMATEL that combine with trapezoidal IT2 fuzzy numbers. Framework of the proposed method is basically similar to fuzzy DEMATEL, but the fuzzy numbers used in the proposed methods are given in trapezoidal IT2 fuzzy numbers where few other implications will emerge from this modification. There are several key features emerged from the IT2 fuzzy DEMATEL. The introduction of IT2FS in DEMATEL uses IT2 trapezoidal fuzzy numbers instead of using triangular type-1 fuzzy numbers. Most of the description of IT2FS in decision making used trapezoidal fuzzy numbers thanks to the non-existing of one single maximum membership where this feature will further enhance the group decision in fuzzy environment. Instead of using interval approach provided by Wu and Mendel (2008) to obtain linguistic scale, the proposed method uses IT2FS preference scale proposed by Abdullah and Najib (2014) in defining the linguistic variables. This preference scale avoids the computation of mean and standard deviation where these statistical measures would undermine the expert knowledge in giving evaluations. Moreover, this preference scale offers more comprehensive evaluation due to the property of IT2FS which can deal with more room of uncertainty. The last feature is the use of normalization method. The proposed method uses the concept of expected value

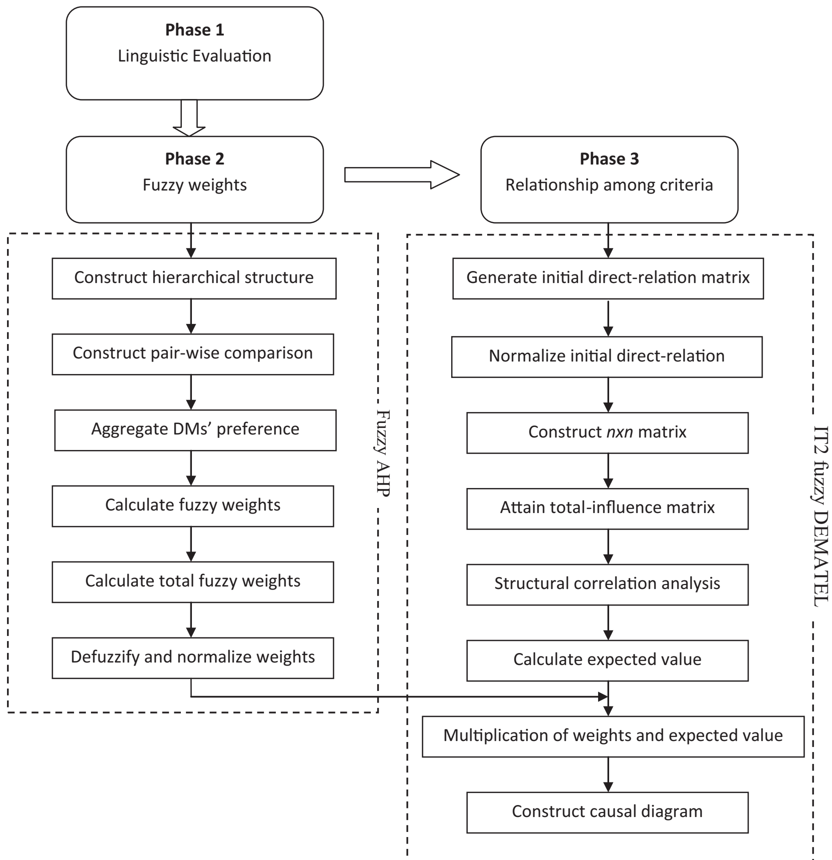

Fig. 4. Framework of the integration method.

proposed by Hu et al. (2013) instead of Jaccard similarity measure and min–max normalization method. The Jaccard similarity measure and min–max normalization method confronted with higher computational risk as compared to the expected value method. Furthermore, it has been proven that the expected value method is more reasonable compared to the approaches proposed by Baas and Kwakernaak (1977) and Lee and Li (1988). They analyzed thirteen sets of fuzzy number provided by Bortolan and Degani (1985) to validate the results. Furthermore, the results calculated using the expected value are consistent with those obtained by ranking method (Chen & Lee, 2010). Also, we used the expected value instead of ranking method as to fit with $m \times n$ matrices, $D_i + R_i$ and $D_i - R_i$ of fuzzy DEMATEL. Based on these arguments, we propose a new IT2 fuzzy DEMATEL by introducing trapezoidal IT2 fuzzy numbers with DEMATEL. This new approach combines the advantages of IT2FS and the interconnected features of DEMATEL, which can find the relationship among criteria network in the framework of group decision making. The procedures of IT2 fuzzy DEMATEL are summarized as follow:

Step 1: Data is collected from group experts or decision makers (DMs). They are asked to fill the ratio from '0' to '4', from no influence to very high influence.
Step 2: The initial direct-relation matrix is generated by aggregating the DMs' opinions.
Step 3: The normalized initial direct-relation matrix is calculated.
Step 4: Construction of $n \times n$ matrix to fit the identity matrix.
Step 5: Attaining the total-influence matrix, T.
Step 6: Structural correlation analysis is done.
Step 7: Calculate expected value, $E(W)$ to convert IT2 FS into crisp numbers.
Step 8: Construct causal diagram based on the $E(D_i + R_i)$ and $E(D_i - R_i)$.

The proposed IT2 fuzzy DEMATEL is a preliminary method prior to proposing a new integration method. The proposed integration method is explicitly explained in the Section 3.2.

3.2. The integration of fuzzy AHP and IT2 fuzzy DEMATEL

This paper proposes an integration of fuzzy AHP and IT2 fuzzy DEMATEL. There are two innovations to be merged from this integration. To start with, we merge trapezoidal IT2FS and DEMATEL to deal with the ambiguity of the real word. The IT2FS that characterized by upper and lower membership functions would allow some extent of freedom to represent uncertainty and vagueness of the real world problem. Secondly, we merge fuzzy AHP and IT2 fuzzy DEMATEL. The fuzzy AHP method will yield the relative weights of criteria and IT2 fuzzy DEMATEL could visualize the causal relationship of criteria. The weights from fuzzy AHP method will become the input data to IT2 fuzzy DEMATEL and the results are summarized in the causal diagram. Moreover, the criteria could be divided into two groups; cause and effect group. We could clearly see the most influential criteria and the highest degree of important criteria.

The proposed method is carried out in three phases. In Phase 1, data are collected via linguistic rating provided by DMs. The main purpose of Phase 2 is weighting the criteria using fuzzy AHP. The IT2 fuzzy DEMATEL is applied in Phase 3 to capture the complex relationships between the evaluation dimensions and criteria. The framework is summarized in Fig. 4.

For a better understanding of the integration of fuzzy AHP and IT2 fuzzy DEMATEL, the following procedures are proposed.

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Table 1
Trapezoidal fuzzy number preference scale (Zheng, Zhu, Tian, Chen, & Sun, 2012).

Linguistic variables	Scale of relative important of AHP crisp number	Trapezoidal fuzzy number	Reciprocal trapezoidal fuzzy number
Equally important (EI)	1	(1, 1, 1, 1)	(1, 1, 1, 1)
Intermediate value (IV)	2	(1, 3/2, 5/2, 3)	(1/3, 2/5, 2/3, 1)
Moderately more important (MMI)	3	(2, 5/2, 7/2, 4)	(1/4, 2/9, 2/5, 1/2)
Intermediate value (IV)	4	(3, 7/2, 9/2, 5)	(1/5, 2/9, 2/7, 1/3)
Strongly more important (SMI)	5	(4, 9/2, 11/2, 6)	(1/6, 2/11, 2/9, 1/4)
Intermediate value (IV)	6	(5, 11/2, 13/2, 7)	(1/7, 2/13, 2/11, 1/5)
Very strong more important (VSMI)	7	(6, 13/2, 15/2, 8)	(1/8, 2/15, 2/13, 1/6)
Intermediate value (IV)	8	(7, 15/2, 17/2, 9)	(1/9, 2/17, 2/15, 1/7)
Extremely more important (EMI)	9	(8, 17/2, 9, 9)	(1/9, 1/9, 2/17, 1/8)

Table 2
Linguistic variables (Abdullah & Najib, 2014).

Linguistic variables	IT2 FN
Very high influence	((0.8, 0.9, 0.9, 1.0; 1, 1), (0.85, 0.9, 0.9, 0.95; 0.9, 0.9))
High influence	((0.6, 0.7, 0.7, 0.8; 1, 1), (0.65, 0.7, 0.7, 0.75; 0.9, 0.9))
Low influence	((0.4, 0.5, 0.5, 0.6; 1, 1), (0.45, 0.5, 0.5, 0.55; 0.9, 0.9))
Very low influence	((0.2, 0.3, 0.3, 0.4; 1, 1), (0.25, 0.3, 0.3, 0.35; 0.9, 0.9))
No influence	((0, 0.1, 0.1, 0.1; 1, 1), (0, 0.1, 0.1, 0.05; 0.9, 0.9))

3.2.1. Phase 1: linguistic evaluation

In MCDM problems, responses from group DMs are mainly focused on opinions of the DMs regarding the rating of the dimensions against the identified criteria. DMs group is created from number of experts to form linguistic data and two sessions of data collection would be conducted. In the first session, they are asked to rate in nine point scales of pair-wise comparison of fuzzy AHP. The linguistic variables are shown in Table 1.

In the second session, the DMs are asked to specify rating using five DEMATEL linguistic scales varying from 'no influence' to 'very high influence' over the criteria of MCDM problem. The linguistic variables for IT2 fuzzy DEMATEL are shown in Table 2.

3.2.2. Phase 2: Fuzzy weights

Step 1: Construct a hierarchical structural.
Hierarchical structural is divided into two levels. The upper level of the structural describes the focus of the detailed problem called as dimensions while the second level of the hierarchical structure explains the attributes or criteria of the dimensions.

Step 2: Construct a pair-wise comparison.
The pair-wise comparison is constructed among all criteria in the dimensions of the hierarchy system based on the DMs' preferences in phase 1 as following matrix A,

$$A = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & 1/\tilde{a}_{n2} & \dots & 1 \end{bmatrix} \tag{14}$$

Step 3: Aggregate DMs' preferences.
The pair-wise comparisons matrices are aggregated using geometric mean suggested by Buckley (1985) as shown in Eq. (15)

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^1 \otimes \tilde{a}_{ij}^2 \times \dots \otimes \tilde{a}_{ij}^n)^{1/n} \tag{15}$$

where n is the number of DMs.

Step 4: Calculate the fuzzy weights.
The aggregated matrix comparison of each dimension and criterion is constructed using Eq. (16)

$$\tilde{a}_j = ((\tilde{a}_{m1} \otimes \tilde{a}_{m2} \otimes \dots \otimes \tilde{a}_{mn})^{1/n} \tag{16}$$

where $j = 1, 2, \dots, n$ and $m =$ trapezoidal fuzzy number.
The fuzzy weight, w_j is determined using Eq. (17)

$$\tilde{w}_j = \tilde{a}_j \otimes (\tilde{a}_1 \oplus \tilde{a}_2 \dots \oplus \tilde{a}_n)^{-1} \text{ where } j = 1, 2, \dots, n \tag{17}$$

Step 5: Calculate the total fuzzy weights for attributes or criteria of dimensions.
Total fuzzy weights for attributes or criteria are obtained by multiplying the fuzzy weights of dimensions and fuzzy weights of attributes or criteria,

$$T\tilde{w}_j = D\tilde{w}_j \otimes C\tilde{w}_j \tag{18}$$

where $D\tilde{w}_j$ are the weights of dimensions and $C\tilde{w}_j$ are the weights of attributes or criteria.

Step 6: Defuzzify and normalize the fuzzy weights.
Trapezoidal fuzzy weights are defuzzified and normalized using the centroid defuzzification method (Wang, 2009).

$$W_j = \frac{1}{3}\left[a + b + c + d - \frac{dc - ab}{(d + c) - (a + b)}\right] \tag{19}$$

3.2.3. Phase 3: relationship among criteria

Step 7: Generating the initial direct-relation matrix.
The IT2 FN score x_{ij}^k is given by the kth decision-maker and indicated the influential level that criteria i has on criteria j. The $m \times n$ matrix is calculated using Eq. (20) by averaging the individual decision-makers' scores in Phase 1.

$$A_{ij} = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^k \tag{20}$$

where H is the total number of DMs and $x_{ij}^k = ((a, b, c, d, e, f), (g, h, i, j, k, l))$ where a, b, c and d are UMF, g, h, i and j are LMF while e, f, k and l are the height of UMF and LMF. Matrix A_{ij} shows the initial direct-relation that a criterion exerts on and received from other criteria.

Step 8: Calculating the normalized initial direct-relation matrix, D.
On the base of the initial direct-relation matrix, A_{ij}, the normalized initial direct-relation matrix, D can be obtained through the following equations.

$$D = \frac{A}{s} \tag{21}$$

$$s = max\left(\max_{1 \le i \le n}\sum_{j=1}^{n} A_{ij}, \max_{1 \le i \le n}\sum_{i=1}^{n} A_{ij}\right), \tag{22}$$

where $\max_{1 \leqslant i \leqslant n}\sum_{j=1}^{n} A_{ij}$ = the total direct effects of the criterion i with the most direct effects on others, and $\max_{1 \leqslant i \leqslant n}\sum_{i=1}^{n} A_{ij}$ = the total direct effects that the criterion

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j receives the most direct effects from other criteria.
In other words, Eq. (22) is utilized to find the sum of each row of matrix A represented the total direct effects the criterion i gave to the other criteria and the sum of each column of matrix A represented the total direct effects received to other criteria by criterion i.

Step 9: Construct the $n \times n$ matrix, Z.
Matrix Z is constructed by arranging matrix N according to the membership functions.

$$Z_x = \begin{bmatrix} 0 & x_{12} & \dots & x_{1n} \\ x_{21} & 0 & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & \dots & 0 \end{bmatrix} \quad (23)$$

where $x = (UMF, LMF) = ((a,b,c,d),(g,h,i,j))$. As a result, there are eight $n \times n$ matrices. Construction of $n \times n$ matrix is needed for the calculation in the next step since it involves multiplication of matrices between matrix Z and identity matrix. The row of matrix Z must be matched with column of identity matrix.

Step 10: Attaining the total-influence matrix, T.
The total-influence matrix, T can be acquired using Eq. (24) in which I is denoted as the identity matrix.

$$T_x = Z_x(I - Z_x)^{-1} \quad (24)$$

Step 11: Structural correlation analysis.
The sum of rows and the sum of columns were separately denoted as vector r and c through Eqs. (25)–(27). $D_i + R_i$ is made by adding r to c and $D_i - R_i$ is made by subtracting r from c.

$$T_x = [t_{ij}]_{n\times n}, \quad i,j = 1,2,\dots,n \text{ and} \quad (25)$$

$$r_x = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1=[t_i]n\times 1} \quad (26)$$

$$c_x = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n=[t_j]1\times n} \quad (27)$$

where $x = (UMF, LMF) = ((a,b,c,d),(g,h,i,j))$.

Step 12: Calculate expected value, $E(W)$.
The expected values of $E(D_i + R_i)$ and $E(D_i - R_i)$ are calculated using equation Eq. (28).

$$E(W) = \frac{1}{2}\left(\frac{1}{4}\sum_{i=1}^{4}(w_i^L + w_i^U)\right) \times \frac{1}{4}\left(\sum_{i=1}^{2}(W_i(A^L) + W_i(A^U))\right), \quad (28)$$

where

$$W = (W_1^U, W_i^L) = \left((w_1^U, w_2^U, w_3^U, w_4^U; H_1(W_i^U), H_2(W_i^U)), \times (w_1^L, w_2^L, w_3^L, w_4^L; H_1(W_i^L), H_2(W_i^L))\right)$$

Step 13: Combining fuzzy weights and $E(W)$.
Fuzzy weights from Step 6 in Phase 2 are combined with $E(W)$.
The new expected value is obtained using the multiplication operation as Eq. (29)

$$E(W)_n ew = W_j \otimes E(W) \quad (29)$$

Step 14: Construct causal diagram.
The horizontal axis vector, $D_i + R_i$ named "Prominence" shows the degree of importance that criterion i plays in the system. The vertical axis $D_i - R_i$, named "Relation" shows the net effect the criterion i contributed to the system. When $D_i - R_i$ is positive, criterion i is a net causer and when $D_i - R_i$ is negative, criterion i is a net receiver (Liou, Tzeng, & Chang, 2007; Tamura et al., 2002).

4. A case of human resource management problem

Human resource management (HRM) is the process of hiring and developing employees so that they become more valuable to the organization. Since the twenty first century in particular, HRM as the root of national competitiveness has been raised to the level of a national strategy (Zhao & Du, 2012). This includes the agreement that people should be given top priority in enterprises and HRM plays a significant role for a success. There is a higher demand and recognition for effective HRM because of the growing trends of economic globalization and improved education. Recently, HRM is widely practiced in various industries. For example, Celik, Er, and Topcu (2009) investigated a case of HRM in maritime transportation industry using the analytic network process. This model was used to support the personnel selection facilities of crewing departments in ship management companies. There are many authors dealt with cases of HRM in hotels, restaurants and tourism industries (Bartolome & Mercedes, 2013; Kelliher & Perrent, 2001; Smith, Webber, & White, 2011; Wilton, 2008).

The present study conducts an empirical study of HRM problem to test the proposed integrated method. In this HRM evaluation, three DMs were invited to evaluate the criteria and dimensions of HRM problem. Two professors from Masters of Business Administration (MBA) program and one senior assistant registrar at registrar office at a public university in Malaysia were invited to make evaluation. They were asked to make evaluation of the dimensions and criteria of HRM which were partly adopted from Chou et al. (2012). The HRM problem comprises three dimensions and eight criteria. The three dimensions are infrastructures (D_1), input (D_2) and output (D_3) while the eight criteria are education (C_1), value (C_2), cooperation (C_3), labor market (C_4), Research & Development (R&D) expenses (C_5), human capital (C_6), intermediate output (C_7) and immediate output (C_8). In Phase 1 of this empirical study, linguistic evaluation of the HRM based on the dimensions and criteria were provided from the three DMs via guided interview. All the technical terms of linguistic variables and fuzzy numbers in preference scales were not directly explained during interview. The DMs only need to provide linguistic evaluation based on the natural linguistic about the importance of the criteria and degree of influence of the dimensions and the criteria. The collected linguistic evaluations or ratings in Phase 1 were then used as input data to the Phase 2. In Phase 2, this empirical study attempts to establish relative weights of the criteria using the method of fuzzy AHP. The established relative weights are then used as a multiplying factor to the dimensions in the last two steps of the proposed IT2 fuzzy DEMATEL. The fuzzy arithmetic multiplication operations are part of Phase 3 of IT2 fuzzy DEMATEL with the aim to explain the relationships between criteria and dimensions of the HRM problem. The detailed computations of this empirical study are executed in the following steps.

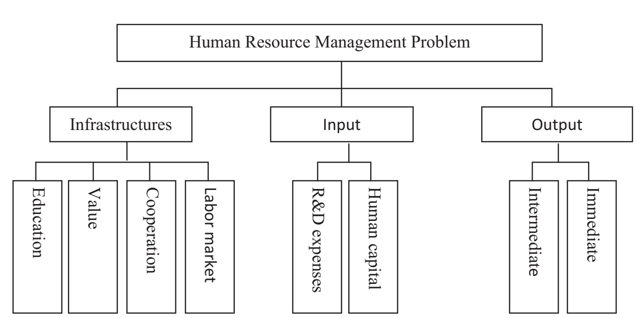

Fig. 5. Hierarchical structure of HRM.

4.1. Phase 1: linguistic evaluation

The three DMs provide linguistic evaluation according to the defined scales. Dimensions/criteria are compared in the pair-wise comparisons. For the method of fuzzy AHP, the DMs were asked to rate the degree of importance of dimension against criteria using the linguistic scale in Table 1.

In the second part of linguistic evaluation, DMs were asked to provide ratings of the criteria using linguistic scales in Table 2. These linguistic evaluations are a prerequisite prior to computing in Phase 2 and Phase 3.

4.2. Phase 2: obtain the weights of evaluation dimensions and criteria using fuzzy AHP.

Step 1: Construct hierarchical structure of HRM problem.
The hierarchical structure of HRM is given in Fig. 5. It can be seen that there are three dimensions of HRM; infrastructures, input and output in second layer of the hierarchical structure. The eight criteria; education, value, cooperation, labor market, R&D expenses, human capital, intermediate output and immediate output are structured as third layer in the hierarchy.

Step 2: Construct a pair-wise comparison.
The pair-wise comparison is constructed among all criteria in the dimensions of the hierarchy system by applying fuzzy numbers and linguistic variables in Table 1.The linguistic evaluations from Phase 1 are translated into trapezoidal fuzzy numbers. Linguistic ratings of dimensions (D_1, D_2 and D_3) given by one of the DMs are shown in Table 3.

Step 3: Aggregate the DMs' preferences.
The pair-wise comparisons matrices are aggregated using Eq. (15).
For example, in Dimension 2 (D_2)

$$\begin{aligned} a_{12} &= ((6,6.5,7.5,8)\times(3,3.5,4.5,5)\times(5,5.5,6.5,7))^{1/3} \\ &= ((6\times3\times5)^{1/3},(6.5\times3.5\times5.5)^{1/3},(7.5\times4.5\times6.5)^{1/3}, \\ &\quad \times(8\times5\times7)^{1/3}) = (4.48,5,6.03,6.54) \end{aligned}$$

The other matrix elements are obtained by the similar computational procedure. Therefore, the aggregate matrix for dimensions is constructed as

$$D=\begin{bmatrix} (1.00,1.00,1.00,1.00) & (4.48,5.00,6.03,6.54) & (3.42,3.96,5.00,5.52) \\ (0.15,0.17,0.20,0.22) & (1.00,1.00,1.00,1.00) & (5.94,6.45,7.46,7.96) \\ (0.18,0.20,0.25,0.29) & (0.13,0.13,0.16,0.17) & (1.00,1.00,1.00,1.00) \end{bmatrix}$$

Step 4: Calculate the fuzzy weights.
To calculate the fuzzy weights of the dimensions, the computational procedures using Eqs. (16) and (17) are executed.
The aggregated matrix comparison of each dimension and criterion is constructed using Eq. (16)

$$\begin{aligned} D_1 &= \left((1\times4.48\times3.42)^{1/3},(1\times5\times3.96)^{1/3},\right. \\ &\quad \left.(1\times6.03\times5)^{1/3},(1\times6.54\times5.52)^{1/3}\right) \\ &= (2.484,2.705,3.113,3.305) \end{aligned}$$

Similarly, we obtain the remaining as follows,

$$D_2 = (0.969,1.023,1.142,1.211)$$
$$D_3 = (0.283,0.299,0.340,0.366)$$

The fuzzy weights of dimensions, Dw_j are determined using Eq. (17)

$$\begin{aligned} Dw_1 &= D_1\otimes(D_1\oplus D_2\oplus D_3)^{-1} \\ &= (2.484,2.705,3.113,3.305) \\ &\quad \times((1/(3.305+1.211+0.366)), \\ &\quad \times(1/(3.113+1.142+0.340)), \\ &\quad \times(1/(2.484+0.969+0.283))) \\ &= (0.509,0.589.0.773,0.885) \end{aligned}$$

The other two fuzzy weights of dimensions are also calculated with the similar fashion,

$$Dw_2 = (0.198,0.223,0.284.0.324)$$
$$Dw_3 = (0.058,0.065,0.084,0.098)$$

Step 5: Calculate the total fuzzy weights for criteria.
Similarly, the fuzzy weights of criteria are calculated using Step 1 to Step 4.

$$Cw_1 = (0.251,0.302,0.408,0.451)$$
$$Cw_2 = (0.183,0217,0.288,0.316)$$
$$\vdots$$
$$Cw_8 = (0.054,0.012,0.014,0.018)$$

Total fuzzy weights for criteria are obtained by multiplying the fuzzy weights of dimensions and fuzzy weights of criteria using Eq. (18). C_1, C_2, C_3, C_4 are multiplied by D_1, C_5 and C_6 are multiplied by D_2, and C_7 and C_8 are multiplied by D_3.

$$\begin{aligned} Tw_1 &= Dw_1\times Cw_1 \\ &= (0.509,0.589,0.773,0.885) \\ &\quad \times(0.251,0.302,0.408,0.451) \\ &= (0.127,0.178,0.316,0.399) \end{aligned}$$

The fuzzy weights for other criteria are obtained by the similar calculation. So, the total weights are shown in Table 4.

Step 6: Defuzzify and normalize the fuzzy weights
Trapezoidal fuzzy weights are defuzzified and normalized using Eq. (19). Results of the defuzzification are presented in Table 5.

4.3. Phase 3: capturing the complex relationship among the dimensions and criteria using IT2 fuzzy DEMATEL.

Step 7: Generating the initial direct-relation matrix.
Using the rating in Phase 1, the average of DMs' opinions are calculated in using Eq. (20). For example, initial direct-relation matrix for dimensions of HRM is obtained as shown in matrix A.

$$A=\begin{bmatrix} 0 & A_{12} & A_{13} \\ A_{21} & 0 & A_{23} \\ A_{31} & A_{32} & 0 \end{bmatrix}$$

Table 3
Pair-wise comparison.

	D_1				D_2				D_3			
D_1	(1.00	1.00	1.00	1.00)	(6.00	6.50	7.50	8.00)	(5.00	5.50	6.50	7.00)
D_2	(0.13	0.13	0.15	0.17)	(1.00	1.00	1.00	1.00)	(7.00	7.50	8.50	9.00)
D_3	(0.14	0.15	0.18	0.20)	(0.11	0.12	0.13	0.14)	(1.00	1.00	1.00	1.00)

Table 4
Total fuzzy weights for criteria of dimensions.

Total weights	Fuzzy numbers			
Tw_1	0.1274	0.1780	0.3155	0.3988
Tw_2	0.0931	0.1279	0.2223	0.2799
Tw_3	0.0585	0.0804	0.1242	0.1755
Tw_4	0.0369	0.0512	0.0904	0.1151
Tw_5	0.0091	0.0121	0.0207	0.0265
Tw_6	0.0069	0.0092	0.0159	0.0209
Tw_7	0.0011	0.0014	0.0024	0.0031
Tw_8	0.0031	0.0008	0.0012	0.0017

where

$$A_{12} = ((0.60, 0.70, 0.70, 0.80 : 1, 1)(0.65, 0.70, 0.70, 0.75 : 0.9, 0.9))$$

$$A_{13} = ((0.67, 0.77, 0.77, 0.87 : 1, 1)(0.72, 0.77, 0.77, 0.82 : 0.9, 0.9))$$

$$A_{21} = ((0.40, 0.50, 0.50, 0.60 : 1, 1)(0.40, 0.50, 0.50, 0.55 : 0.9, 0.9))$$

$$A_{23} = ((0.80, 0.90, 0.90, 1.00 : 1, 1)(0.85, 0.90, 0.90, 0.95 : 0.9, 0.9))$$

$$A_{31} = ((0.47, 0.57, 0.57, 0.67 : 1, 1)(0.52, 0.57, 0.57, 0.62 : 0.9, 0.9))$$

$$A_{32} = ((0.40, 0.50, 0.50, 0.60 : 1, 1)(0.45, 0.50, 0.50, 0.55 : 0.9, 0.9))$$

The initial direct-relation matrix for criteria is generated with the similar computations.

Step 8: Normalizing the initial direct-relation matrix.
The normalized direct relation matrix for dimensions can be obtained using Eqs. (21) and (22) and matrix D is obtained as

$$D = \begin{bmatrix} 0 & D_{12} & D_{13} \\ D_{21} & 0 & D_{23} \\ D_{31} & D_{32} & 0 \end{bmatrix}$$

where $D_{i,j} = \left(\frac{A^U_{i,j}}{1.867}, \frac{A^L_{i,j}}{1.867}\right)$.

$$D_{12} = ((0.321, 0.375, 0.375, 0.429 : 1, 1)(0.348, 0.375, 0.375, 0.402 : 0.9, 0.9))$$
$$D_{13} = ((0.357, 0.411, 0.411, 0.464 : 1, 1)(0.384, 0.411, 0.411, 0.438 : 0.9, 0.9))$$
$$D_{21} = ((0.214, 0.268, 0.268, 0.321 : 1, 1)(0.241, 0.268, 0.268, 0.295 : 0.9, 0.9))$$
$$D_{23} = ((0.429, 0.482, 0.482, 0.536 : 1, 1)(0.455, 0.482, 0.482, 0.509 : 0.9, 0.9))$$
$$D_{31} = ((0.250, 0.304, 0.304, 0.357 : 1.1)(0.277, 0.304, 0.304, 0.331 : 0.9, 0.9))$$
$$D_{32} = ((0.214, 0.268, 0.268, 0.321 : 1, 1)(0.241, 0.268, 0.268, 0.295 : 0.9, 0.9))$$

The entries of matrix D is listed as follows.The normalized matrix for criteria is calculated in the similar manner.

Step 9: Construct the $n \times n$ matrix, Z_x.
Matrix Z_x are arranged from matrix D according to the membership functions using Eq. (23). There are eight $n \times n$ matrices; $Z_a, Z_b, Z_c, Z_d, Z_g, Z_h, Z_i$ and Z_j.
As an example, the matrix of Z_a is given as

Table 5
Defuzzification results.

Criteria	Weight	Rank
C_1	0.2558	1
C_2	0.1814	2
C_3	0.1108	3
C_4	0.0737	4
C_5	0.0172	5
C_6	0.0133	6
C_7	0.0020	8
C_8	0.0021	7

$$Z_a = \begin{bmatrix} 0 & 0.321 & 0.357 \\ 0.214 & 0 & 0.429 \\ 0.250 & 0.304 & 0.357 \end{bmatrix}$$

Step 10: Attaining the total-influence matrix, T_x.
Total-influence matrix can be obtained using Eq. (24). In this empirical study, we used 3×3 identity matrix for dimensions of HRM and 8×8 identity matrix for criteria of dimensions.
Computation of T_a:

$$T_a = Z_a(I - Z_a)^{-1} = \begin{bmatrix} 0 & 0.321 & 0.357 \\ 0.214 & 0 & 0.429 \\ 0.250 & 0.304 & 0.357 \end{bmatrix} \times \left(\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} - \begin{bmatrix} 0 & 0.321 & 0.357 \\ 0.214 & 0 & 0.429 \\ 0.250 & 0.304 & 0.357 \end{bmatrix} \right)^{-1} = \begin{bmatrix} 0.299 & 0.569 & 0.708 \\ 0.460 & 0.303 & 0.722 \\ 0.423 & 0.421 & 0.332 \end{bmatrix}$$

The computations of $T_b, T_c, T_d, T_g, T_h, T_i$ and T_j are executed with the similar fashion.

Step 11: Structural correlation analysis.
The sum of rows and the sum of columns are calculated to obtain structural correlation analysis. Eqs. (25)–(27) are utilized to obtain $D_i + R_i$ and $D_i - R_i$. For example, the first elements of upper IT2FS of D1

$$\begin{aligned} D_1 + R_1 &= (0.299 + 0.569 + 0.708) \\ &\quad + (0.299 + 0.460 + 0.423) \\ &= 2.7583 \\ &= 2.76 \text{ (rounded up to two decimal places)} \end{aligned}$$

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$$D_1 - R_1 = (0.299 + 0.569 + 0.708) - (0.299 + 0.460 + 0.423) = 0.3939 = 0.39$$

The other elements of upper and lower IT2FS of dimensions (D_1, D_2 and D_3) are shown in Tables 6 and 7 respectively. Elements of upper and lower IT2FS of criteria are given in Tables 8 and 9 respectively.

Step 12: Calculate expected value, $E(W)$.
Expected values convert the IT2 trapezoidal fuzzy numbers of $D_i + R_i$ and $D_i - R_i$ into crisp values using Eq. (28). The crisp values of $D_i + R_i$ and $D_i - R_i$ for dimensions and criteria are presented in Tables 10 and 11 respectively.

Step 13: Combining fuzzy weights and $E(W)$.
By using Eq. (29), the new $D_i + R_i$ and $D_i - R_i$ are shown in Table 12.

Step 13: Construct causal diagram.

The causal diagrams are constructed with the horizontal axis $D_i + R_i$ and the vertical axis $D_i - R_i$. Causal diagrams of dimensions and criteria are shown in Figs. 6 and 7 respectively.

Table 10
Crisp values of dimensions.

Dimension	$D + R$	$D - R$
D_1	4.4673	0.5042
D_2	4.4947	0.2455
D_3	4.6993	−0.75

Table 11
Crisp values of criteria.

Criteria	$D + R$	$D - R$
C_1	8.4234	0.6295
C_2	7.3119	−0.427
C_3	8.8147	0.1173
C_4	7.857	−0.347
C_5	8.6665	0.2713
C_6	8.1468	−0.017
C_7	7.5608	−0.164
C_8	9.0456	−0.064

Table 6
$D + R$ of dimensions.

$D + R$										
D_1	((2.76	4.43	4.43	7.89	:1, 1)	(3.47	4.43	4.43	5.79	:0.9, 0.9))
D_2	((2.78	4.45	4.45	7.93	:1, 1)	(3.49	4.45	4.45	5.83	:0.9, 0.9))
D_3	((2.94	4.66	4.66	8.24	:1,1)	(3.67	4.66	4.66	6.07	:0.9, 0.9))

Table 7
$D - R$ of dimensions.

$D - R$										
D_1	((0.39	0.51	0.51	0.76	:1, 1)	(0.44	0.51	0.51	0.61	:0.9, 0.9))
D_2	((0.19	0.25	0.25	0.37	:1, 1)	(0.22	0.25	0.25	0.30	:0.9, 0.9))
D_3	((−0.59	−0.76	−0.76	−1.13	:1, 1)	(−0.66	−0.76	−0.76	−0.90	:0.9, 0.9))

Table 8
$D + R$ of criteria.

$D + R$										
C_1	((4.17	7.59	7.59	19.63	:1, 1)	(5.51	7.59	7.59	11.28	:0.9, 0.9))
C_2	((3.48	6.55	6.55	17.36	:1, 1)	(4.68	6.55	6.55	9.87	:0.9, 0.9))
C_3	((4.39	7.95	7.95	20.48	:1, 1)	(5.78	7.95	7.95	11.79	:0.9, 0.9))
C_4	((3.81	7.06	7.06	18.50	:1, 1)	(5.08	7.06	7.06	10.56	:0.9, 0.9))
C_5	((4.30	7.81	7.81	20.17	:1, 1)	(5.67	7.81	7.81	11.60	:0.9, 0.9))
C_6	((4.00	7.35	7.35	19.15	:1, 1)	(5.31	7.35	7.35	10.97	:0.9, 0.9))
C_7	((3.65	6.79	6.79	17.84	:1, 1)	(4.87	6.79	6.79	10.18	:0.9, 0.9))
C_8	((4.53	8.16	8.16	20.96	:1, 1)	(5.95	8.16	8.16	12.09	:0.9, 0.9))

Table 9
$D -$ R of criteria.

$D - R$										
C_1	((0.36	0.58	0.58	1.35	:1, 1)	(0.45	0.58	0.58	0.82	:0.9, 0.9))
C_2	((−0.26	−0.40	−0.40	−0.88	:1, 1)	(−0.31	−0.40	−0.40	−0.55	:0.9, 0.9))
C_3	((0.07	0.11	0.11	0.24	:1, 1)	(0.09	0.11	0.11	0.15	:0.9, 0.9))
C_4	((−0.21	−0.32	−0.32	−0.72	:1, 1)	(−0.25	−0.32	−0.32	−0.44	:0.9, 0.9))
C_5	((0.16	0.25	0.25	0.56	:1, 1)	(0.20	0.25	0.25	0.348	:0.9, 0.9))
C_6	((−0.01	−0.02	−0.02	−0.03	:1, 1)	(−0.01	−0.02	−0.02	−0.02	:0.9,0.9))
C_7	((−0.08	−0.15	−0.15	−0.38	:1, 1)	(−0.11	−0.15	−0.15	−0.22	:0.9, 0.9))
C_8	((−0.04	−0.01	−0.01	−0.13	:1, 1)	(−0.05	−0.01	−0.01	−0.08	:0.9, 0.9))

Table 12
Crisp values of new expected values.

Criteria	New $D+R$	New $D-R$
C_1	2.1547	0.1610
C_2	1.3264	−0.0775
C_3	0.9767	0.0130
C_4	0.5791	−0.0256
C_5	0.1491	0.0005
C_6	0.1084	−0.0002
C_7	0.01512	−0.0003
C_8	0.0190	−0.0001

The integration of fuzzy AHP and IT2 fuzzy DEMATEL emerges several new findings. First, by observing the weights of the criteria in Table 5, we can see that C_1 (education) from D_1 (infrastructures) is the most important criteria in this case of HRM. The management is suggested to pay more attention on education for achieving their competitiveness in organization. The result from the integrated model provides other interesting findings. Table 12 may help the organization in making profound decisions. For example, of the eight criteria, C_1 is the most important criteria with the highest $(D+R)$ priority of 2.1547. The criteria C_1 also indicate the most influencing criteria with the highest $(D-R)$ priority of 0.1610. The criteria C_2 (value) has the lowest $(D-R)$ priority of −0.0775. Therefore, C_2 is the most easily influenced. However, according to the degree of importance $(D+R)$, the order of criteria is identified as $C_1 > C_2 > C_3 > C_4 > C_5 > C_6 > C_8 > C_7$.

The contextual relations among criteria tell how improvement actions could be taken in order to improve the performance of human resource effectively. The horizontal axis of causal diagram shows the importance of each criterion has, whereas the vertical axis may divide criteria into cause group and effect group. Causal diagrams can visualize the complicated causal relationships of criteria into a visible structural model, providing valuable insight for problem-solving. Further, with the help of a causal diagram, we can make better decisions by recognizing the difference between cause and effect criteria (Wu, 2012). The evaluation criteria, C_1, C_3 and C_5 are grouped into the cause criteria group which is called net causer, while effect criteria group C_2, C_4, C_6, C_7 and C_8 are known as net receivers. In order to obtain high performances in terms of the net causers, it is necessary to control and pay more

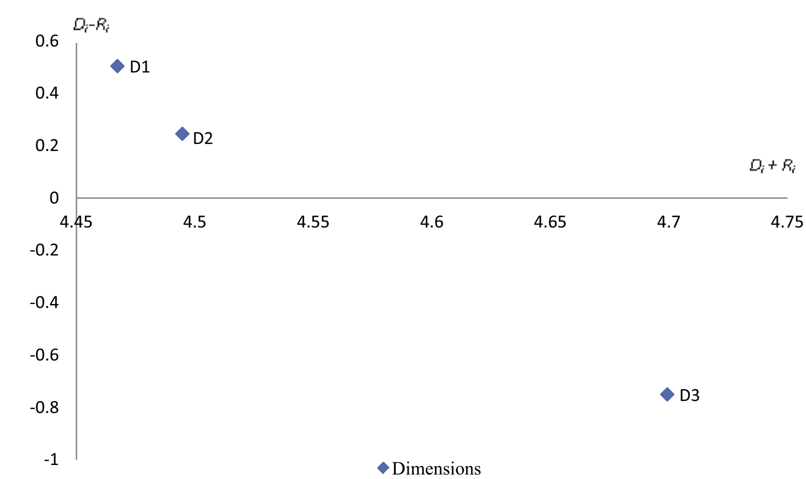

Fig. 6. Causal diagram of the dimensions.

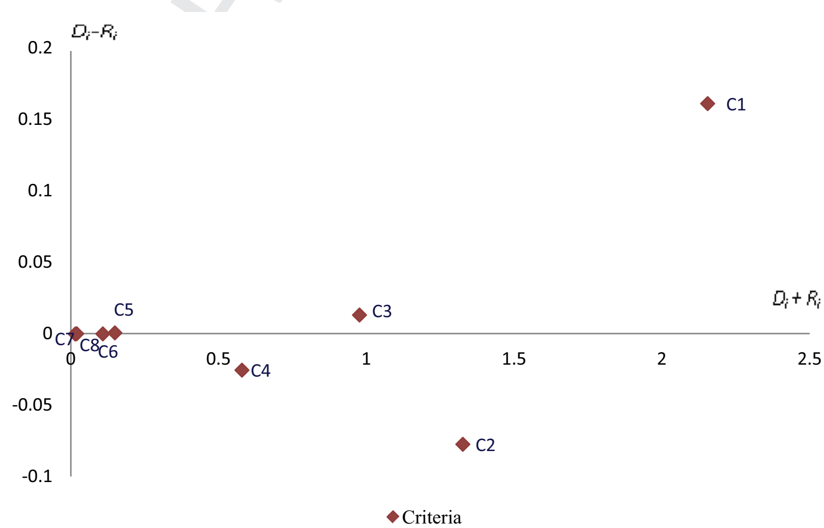

Fig. 7. Causal diagram of the criteria.

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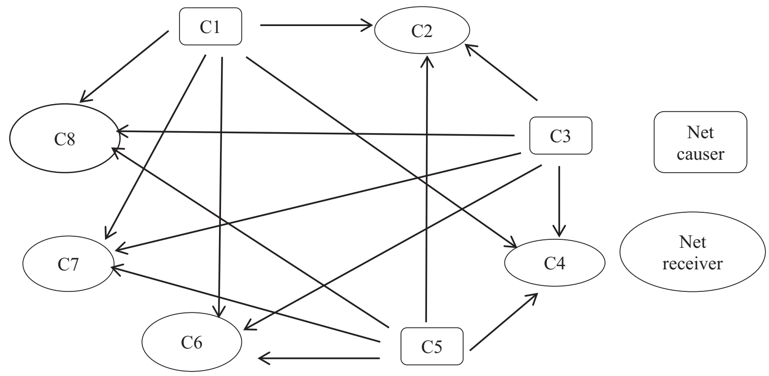

Fig. 8. Relationship between net causer and net receiver.

Table 13
The results of CVS problem under different methods.

Evaluation	Degree of importance
DEMATEL (Gabus & Fontela, 1973)	$C_8 > C_3 > C_6 > C_1 > C_5 > C_4 > C_7 > C_2$
Fuzzy DEMATEL (Lin & Wu, 2004)	$C_8 > C_3 > C_5 > C_1 > C_6 > C_4 > C_7 > C_2$
Proposed method of integration FAHP and IT2 DEMATEL	$C_1 > C_2 > C_3 > C_4 > C_5 > C_6 > C_8 > C_7$

attention to the cause criteria group beforehand. This is due to the cause criteria group implies the meaning of the influencing criteria, whereas the effect criteria group denotes the meaning of the influenced criteria (Fontela & Gabus, 1976). In other words, net causers are difficult to move, while the net receivers are easily moved (Hori & Shimizu, 1999). The relationship between net causers and net receivers are presented in Fig. 8.

Criteria with rectangular shaped are net causers while criteria in oval shaped are net receivers. The arrows show the net causers influence and affect the net receivers.

The causal diagram (see Figs. 6, 7 and 8) confirms that C_1 from D_1 is the most influential criterion. It is the real source which affects the other criteria directly.

The summary of degree importance using the proposed method and degree of importance proposed by Gabus and Fontela (1973), and Lin and Wu (2004) is presented in Table 13.

Table 13 shows that the results of two single methods. The DEMATEL and fuzzy DEMATEL method produced similar results but different results are obtained from the integration method. The single methods unveil C_8 as the most important criteria while the proposed integration method highlights C_1 as the most important criteria. In spite of this, it is better to note that the proposed integration method gives a different result because it integrates two MCDM methods and applies IT2 FS in fuzzy DEMATEL. As advocated by Zhang and Zhang (2013), IT2 FS can provide us with more degrees of freedom to represent uncertainty and vagueness in information and also fuzziness in human preferences.

5. Conclusions

Integration is the process of combining or merging of two or more methods to give a better and more effective result. Recently, integration of fuzzy DEMATEL and fuzzy AHP had been developed by Chou et al. (2012). However, there was no clear step of integration between the two methods since the fuzzy DEMATEL and fuzzy AHP were integrated one after another. Moreover, the existence of vague and imprecise judgments made the results less effective in capturing causal diagrams. Thus, we developed a new study of integration of IT2 fuzzy DEMATEL and fuzzy AHP to overcome the problems. In this paper, the framework of integration between fuzzy AHP and IT2fuzzy DEMATEL was presented. There were three phases pertaining to the proposed method. In Phase 1, data were collected from a group of DMs using the defined linguistic scale. The fuzzy AHP was applied in Phase 2 where the relative weights of the criteria were obtained. In Phase 3, IT2 fuzzy DEMATEL was used by applying IT2 trapezoidal fuzzy numbers so as to avoid inadequate reflection of the vagueness in the MCDM problems. The IT2 fuzzy DEMATEL divides the criteria into cause group and effect group. Our method is more flexible thanks to the introduction of trapezoidal fuzzy numbers in fuzzy AHP and IT2 trapezoidal fuzzy numbers in DEMATEL. It allows us to model imprecise, uncertain and ambiguous information that was commonly encountered in the real world problems. The method also incorporated the fuzzy AHP and IT2 fuzzy DEMATEL by applying the weights obtained from fuzzy AHP in Phase 2 into the expected value in Phase 3. In fact, this integration method was capable to handle fuzzy MCDM problems with more comprehensible approach thanks to the knowledge of interval type-2 fuzzy sets. The proposed integration method was applied to a case of human resource management where three decision makers were invited to evaluate three dimensions and eight criteria. It was consensually agreed on the criteria of education from the dimension of infrastructure as the most influential criteria in human resource management. Nonetheless, this study holds several limitations. The number of DMs needs to be reviewed for ensuring the validity of the research. Future research may consider a bigger number of DMs. It is believed that setting a new threshold value for fuzzy DEMATEL will offer an alternative results and a new network relationship map can be obtained. It is also suggested that further research needs to be undertaken to scrutinize the proposed method. The developed approach might be tested to other real case studies in group decision making problems such as supplier selections and customer satisfactions.

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