An Interval Fuzzy-Valued M-TOPSIS Model for Design Concept Selection

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Abstract— This paper presents an easy and a reliable approach for evaluating and selecting product design concept, by using a modified improved score function and a weighted Normalized Hamming distance method for calculating the separation measures of alternatives in a fuzzy Delphi and Modified Technique for Order Preference by Similarity to the Ideal Solution model. The proposed model has successfully been implemented to select the most appropriate printed circuit board (PCB) design for an electronic related manufacturing company located around Pekan area in Malaysia and it has also been applied for a modified hypothetical example originally presented by Rouyendegh,[1], which is based on the selection of a preferred Car as a reference for a new design. The result from this study is hoped to serve as a guide for companies/managers planning to select new designs for their products as well as in the evaluation of their current practices.

Keywords— Interval Fuzzy-Valued M-TOPSIS model; fuzzy Delphi method; Multi-Criteria Decision-Making; Improved Score Function; weighted Normalized Hamming distance method

1. INTRODUCTION

The design concept stage can be described as one of the most critical stages in the product development process. This is the stage where the final decision to either select or reject a particular design concept for a given product is made. According to Geng et al. (2010), the decision made in the early phases of new product development (design concept stage) is most crucial for determining the success of both the developed product as well as the development process. While Nikander et al. (2014) describe concept selection as the most important activities in new product development and that the consequences of a poor concept decisions may be disastrous at worst.

Design concept selection is a complex multi-criteria (group) decision-making (MCDM) process, which involves several imprecise factors ranging from product complexity, customer related requirements, insufficient information about the design, and the diversity and expertise of the decision makers (DMs) etc. According to Lo et al. [4], the DMs' preferences often lack the precision and level of confidence required for a proper concept selection and in most cases often contributes to the various degrees of uncertainties in the selection process. Hence, coping with these uncertainties becomes critical to the effectiveness of decision-making process.

Several approaches and methodology have been proposed in the past to assist design concept evaluation. These methods and approaches can be classified into two categories, namely the numerical methods and the non-numerical methods. The non-numerical approach involves the traditional approaches as recorded in concept screening [6] and concept selection and evaluation [7], while the numerical methods comprise of the decision matrixes [8], quality function deployment [9]–[11], fuzzy set concepts [9], [12], [13], grey relation analysis [5] etc.

Amongst the various numerical methods that have been proposed, the fuzzy concepts application has remained the most wildly used approach for design concept evaluation, where this is due to their ability to handle uncertainty. The vagueness in the evaluation of design concept has made fuzzy concepts a topic of great interest to many product design researchers and design managers. In handling the vagueness and uncertainty Zadeh [14], who introduced the concept of fuzzy set theory, has outlined how fuzzy set could be used to characterize complex systems and decision-making processes. This breakthrough, however, is the result of the numerous extensions of the MCDM techniques in the fuzzy environment today.

In this paper, we are presenting an easy and a reliable fuzzy model, which is based on the integration of fuzzy Delphi method and M-TOPSIS model for the evaluation and selection of design concept by exploring the application of the two distance methods (i.e. an improved score function and normalized Hamming distance) which hinder to have not been applied in this domain and combining them using a new reflection defuzzification integration formula. The proposed model have been applied for the selection of the most appropriate printed circuit board (PCB) for an electronic related manufacturing company located around Pekan in Malaysia. By using the two distance separation measures in this study we have succeeded in eliminating the bias of using a single distance separation method in the M-TOPSIS model, and the decision-making problem created in determining the fittest distance separation method.

The efficacy of the proposed integrated model has been tested by comparing it with an existing model using a modified hypothetical example originally presented by Rouyendegh,[1] to make a new example that is based on the selection a preferred Car as a reference for a new design. The rest of this paper is organized as follows. Section 2 briefly presents the concepts of Fuzzy Set theory and fuzzy number, the introduction of the Fuzzy Delphi and M-TOPSIS model. In Section 3, the proposed integrated model is presented, while the numerical case study is presented in section 4. Finally, the conclusion is presented in section 5.

2. BASIC CONCEPT OF FUZZY SET THEORY

A. Preliminary

Fuzzy set theory was introduced by Zadeh in 1965. It concept is based on the fact that, the range of truth value of membership function (relations) are the closed interval [0,1] of real numbers [14]. The Fuzzy set theory is designed in such a way that it can deal with problems in which source of vagueness and uncertainties are involved. The concept has been successfully utilized in modeling and incorporating imprecise and vague information into decision framework and judgments of decision makers.

Mathematically fuzzy set (e.g. fuzzy set $\tilde{A}$) are defined by means of membership function$\mu_A(x)$, which associates with each element *x* in the universe of discourse *X* a real number in the interval [0, 1]. A triangular fuzzy number $\widetilde{A}$ which can be defined by the triplet(l_1, m_1, u_1), their membership function are express as;

$$\mu_A(x) = \begin{cases} \frac{x-1}{m-1} & \text{for } l \le x \le m, \\ \frac{u-x}{x-m} & \text{for } m \le x \le u, \\ 0 & \text{for } x > u, \end{cases} \tag{1}$$

where *l*, *m* and *u* are real numbers and *l* < *m* < *u*. Outside the interval [*l*, *u*], the pertinence degree is null, and *m* represents the point in which the pertinence degree is maximum. The basic arithmetic operations on the triangular fuzzy numbers are shown below;

Definition 1. Given any real number K and two fuzzy triangular numbers $\tilde{A} = (l_1, m_1, u_1)$ and $\widetilde{B} = (l_2, m_2, u_2)$, the main algebraic operations are expressed as follows:

(1) Addition of two triangular fuzzy numbers

$$\tilde{A}(+)\tilde{B} = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2), \quad l_1 \ge 0, l_2 \ge 0 \tag{2}$$

(2) Multiplication of two triangular fuzzy numbers

$$\tilde{A}(\times)\tilde{B} = (l_1 \times l_2,\ m_1 \times m_2,\ u_1 \times u_2), \quad l_1 \ge 0, l_2 \ge 0 \tag{3}$$

(3) Subtraction of two triangular fuzzy numbers

$$\tilde{A}(-)\tilde{B} = (l_1 - l_2,\ m_1 - m_2,\ u_1 - u_2), \quad l_1 \ge 0, l_2 \ge 0 \tag{4}$$

(4) Division of two triangular fuzzy numbers

$$\tilde{A}(\div)\tilde{B} = (l_1 \div l_2,\ m_1 \div m_2,\ u_1 \div u_2), \quad l_1 \geq 0, l_2 \geq 0 \tag{5}$$

(5) Inverse of a triangular fuzzy number

$$\tilde{A}^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \geq 0 \tag{6}$$

(6) Multiplication of a triangular fuzzy number by a constant

$$k \times \tilde{A} = (k \times l_1, k \times m_1, k \times u_1)\ l_1 \geq 0, k \geq 0 \tag{7}$$

(7) Division of a triangular fuzzy number by a constant

$$\frac{\tilde{A}}{k} = \left(\frac{l_1}{k}, \frac{m_1}{k}, \frac{u_1}{k}\right) \quad l_1 \geq 0, k \geq 0 \tag{8}$$

Definition 2. Given a fuzzy number in the form$\tilde{A} = (l_1, m_1, u_1)$, let $\tilde{A}$ be the α-cut level [15], so we have;

$$\widetilde{A_\alpha} = \left[\widetilde{A_\alpha{}^L}, \widetilde{A_\alpha{}^U}\right] = [\mathrm{L} + \alpha(\mathrm{M} - \mathrm{L}), \mathrm{U} - \alpha(\mathrm{U} - \mathrm{M})]; \quad \forall\alpha \in [0,1], \tag{9}$$

B. The Fuzzy Delphi method

The Fuzzy Delphi method which is an extension of the traditional Delphi method was proposed by Ishikawa et al.,[16] to improve and handle vagueness and uncertainties in its application. The Fuzzy Delphi method which integrates expert's opinions with fuzzy numbers by using the concepts of cumulative frequency distribution and fuzzy integral to handle the ambiguities due to the differences in the meanings and understanding of the experts' opinions and estimates [17], can be called a collective decision-making method [18].

Due to the easy computation of the Fuzzy Delphi methodology, it has found applications in several fields including management [19], engineering [20], construction [21] etc. In an attempt to handle the many uncertainties in the expert's opinions several approaches has been adopted including the use of triangular fuzzy number, Gaussian fuzzy number, trapezoidal fuzzy number and triangular membership function [20]. However, in this study, the Triangular Fuzzy Number is applied. The Fuzzy Delphi method is used to determine the weight of the criteria in this study and its algorithm are given below.

C. Interval Fuzzy-Valued M-TOPSIS model

TOPSIS model which is an abbreviation of Technique for Order Preference by Similarity to the Ideal Solution which was originally proposed by Hwang and Yoon in 1981 [22] has remained one of the most widely used MCDM methods with so many papers published on its applications. Some of the field of study that it has been applied includes Accounting [23], Management [24], Agriculture [25], Chemical science [26], Design [27], Business [28], Engineering [29], Health and medicine [30], etc. However, due to some of its limitations, many different improvement and modifications have been proposed and applied over the years, prominently is the M-TOPSIS model proposed by Ren et al., in 2007 [31].

The M-TOPSIS which is an abbreviation of Modified Technique for Order Preference by Similarity to the Ideal Solution was presented was presented to meet the need for a better and simpler method. It creates an understanding of the inherent relationship between the Relative closeness (R) value and alternative evaluation. The M-TOPSIS method is "described as a process of calculating the distance between the alternatives and the reference points in the d^+, d^- plane and constructing the R value to evaluate the quality of the alternative" [31].

The M-TOPSIS method is unique for its ability to solve ranking reversals issues in TOPSIS and to evaluate failure when alternatives are symmetrical. This study intends to explore the application of the M-TOPSIS method in a fuzzy environment and to apply a modified improved score function and weighted normalized hamming distance method for the calculation of the separation measures of each alternative (candidates) from the positive and negative ideal solutions using interval fuzzy values. From the best of our knowledge, this is the first study to apply the M-TOPSIS method in a fuzzy environment and to apply score function and weighted normalized hamming distance method for the calculation of the separation measures of alternatives. The interval fuzzy valued M-TOPSIS can be expressed concisely as stated in the following section below.

3. THE FUZZY DELPHI METHOD AND IFV-MTOPSIS ALGORITHM

In this section, the algorithm for the proposed integrated model is concisely expressed using the stepwise procedure. The implementation steps which is partly from [32] algorithm has been modified to suit the present study. The schematic diagram of the proposed integrated model is shown in Fig 1 below.

Step 1. Set up a group of Decision Makers (DMs). With their opinion construct the interval-fuzzy valued decision matrix $D_{nxm}(x_{ij})$ of the alternatives (A_i) with respect to the criteria (C_i), using linguistic variables and the interval fuzzy valued (see Table 1) $\boldsymbol{x_{ij}} = \left(\boldsymbol{a_{ij}}, \boldsymbol{b_{ij}}\right)$, $i = 1,2,\dots,m$; $\boldsymbol{j = 1,\dots,n}$

$$D_{nxm}(x_{ij}) = \begin{bmatrix} (a_{11}, b_{11}) & (a_{12}, b_{12}) & \dots & (a_{1n}, b_{1n}) \\ (a_{21}, b_{21}) & (a_{22}, b_{22}) & \cdots & (a_{2n}, b_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ (a_{m1}, b_{m1}) & (a_{m2}, b_{m2}) & \cdots & (a_{mn}, b_{mn}) \end{bmatrix} \tag{10}$$

Step 2. Convert the interval-valued fuzzy decision matrix $D_{mxn}(x_{ij})$to the improved score matrix $R_{mxn}\left(I_{ij}\left(a_{ij}\right)\right)$;

$$R_{mxn}\left(I_{ij}\left(a_{ij}\right)\right) = \begin{bmatrix} I_{11}(x_{11}) & I_{12}(x_{12}) & \dots & I_{1n}(x_{1n}) \\ I_{22}(x_{22}) & I_{22}(x_{22}) & \cdots & I_{2n}(x_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ I_{m1}(x_{m1}) & I_{m2}(x_{m2}) & \cdots & I_{mn}(x_{mn}) \end{bmatrix} \tag{11}$$

Where the improved score function [32] $I(A) = \frac{a+a(1-a-c)+b+b(1-b-d)}{2}$ for Interval-Valued Intuitionistic Fuzzy Set (IVIFS) $A = ([a,b],[c,d])$ is modified to suit the study and is given as$I(A) = \frac{a+a(1-a)+b+b(1-b)}{2}$, when $c = d = 0$ to form $A_{ij} = \left(a_{ij}, b_{ij}\right)$.

Step 3. Determine the weight of each of the evaluating criteria w_j using the Fuzzy Delphi method. This is achieved by first collecting opinions of the decision group concerning the criteria, using linguistic variables and then converts them to the TFN (see Table 1).

- Calculate the evaluation value of the TFN for each alternate criteria given by DMs, and find out the significance TFN of the alternate criteria.

Example 1. Let's assume the evaluation value of the significance of *n* element given by *m* DMs is $\boldsymbol{x_{ij}} = \left(a_{ij}, \boldsymbol{b_{ij}}, \boldsymbol{c_{ij}}\right)$, $i = 1,2,\dots,n$; $\boldsymbol{j = 1},\dots,m$ then the fuzzy weight of the *n* element is; $w_j = \left(a_j, b_j, c_j\right)$, $j = 1,\dots,m$

$$w_{\boldsymbol{j}} = \left(\frac{\sum_{ij}^{m} a_{ij}}{m}, \frac{\sum_{ij}^{m} b_{ij}}{m}, \frac{\sum_{ij}^{m} c_{ij}}{m}\right) \tag{12}$$

Finally, defuzzified the result using center of gravity method;

$$w_j = \frac{a_j + \boldsymbol{b_j} + \boldsymbol{c_j}}{3} \tag{13}$$

Table I. Intuitionistic Fuzzy Numbers for approximating the linguistic variable

Linguistic terms	Interval fuzzy Value	Triangular Fuzzy Numbers (TFN)
Very low (VL)	(0.1, 0.3)	(0.1, 0.25, 0.3)
Low (L)	(0.2, 0.55)	(0.2, 0.3, 0.55)
Good (G)	(0.3, 0.6)	(0.3, 0.45, 0.6)
High (H)	(0.5, 0.7)	(0.5, 0.6, 0.7)
Excellent (EX)	(0.6, 0.9)	(0.6, 0.75, 0.9)

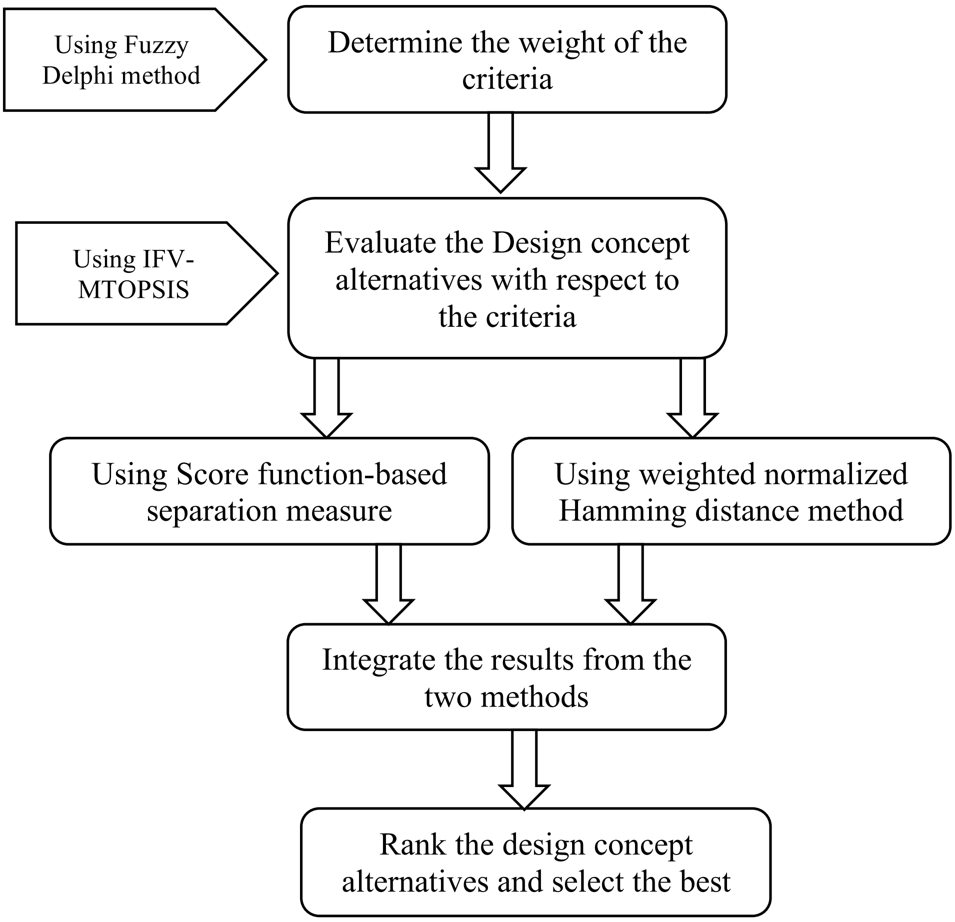

Fig 1. The schematic diagram of the proposed integrated model

Step 4. Define the Positive Ideal Solution (A^+) and Negative Ideal Solution (A^-) for the score function-based matrix and for the weighted normalized Hamming distance method;

$$A^+ = (a_j, b_j),\ A^- = (a_j, b_j),$$

$$A^+ = ([1,1]), \quad j = 1, \dots, n \tag{14}$$

$$A^- = ([0,0]), \quad j = 1, \dots, n \tag{15}$$

Step 5. Compute the score function-based separation measures ($d^+{}_i(A^+,\ A_i)$ and ($d^-{}_i(A^-,\ A_i)$ for each alternative from the positive ideal and negative ideal solutions using the equation (16) and (17), also for the weighted normalized Hamming distance method in a fuzzy environment, the separation measure for two fuzzy numbers are calculated using equation (18) and (19) [33] as shown below.

$$d^+{}_i(A^+,\ \boldsymbol{A_i}) = \sqrt{\sum_{i=1}^{n}\left[w_j\ (1 - \left(\boldsymbol{I_{ij}}\left(\boldsymbol{x_{ij}}\right)\right)\right]^2} \tag{16}$$

Similarly,

$$d^-{}_i(A^-,\ \boldsymbol{A_i}) = \sqrt{\sum_{i=1}^{n}\left[w_j\ \left(\boldsymbol{I_{ij}}\left(\boldsymbol{x_{ij}}\right)\right)\right]^2} \tag{17}$$

$$d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i}) = \sqrt{\sum_{i=1}^{n}\frac{1}{6}\left[w_j([l_{ij}-\tilde{v}_j^{+}]^2+([u_{ij}-\tilde{v}_j^{+}]^2)\right]} \tag{18}$$

Similarly,

$$d^{-}{}_{i}(A^{+},\ \boldsymbol{A_i}) = \sqrt{\sum_{i=1}^{n}\frac{1}{6}\left[w_j([l_{ij}-\tilde{v}_j^{-}]^2+([u_{ij}-\tilde{v}_j^{-}]^2)\right]} \tag{19}$$

Step 6. To combine the distance separation measure as proposed in this study, the new reflection defuzzification integration formula is applied as shown in equation (20) and (21) for both the positive and negative distance points respectively.

$$D^{+}{}_{i}(A^{+},\ \boldsymbol{A_i})_{\text{total}} = \alpha_1 d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i}) + \alpha_2 d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i}) \tag{20}$$

Similarly,

$$D^{-}{}_{i}(A^{-},\ \boldsymbol{A_i})_{\text{total}} = \alpha_1 d^{-}{}_{i}(A^{-},\ \boldsymbol{A_i}) + \alpha_2 d^{-}{}_{i}(A^{-},\ \boldsymbol{A_i}) \tag{21}$$

Step 7. Set a point, say B as the optimized ideal references point($d_i(A,\ \boldsymbol{A_i})$, for the alternatives that is; B ($min\ d(A^{+},\ \boldsymbol{A_i})$, max$d(A^{-},\ \boldsymbol{A_i})$). Then calculate the distances from each alternative. The relative closeness R_i to the ideal solution is calculated as shown in the equation,

$$R_i = \sqrt{[(d(A^{+},\ \boldsymbol{A_i}), -min\ d(A^{+},\ \boldsymbol{A_i}))^2 + (d(A^{-},\ \boldsymbol{A_i}), -max\ d(A^{-},\ \boldsymbol{A_i})\ ^2]} \tag{22}$$

Step 8. Rank the preference order. For ranking of alternative, R_i should be ranked in increasing order. However if there are two alternatives say A_1 and A_2, with $R_1 = R_2$ where$1 \neq 2$, then R_i is calculated using equation (23) then choose the better one with the smaller R_i value for all three method.

$$R_i = (d(A^{+},\ \boldsymbol{A_i}), -min\ d(A^{+},\ \boldsymbol{A_i})) \tag{23}$$

Rank the preference order of the alternatives according to their relative closeness to the ideal solution. The greater value of relative closeness represents a higher-ranking order among alternatives and will be chosen as a recommended alternative.

4. APPLICATION OF THE IFV-MTOPSIS AND FUZZY DELPHI METHOD

A. Problem formulation

In this section, we demonstrate the computational process of the M-TOPSIS model and Fuzzy Delphi method algorithm proposed herein, by using a real case study for case 1 and a hypothetical example for case 2, this is mainly to compare the effectiveness of the model.

CASE 1. An electronic related manufacturing company located around Pekan area Malaysia needed to select a preferred printed circuit board (PCB) from a group of candidates; A_1, A_2, A_3 and A_4 as a reference PCB for a new design. A committee of three experts in the company, i.e. *E1, E2*, and *E3* were formed to determine the most appropriate PCB design. Twelve (12) criteria were chosen for the evaluation i.e.; Mass and size (C_1), Ergonomics (C_2), Simple assembly (C_3), Easy handling (C_4), Easy maintenance (C_5), Few production errors (C_6), Cost (C_7), Fewer spec controls (C_8), Safety standard (C_9), Fulfills environmental standard (C_{10}), Attractive design (C_{11}), and Modifiable (C_{12}). Considering the twelve criteria, the design is selected by implementing the proposed IFV-M-TOPSIS model and Fuzzy Delphi method. The implementation procedures are summarized as follows, using the assessment reports from the three (3) experts.

Step 1. Construct the fuzzy decision matrix; the study uses the linguistic variables in Table 1 and then the interval fuzzy values to express the ratings of the four candidates A_i with respect to each of the twelve criteria C_j to form the fuzzy decision matrix $\boldsymbol{D_{mxn}}(\boldsymbol{x_{ij}})$as shown in Table 2 & 3.

Step 2 & 3: Using the improved score function (equation (3)) the interval fuzzy valued decision matrix $\boldsymbol{D_{mxn}}(\boldsymbol{x_{ij}})$ is converted to the improved score matrix $\boldsymbol{R_{mxn}}\left(\boldsymbol{I_{ij}}\left(\boldsymbol{a_{ij}}\right)\right)$ (i.e. equation (11)) as show in the Table 4. Also, by following the implementation procedure for the Fuzzy Delphi method, the weights of the criteria are determined. The results for criteria weights are shown in Table 5.

Step 4-8. By using equation (16) and (17), the separation measure ($d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i})$ and ($d^{-}{}_{i}(A^{-},\ \boldsymbol{A_i})$ ($i = 1,2,3,4$) for the Score function-based separation measures approach is calculated and the results are as follows;

Table 2. Experts ratings with Linguistic terms

C_i	E1	E2	E3	E1	E2	E3	E1	E2	E3	E1	E2	E3
	A_1			A_2			A_3			A_4		
C1	L	G	VL	H	L	H	VL	H	G	G	L	VL
C_2	H	H	VL	EX	G	EX	L	EX	H	VL	G	L
C_3	EX	EX	L	VL	H	H	G	H	EX	L	H	G
C_4	H	H	G	L	G	G	L	L	VL	G	L	VL
C_5	H	G	L	G	H	G	H	G	L	L	G	L
C_6	VL	G	H	H	EX	H	EX	L	VL	G	H	G
C_7	L	H	VL	EX	H	H	L	G	L	H	G	H
C_8	H	EX	L	VL	EX	EX	G	H	G	G	H	L
C_9	VL	H	H	VL	H	H	VL	G	VL	G	VL	G
C_{10}	L	VL	EX	L	EX	EX	L	L	L	H	L	H
C_{11}	G	L	H	VL	H	H	G	G	G	EX	G	H
C_{12}	VL	H	G	H	H	G	VL	H	H	L	EX	G

Table 3. Decision matrix for the proposed fuzzy model

	A_1	A_2	A_3	A_4
C_1	(0.20, 0.48)	(0.40, 0.65)	(0.30, 0.53)	(0.20, 0.48)
C_2	(0.37, 0.57)	(0.47, 0.80)	(0.43, 0.72)	(0.20, 0.48)
C_3	(0.43, 0.67)	(0.27, 0.58)	(0.17, 0.47)	(0.20, 0.48)
C_4	(0.33, 0.62)	(0.37, 0.63)	(0.33, 0.62)	(0.23, 0.57)
C_5	(0.30, 0.53)	(0.53, 0.77)	(0.30, 0.58)	(0.37, 0.63)
C_6	(0.27, 0.52)	(0.53, 0.77)	(0.23, 0.57)	(0.43, 0.67)
C_7	(0.43, 0.72)	(0.43, 0.70)	(0.37, 0.63)	(0.33, 0.62)
C_8	(0.37, 0.57)	(0.37, 0.57)	(0.17, 0.40)	(0.23, 0.50)
C_9	(0.30, 0.58)	(0.47, 0.78)	(0.20, 0.55)	(0.40, 0.65)
C_{10}	(0.33, 0.62)	(0.37, 0.57)	(0.30, 0.60)	(0.47, 0.73)
C_{11}	(0.30, 0.58)	(0.10, 0.30)	(0.23, 0.43	(0.43, 0.67)
C_{12}	(0.40, 0.65)	(0.27, 0.58)	(0.33, 0.62)	(0.37, 0.68)

Table 4. Improved score matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	0.385	0.449	0.380	0.418	0.413	0.416	0.482	0.398	0.428	0.428	0.420	0.470
A_2	0.448	0.335	0.417	0.445	0.429	0.344	0.440	0.370	0.460	0.378	0.248	0.394
A_3	0.426	0.428	0.315	0.387	0.457	0.439	0.468	0.314	0.417	0.443	0.359	0.443
A_4	0.385	0.385	0.361	0.420	0.455	0.440	0.421	0.377	0.474	0.445	0.404	0.410

Table 5. Fuzzy Delphi weight

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
$\boldsymbol{w_j}$	0.086	0.086	0.084	0.083	0.086	0.079	0.081	0.084	0.079	0.081	0.084	0.088

$(d^{+}{}_{1}(A^{+},\ \boldsymbol{A_1}) = 0.562,\ (d^{-}{}_{1}(A^{-},\ \boldsymbol{A_1}) = 1.234,$
$(d^{+}{}_{2}(A^{+},\ \boldsymbol{A_2}) = 0.536,\ (d^{-}{}_{2}(A^{-},\ \boldsymbol{A_2}) = 1.318$
$(d^{+}{}_{3}(A^{+},\ \boldsymbol{A_3}) = 0.665, (d^{-}{}_{3}(A^{-}, A_3) = 1.143$, and
$(d^{+}{}_{4}(A^{+}, A_4) = 0.607, (d^{-}{}_{4}(A^{-}, A_4) = 1.211.$

While using equation (18) and (19), we compute the separation measure $(d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i})$ and $(d^{-}{}_{i}(A^{-},\ \boldsymbol{A_i})$ $(i = 1,2,3,4)$ for the weighted Normalized Hamming distance method, the results are as follows;

$(d^{+}{}_{1}(A^{+},\ \boldsymbol{A_1}) = 0.541, (d^{-}{}_{1}(A^{-},\ \boldsymbol{A_1}) = 0.294,$
$(d^{+}{}_{2}(A^{+},\ \boldsymbol{A_2}) = 0.504,\ (d^{-}{}_{2}(A^{-},\ \boldsymbol{A_2}) = 0.320,$
$(d^{+}{}_{3}(A^{+},\ \boldsymbol{A_3}) = 0.564, (d^{-}{}_{3}(A^{-}, A_3) = 0.267$, and
$(d^{+}{}_{4}(A^{+}, A_4) = 0.552, (d^{-}{}_{4}(A^{-}, A_4) = 0.288.$

Using the new reflection defuzzification integration formula, i.e. equation (20) and (21), the two separation distance measures approaches are integrated. The results are as follows;

$(D^{+}(A^{+},\ \boldsymbol{A_1}) = 1.103,\ (D^{-}{}_{1}(A^{-},\ \boldsymbol{A_1}) = 1.528,$
$(D^{+}{}_{2}(A^{+},\ \boldsymbol{A_2}) = 1.040,\ (D^{-}{}_{2}(A^{-},\ \boldsymbol{A_2}) = 1.638,$
$(D^{+}{}_{3}(A^{+},\ \boldsymbol{A_3}) = 1.228, (D^{-}{}_{3}(A^{-}, A_3) = 1.410$, and
$(D^{+}{}_{4}(A^{+}, A_4) = 1.159, (D^{-}{}_{4}(A^{-}, A_4) = 1.499.$

Finally, the results for the relative closeness R_i , $(i = 1,2,3,4)$ to the ideal solution is calculated using equation (22) and the final results are; $R_1 = 0.133,\ R_2 = 0.228,\ R_3 = 0.188,$ and $R_4 = 0.149.$ The ranking orders for the four candidates are in the form (increasing order) $A_1 < A_4 < A_3 < A_2$. Obviously, A_2 is the best candidate according to the M-TOPSIS model.

CASE 2. Let us consider the decision-making problem discussed in [1] and modify it to make a new example for a Car manufacturing company. A Car manufacturing company wants to select a preferred car from a group of candidates; A_1, A_2, A_3 A_4 A_5 and A_6 as a reference car for a new design. The expert has to make a decision according to the following, Performance (C_1), Equipment (C_2), Economy (C_3), Automation (C_4), Safety (C_5) and Appearance (C_6) [34].

The criteria weights are given as $w_i = \{0.170, 0.205, 0.148, 0.170, 0.159, 0.148\}$. The six candidates $A_i(\ i = 1,2,3,4,5,6)$are evaluated using the M-TOPSIS model with the two separation distance measure approaches. To suit our model the Intuitionistic Fuzzy Numbers $\tilde{A} = (L, M, U)$ in the aggregated Intuitionistic Fuzzy Decision matrix which are based on aggregation of DMs' opinions in [1] as shown in Table 6 are converted to interval fuzzy values using equation (9) with α-cut level =0.3 (see Table 7 for the results).

By following the proposed algorithm just as in case 1, we compute the separation measure $(d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i})$ and $(d^{-}{}_{i}(A^{-},\ \boldsymbol{A_i})$ $(i = 1,2,3,4)$ using the Score function-based separation measures approach as shown in equation (16) and (17). The computational results are as follows;

$(d^{+}{}_{1}(A^{+},\ \boldsymbol{A_1}) = 0.200,\ (d^{-}{}_{1}(A^{-},\ \boldsymbol{A_1}) = 0.210,$
$(d^{+}{}_{2}(A^{+},\ \boldsymbol{A_2}) = 0.200,\ (d^{-}{}_{2}(A^{-},\ \boldsymbol{A_2}) = 0.210,$
$(d^{+}{}_{3}(A^{+},\ \boldsymbol{A_3}) = 0.200, (d^{-}{}_{3}(A^{-}, A_3) = 0.210,$
$(d^{+}{}_{4}(A^{+}, A_4) = 0.200, (d^{-}{}_{4}(A^{-}, A_4) = 0.210,$
$(d^{+}{}_{5}(A^{+}, A_5) = 0.190, (d^{-}{}_{5}(A^{-}, A_5) = 0.220,$ and
$(d^{+}{}_{6}(A^{+}, A_6) = 0.200, (d^{-}{}_{6}(A^{-}, A_6) = 0.210.$

While using equation (18) and (19), $(d^{+}{}_{i}(A^{+},\ \boldsymbol{A_i})$ and $(d^{-}{}_{i}(A^{-},\ \boldsymbol{A_i})$ $(i = 1,2,3,4)$ are computed for the weighted Normalized Hamming distance method and the results are as follows;

$(d^{+}{}_{1}(A^{+},\ \boldsymbol{A_1}) = 0.097,\ (d^{-}{}_{1}(A^{-},\ \boldsymbol{A_1}) = 1.334,$
$(d^{+}{}_{2}(A^{+},\ \boldsymbol{A_2}) = 0.097,\ (d^{-}{}_{2}(A^{-},\ \boldsymbol{A_2}) = 1.335,$
$(d^{+}{}_{3}(A^{+},\ \boldsymbol{A_3}) = 0.101, (d^{-}{}_{3}(A^{-}, A_3) = 1.334,$
$(d^{+}{}_{4}(A^{+}, A_4) = 0.101, (d^{-}{}_{4}(A^{-}, A_4) = 1.333,$
$(d^{+}{}_{5}(A^{+}, A_5) = 0.087, (d^{-}{}_{5}(A^{-}, A_5) = 1.336$ and
$(d^{+}{}_{6}(A^{+}, A_6) = 0.097, (d^{-}{}_{6}(A^{-}, A_6) = 1.334.$

Table 6. Aggregated Intuitionistic Fuzzy Decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(0.80,0.08,0.12)	(0.69,0.20,0.11)	(0.76,0.12,0.12)	(0.80,0.09,0.11)	(0.78,0.11,0.11)	(0.69,0.20,0.11)
A_2	(0.68,0.20,0.12)	(0.78,0.11,0.11)	(0.74,0.13,0.13)	(0.78,0.11,0.11)	(0.69,0.21,0.10)	(0.75,0.13,0.12)
A_3	(0.82,0.07,0.11)	(0.79,0.10,0.11)	(0.79,0.10,0.11)	(0.84,0.05,0.11)	(0.84,0.05,0.11)	(0.84,0.05,0.11)
A_4	(0.83,0.16,0.1)	(0.75,0.14,0.11)	(0.70,0.19,0.11)	(0.81,0.08,0.11)	(0.82,0.07,0.11)	(0.85,0.05,0.10)
A_5	(0.55,0.38,0.07)	(0.42,0.52,0.06)	(0.64,0.40,0.06)	(0.55,0.33,0.12)	(0.54,0.33,0.13)	(0.40,0.54,0.06)
A_6	(0.75,0.13,0.12)	(0.69,0.19,0.12)	(0.75,0.13,0.12)	(0.75,0.13,0.12)	(0.85,0.05,0.10)	(0.78,0.11,0.11)

Table 7. Aggregated Fuzzy Decision matrix in interval

	C1	C2	C3	C4	C5	C6
A_1	(0.58, 0.11)	(0.54, 0.14)	(0.57, 0.12)	(0.59, 0.10)	(0.58, 0.11)	(0.54, 0.14)
A_2	(0.54, 0.14)	(0.58, 0.11)	(0.56, 0.13)	(0.58, 0.11)	(0.55, 0.13)	(0.56, 0.12)
A_3	(0.60, 0.10)	(0.58, 0.11)	(0.58, 0.11)	(0.60, 0.09)	(0.60, 0.09)	(0.60, 0.09)
A_4	(0.63, 0.12)	(0.57, 0.12)	(0.55, 0.13)	(0.59, 0.10)	(0.60, 0.10)	(0.61, 0.09)
A_5	(0.50, 0.16)	(0.45, 0.20)	(0.57, 0.16)	(0.48, 0.18)	(0.48, 0.19)	(0.44, 0.20)
A_6	(0.56, 0.12)	(0.54, 0.14)	(0.56, 0.12)	(0.56, 0.12)	(0.61, 0.09)	(0.58, 0.11)

Using the new reflection defuzzification integration formula, equation (20) and (21), the two separation measures approaches are integrated and the results are as follows;

$$(D^{+}{}_{1}(A^{+},\ \boldsymbol{A_1}) = 0.297,\ (D^{-}{}_{1}(A^{-},\ \boldsymbol{A_1}) = 1.544,$$
$$(D^{+}{}_{2}(A^{+},\ \boldsymbol{A_2}) = 0.297,\ (D^{-}{}_{2}(A^{-},\ \boldsymbol{A_2}) = 1.545,$$
$$(D^{+}{}_{3}(A^{+},\ \boldsymbol{A_3}) = 0.301,\ (D^{-}{}_{3}(A^{-}, A_3) = 1.544,$$
$$(D^{+}{}_{4}(A^{+}, A_4) = 0.301,\ (D^{-}{}_{4}(A^{-}, A_4) = 1.543,$$
$$(D^{+}{}_{5}(A^{+}, A_5) = 0.277,\ (D^{-}{}_{5}(A^{-}, A_5) = 1.556 \text{ and}$$
$$(D^{+}{}_{6}(A^{+}, A_6) = 0.297,\ (D^{-}{}_{6}(A^{-}, A_6) = 1.544.$$

Finally, the results for the relative closeness R_i , $(i = 1,2,3,4)$ to the ideal solution is calculated using equation (22) and the final results are; $R_1 = 0.023,\ R_2 = 0.022,\ R_3 = 0.028,$ and $R_4 = 0.027, R_5 = 0.000,$ and $R_6 = 0.024$ therefore the ranking orders for the four candidates are in the form (increasing order) $A_5 < A_2 < A_1 < A_6 < A_4 < A_3$, obviously, A_3 is the best candidate according to the M-TOPSIS model. These results are in agreement with the ones obtained in [1].

5. CONCLUSION

This paper presents a reliable, easy and more objective approach for selecting and determining design concept, ranking and determining preference in a multi-criteria decision-making problem. We proposed an integration of M-TOPSIS model and fuzzy Delphi model using interval fuzzy values on a score function and a weighted Normalized Hamming distance method for the calculation of the separation measures of each alternative (candidates) from the positive and negative ideal solutions. The results from score function-based separation measure and that of the weighted Normalized Hamming distance method are combined using a new reflection defuzzification integration formula introduced in this study. By using the two distance separation measures in this study we have eliminated the bias of using a single distance separation method, and the decision-making problem created in determining the distance separation method that is fittest.

The proposed model has successfully been implemented to rank and determined the most appropriate printed circuit board (PCB) for an electronic related manufacturing company located in Pekan-Malaysia and for a modified hypothetical example which is based on the selection of a preferred Car as a reference for a new design. Also, the proposed model has been compared with existing model as shown Case 2.

The result from this study we hope will serve as an advisory system and a guide for managers and companies planning to select business partners as well as in the evaluation of their current practices and status. Finally, in the future, we hope to apply the proposed model to other domains.

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