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Supplier Selection Based on Two-Phased Fuzzy Decision Making

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Abstract Supplier selection depends on human evaluation which is subjective and vague in nature. Fuzzy approach is deemed appropriate to measure these uncertainties in the decision making process, rather than using real or crisp values. Predominant in many studies on fuzzy decision making, fixed triangular or trapezoidal fuzzy numbers with symmetric spread from the literature were incorporated. However, these fuzzy numbers do not explain the actual respondents' opinions which will affect the overall decision making process. Therefore, fuzzy numbers based on respondents should be developed beforehand to be integrated into the existing fuzzy decision making tool. This paper aims to develop triangular fuzzy numbers based on respondents' opinions. These fuzzy numbers were adopted into a fuzzy evaluation method used in a supplier selection problem. The ranking results were analyzed using three different groups of fuzzy numbers. It was found that the linguistic terms for all three groups are not symmetric with the largest difference in spread that occurs for G_2. There is also a variation in ranking of sub-criterion "Background of Supplier" in G_2. Future studies in fuzzy decision making should include fuzzy numbers built based on respondents as they provide more reliable outcomes.

Keywords Fuzzy decision making; fuzzy evaluation; respondent based fuzzy numbers; supplier selection.

1 Introduction

Supplier selection requires comprehensive evaluation of multiple criteria which depends on human quantitative and qualitative assessments. Since human judgements are dependent on prior knowledge, feelings and intuitions, it is somewhat unnatural to represent these uncertainties using real or crisp values. Hence, many decision making problems are modelled by adopting fuzzy set theory to correctly define the ambiguity and imprecise data (Zadeh, 1965). In the case of supplier selection, linguistic terms, such as "Very Good", "Fair" or "Poor" are seen to be more appropriate to measure criteria, such as "quality of product", "quality of service" and so forth.

Numerous methodologies have been proposed to improve the evaluation and selection processes involved in the decision making, including the problem of supplier selection. Special emphasis is given in the context of research that has been done specifically in the use of fuzzy approach in the supplier selection problem. Chen, Lin and Huang (2006) presented a fuzzy approach to supplier selection problem by adopting linguistic values into a well-established model called Technique of order Performance by Similarity to Ideal Solution (TOPSIS). A number of hybrid models were proposed that have also integrated the fuzzy approach into Multi-Criteria Decision Making (MCDM) models, which includes Analytical Hierarchy Process (AHP), the Decision Making Trial and Evaluation Laboratory (DEMATEL) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (i.e. VIKOR). Some recent findings were presented by Deng and Chan (2011), Dalalah, Hayajneh and Batieha (2011) and Shemshadi, Shirazi, Toreihi and Tarokh (2011) that brought forward the use of triangular or trapezoidal fuzzy numbers to represent the linguistic terms in order to overcome the vagueness and fuzziness of human decision making.

Predominant in fuzzy decision making, the linguistic terms are usually represented by fixed triangular or trapezoidal fuzzy numbers taken from the previous literature. Most of these fixed fuzzy numbers have symmetric spread with the right and left spread that is equal. Benítez, Martín and Román (2007) disputed that respondents may have different perception on the representation of these fuzzy numbers. Therefore, it can be argued that fuzzy numbers taken from the literature do not represent actual respondents' or experts' opinions.

There is a need to consider building fuzzy numbers based on respondents to be integrated into decision making models. Previously, Yeh (2002) mentioned that decision makers have the option of defining their own value range for the linguistic terms to be used in the assessment process. However, default values for the linguistic terms were assumed if they have no personal preferences. Li and Kuo (2008) also stated the possibility of constructing own fuzzy numbers according to decision makers, although the method of construction was not visible.

The construction of fuzzy numbers based on respondents was presented by Tolosa and Guadarrama (2010), where fuzzy numbers were developed from non-expert users based on surveys or observations. Recently, Ishazaka and Nguyen (2013) proposed a method to construct the membership functions of fuzzy numbers that were customised to individual respondents and incorporated the numbers in the evaluation process. Apart from these, not much work has been found that develops fuzzy numbers based on respondents' opinions.

In essence, it is important to consider the use of fuzzy numbers that are constructed according to respondents' opinions or judgements as it may cause variations in the assessment outcomes. At present in the context of supplier selection, there is no evidence that the construction of these numbers has been used. Hence, this paper aims to develop triangular fuzzy numbers based on different groups of respondents. Next, these fuzzy numbers are integrated into a fuzzy evaluation method used in a supplier selection problem. The ranking results of suppliers are analysed according to different groups of respondents.

The next section of this paper introduces the basic definitions and operations on fuzzy numbers. Section 3 presents the proposed two-phased fuzzy evaluation method. The implementation of the model is presented in Section 4 whereas in Section 5, the obtained results and analysis are presented. Finally, the conclusion is given in Section 6.

2 Preliminaries

This section presents some preliminary concepts of fuzzy numbers that are utilized in solving the fuzzy decision making problem.

2.1 Fuzzy numbers

A fuzzy number is a fuzzy subset in the universe discourse that is both convex and normal. The membership function of a fuzzy number $\tilde{A}$ can be defined as

$$f_{\tilde{A}}(x)=\begin{cases} f_A^L(x) & ,a \le x \le b \\ 1 & ,b \le x \le c \\ f_A^R(x) & ,c \le x \le d \\ 0 & ,\text{otherwise} \end{cases} \tag{1}$$

where f_A^L and f_A^R are the left and right membership functions of the fuzzy number $\tilde{A}$ respectively. Trapezoidal fuzzy numbers are denoted as (a,b,c,d) and triangular fuzzy numbers which are special cases of trapezoidal fuzzy numbers with $b=c$ are denoted as (a,b,d).

2.2 Operations on fuzzy numbers

Let $\tilde{X}$ and $\tilde{Y}$ be two trapezoidal fuzzy numbers parameterized by (x_1,x_2,x_3,x_4) and (y_1,y_2,y_3,y_4) respectively. The fuzzy number arithmetic operations between $\tilde{X}$ and $\tilde{Y}$ are presented as follows:

Addition operation:

$$\tilde{X} \oplus \tilde{Y} = (x_1+y_1, x_2+y_2, x_3+y_3, x_4+y_4), \tag{2}$$

Subtraction operation:

$$\tilde{X} - \tilde{Y} = (x_1-y_4, x_2-y_3, x_3-y_2, x_4-y_1), \tag{3}$$

where x_1, x_2, x_3, x_4, y_1, y_2, y_3, and y_4 are real numbers.

Multiplication operation:

$$\tilde{X} \otimes \tilde{Y} = (x_1y_1, x_2y_2, x_3y_3, x_4y_4), \tag{4}$$

where x_1, x_2, x_3, x_4, y_1, y_2, y_3, and y_4 are positive real numbers.

Division operation:

$$\tilde{X}/\tilde{Y} = \left(x_1/y_4, x_2/y_3, x_3/y_2, x_4/y_1\right), \tag{5}$$

where x_1, x_2, x_3, x_4, y_1, y_2, y_3, and y_4 are nonzero positive real numbers.

3 Methodology

The procedure for fuzzy decision making consists of two phases with Phase I being the development of fuzzy numbers based on respondents' opinion. The procedure for Step 2 in Phase I is taken from Abdolvand, Toloie and Taghiouryan (2008). Phase II is the fuzzy evaluation which consists of Steps 3 to 7 and are taken from Shohaimay, Ramli and Mohamed (2012). The procedures are presented as follows:

3.1 Phase I – Development of fuzzy numbers

Step 1: The appropriate scale of 0 – 1 and 0 – 10 is determined by *k* respondents for seven-scale linguistic terms of importance weights and performance ratings, respectively. The seven linguistic terms for importance weights are "*Very High*" (*VH*), "*High*" (*H*), "*Medium High*" (*MH*), "*Medium*" (*M*), "*Medium Low*" (*ML*), "*Low*" (*L*) and "*Very Low*" (*VL*). The seven linguistic terms for performance ratings are "*Very Good*" (*VG*), "*Good*" (*G*), "*Medium Good*" (*MG*), "*Fair*" (*F*), "*Medium Poor*" (*MP*), "*Poor*" (*P*) and "*Very Poor*" (*VP*).

Step 2: The corresponding fuzzy numbers for the linguistic terms of importance weights and performance ratings are developed based on Abdolvand et al. (2008). For *k* respondents, the lower limit, modal and upper limit of the respective linguistic terms, denoted as *a*, *b* and *d* respectively, are given as

$$a = \min\left(L_1, \quad L_2, \quad L_3, \quad \ldots, \quad L_k\right), \tag{6}$$

$$d = \max\left(U_1, \quad U_2, \quad U_3, \quad \ldots, \quad U_k\right), \tag{7}$$

$$b = \frac{\sum_{i=1}^{k} M_i}{k}, \tag{8}$$

where

L_i is the lower limit of the range of the respective linguistic term for *i*-th respondent,
U_i is the upper limit of the range of the respective linguistic term of the *i*-th respondent, and
$M_i = \frac{1}{2}\left(L_i + U_i\right)$ of the respective linguistic term for *i*-th respondent, for $i = 1,\ 2,\ 3,\ \ldots,\ k$.

3.2 Phase II – Fuzzy evaluation

Step 3: For *K* decision makers, the fuzzy weight $\tilde{w}_j$, of each criterion j is calculated using aggregated fuzzy assessment which is defined as

$$\tilde{w}_j = \frac{\sum_{k=1}^{K} \tilde{w}_j^k}{K}, \tag{9}$$

where $\tilde{w}_j^k$ is the importance weight of the *k*-th decision maker. The fuzzy weighted vector criteria can be represented as $\tilde{W} = \left[\tilde{w}_1 \quad \tilde{w}_2 \quad \cdots \quad \tilde{w}_j\right]^T$.

Step 4: The fuzzy weight $\tilde{g}_{ij}$, of each alternative is calculated using aggregated fuzzy assessment which is defined as

$$\tilde{g}_{ij} = \frac{\sum_{k=1}^{K} \tilde{x}_i^k\, j}{K}, \tag{10}$$

where $\tilde{x}_i^k\, j$ is the rating of the *k*-th decision maker.

Step 5: The fuzzy grade matrix $\tilde{G}$ is built and defined as

$$\tilde{G} = \begin{pmatrix} \tilde{g}_{11} & \tilde{g}_{12} & \cdots & \tilde{g}_{1k} \\ \tilde{g}_{21} & \tilde{g}_{22} & \cdots & \tilde{g}_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{g}_{n1} & \tilde{g}_{n2} & \cdots & \tilde{g}_{nk} \end{pmatrix}, \tag{11}$$

where $\tilde{g}_{ij}$ denotes the fuzzy grade of the *i*-th alternative A_i with respect to the *j*-th criterion X_j, *n* denotes the number of alternatives and *k* denotes the number of criteria.

Step 6: The total fuzzy grade vector $\tilde{R}$ is calculated as

$$\tilde{R} = \tilde{G} \otimes \tilde{W} = \begin{pmatrix} \tilde{R}_1 \\ \tilde{R}_2 \\ \vdots \\ \tilde{R}_k \end{pmatrix}, \tag{12}$$

where $\tilde{R}_i$ denotes the total fuzzy grade of the *i*-th alternative A_i and $1 \le i \le n$.

Step 7: The ranking order of $\tilde{R}_i$ is calculated based on the method of centroid point by Wang, Yang, Xu and Chin (2006) corresponding to a value of $\bar{x}$ defined as

$$\bar{x}\left(\tilde{R}_i\right) = \frac{\int_a^b x f_{\tilde{R}}^{l} dx + \int_b^c xwdx + \int_c^d x f_{\tilde{R}}^{r} dx}{\int_a^b f_{\tilde{R}}^{l} dx + \int_b^c wdx + \int_c^d f_{\tilde{R}}^{r} dx}, \tag{13}$$

where $f_{\tilde{R}}^{r}$ and $f_{\tilde{R}}^{l}$ are right and left membership function of $\tilde{R}_i$, respectively.

A summary of the proposed two-phased fuzzy decision making process is shown in Figure 1.

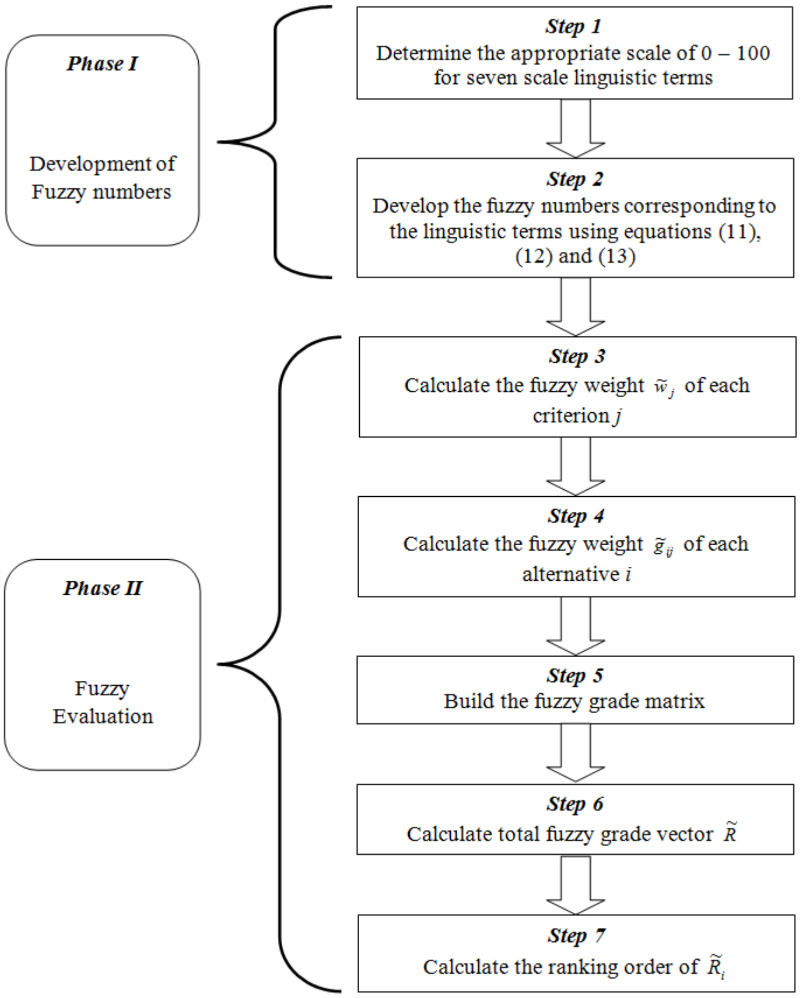

Figure 1: Two-Phased Fuzzy Decision Making Process

4 Implementation

4.1 Phase I – Development of fuzzy numbers

A total of 184 respondents were involved in this study. Respondents were asked to determine the appropriate scale for the seven-scale linguistic terms for importance weights and performance ratings. Triangular fuzzy numbers for each linguistic term were developed based on equations (6), (7) and (8) for all respondents. The respondents were also further categorized into three smaller groups: G_1, G_2, and G_3, according to their background of expertise.

4.2 Phase II – Fuzzy evaluation

In this study, these fuzzy numbers were adopted into a fuzzy evaluation method used in an Information Technology (IT) supplier selection problem. It is based on the evaluation of n supplier, S_n by four decision makers (DMs). The IT supplier selection problem was presented as MCDM problem consisting of three main criteria which are "Background of Supplier" (X_1), "Product Performance" (X_2) and "Service Performance" (X_3). Each of the main criteria was divided into three sub-criteria as follows:

X_{11}: Supply Performance
X_{12}: Location of Firm
X_{13}: Relevant Experience
X_{21}: Product Price
X_{22}: Product Quality
X_{23}: Specification Compliant
X_{31}: Delivery Time
X_{32}: Technical Support
X_{33}: Warranty

The linguistic values given by the DMs are shown in Tables 1 to 3.

Table 1: Importance Weights of Criteria by each DM

Criteria	**Decision Maker**			
	D_1	D_2	D_3	D_4
X_1	H	H	VH	MH
X_2	H	VH	VH	MH
X_3	H	VH	VH	MH

Source: Shohaimay et al. (2012)

Table 2: Performance Ratings of Suppliers based on each Sub-Criterion by D_1 and D_2

Criteria	Sub-Criteria	D_1				D_2			
		S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
X_1	X_{11}	G	G	G	G	VG	G	MG	MG
	X_{12}	G	G	G	G	M	MG	MG	F
	X_{13}	G	G	G	G	G	MG	MG	F
X_2	X_{21}	F	F	F	F	F	F	F	MG
	X_{22}	G	G	G	G	G	MG	MG	MG
	X_{23}	G	G	G	G	G	G	MG	MG
X_3	X_{31}	G	G	G	G	VG	MG	MG	MG
	X_{32}	G	G	G	G	G	F	MG	MG
	X_{33}	G	G	G	G	G	MG	MG	G

Source: Shohaimay et al. (2012)

Table 3: Performance Ratings of Suppliers based on each Sub-Criterion by D_3 and D_4

Criteria	Sub-Criteria	D_3				D_4			
		S_1	S_2	S_3	S_4	S_1	S_2	S_3	S_4
X_1	X_{11}	G	MG	MG	G	G	MG	MG	G
	X_{12}	VG	VG	G	G	G	MG	MG	MG
	X_{13}	VG	G	G	G	MG	MG	MG	G
X_2	X_{21}	G	MG	MG	G	G	MG	MG	MG
	X_{22}	G	G	G	VG	G	MG	MG	MG
	X_{23}	G	G	G	G	G	MG	MG	G
X_3	X_{31}	G	F	G	G	G	MG	MG	MG
	X_{32}	G	MG	G	VG	G	MG	MG	G
	X_{33}	VG	G	G	VG	G	MG	MG	G

Source: Shohaimay et al. (2012)

5 Results and Discussions

5.1 The developed fuzzy numbers

From Phase I, six sets of fuzzy numbers corresponding to each linguistic term were obtained for respondents G_1, G_2, and G_3, as shown in Tables 4 to 6.

Table 4: Linguistic Terms for Importance Weights and Performance Ratings based on Respondents (G_1)

Importance Weights		Performance Ratings	
Linguistic Terms	**Fuzzy Numbers**	**Linguistic Terms**	**Fuzzy Numbers**
Very Low	(0.00, 0.09, 0.50)	Very Poor	(0.00, 0.91, 5.50)
Low	(0.05, 0.25, 0.55)	Poor	(0.50, 2.47, 6.00)
Medium Low	(0.10, 0.38, 0.65)	Medium Poor	(1.00, 3.87, 6.50)
Medium	(0.20, 0.52, 0.80)	Fair	(1.50, 5.21, 8.00)
Medium High	(0.35, 0.66, 0.85)	Medium Good	(4.00, 6.58, 8.90)
High	(0.60, 0.79, 0.98)	Good	(6.00, 7.90, 9.50)
Very High	(0.70, 0.93, 1.00)	Very Good	(7.00, 9.26, 10.00)

Table 5: Linguistic Terms for Importance Weights and Performance Ratings based on Respondents (G_2)

Importance Weights		Performance Ratings	
Linguistic Terms	**Fuzzy Numbers**	**Linguistic Terms**	**Fuzzy Numbers**
Very Low	(0.00, 0.09, 0.60)	Very Poor	(0.00, 0.85, 4.00)
Low	(0.02, 0.23, 0.65)	Poor	(0.50, 2.30, 5.00)
Medium Low	(0.11, 0.36, 0.70)	Medium Poor	(1.10, 3.62, 6.00)
Medium	(0.24, 0.50, 0.75)	Fair	(2.40, 5.00, 7.50)
Medium High	(0.40, 0.65, 0.88)	Medium Good	(4.00, 6.39, 8.80)
High	(0.45, 0.79, 0.92)	Good	(4.50, 7.72, 9.30)
Very High	(0.60, 0.92, 1.00)	Very Good	(6.00, 9.13, 10.00)

Table 6: Linguistic Terms for Importance Weights and Performance Ratings based on Respondents (G_3)

Importance Weights		Performance Ratings	
Linguistic Terms	**Fuzzy Numbers**	**Linguistic Terms**	**Fuzzy Numbers**
Very Low	(0.00, 0.08, 0.40)	Very Poor	(0.00, 0.83, 4.00)
Low	(0.05, 0.24, 0.60)	Poor	(0.50, 2.35, 5.00)
Medium Low	(0.10, 0.38, 0.70)	Medium Poor	(1.00, 3.73, 6.00)
Medium	(0.20, 0.52, 0.80)	Fair	(2.00, 5.15, 8.00)
Medium High	(0.40, 0.66, 0.90)	Medium Good	(4.00, 6.59, 9.00)
High	(0.60, 0.79, 0.95)	Good	(6.00, 7.95, 9.50)
Very High	(0.75, 0.93, 1.00)	Very Good	(7.00, 9.31, 10.00)

Figures 2 and 3 present the graphs of membership functions for the respective fuzzy numbers.

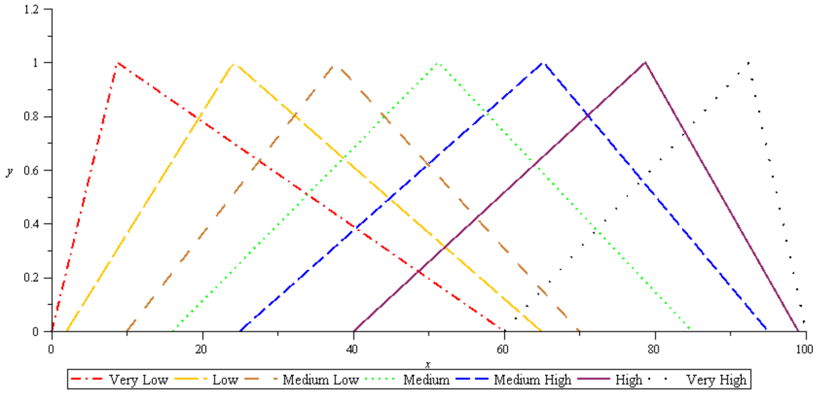

Figure 2: Fuzzy Numbers for Importance Weights

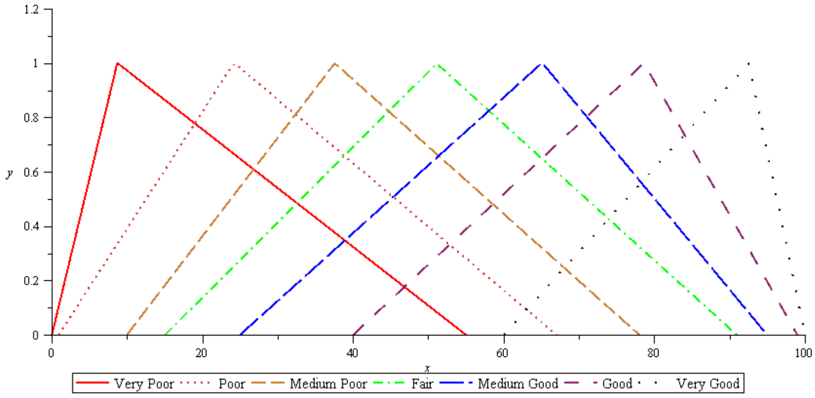

Figure 3: Fuzzy Numbers for Performance Ratings

Based on Tables 3 to 5 and Figures 2 and 3, the spread of fuzzy numbers for importance weights and performance ratings are not symmetric. For importance weights, the largest difference in spread of *VL*, *L*, *ML*, *H* and *VH* occur in G_2. The largest difference in spread of *M* and *MH* occur in G_1. However for performance ratings, the largest difference in spread of *VP*, *P*, *F* and *MG* occur in G_1. For *G* and *VG*, the largest difference in spread occurs in G_2.

5.2 Fuzzy evaluation

The fuzzy weights, fuzzy grade matrices and total fuzzy grade vectors of each group of respondents are shown in Table 7.

Table 7: Fuzzy Weights, Fuzzy Grade Matrix and Fuzzy Grade Vector, based on Respondents of Group, G_1, G_2 and G_3

Group	**Fuzzy weights, Fuzzy Grade Matrix and Fuzzy Grade Vector**	**Value of** $\bar{x}(\tilde{R})$
G	$\tilde{W} = \begin{bmatrix}\tilde{w}_1\\ \tilde{w}_2\\ \tilde{w}_3\end{bmatrix} = \begin{bmatrix}(0.56, & 0.79, & 0.95\\ (0.59, & 0.83, & 0.96)\\ (0.59, & 0.83, & 0.96)\end{bmatrix}$ $\tilde{G} = \begin{array}{cccc} & X_1 & X_2 & X_3 \\ S_1 & (5.92,\ 8.01,\ 9.53) & (5.25,\ 7.45,\ 9.25) & (6.17,\ 8.13,\ 9.58) \\ S_2 & (5.08,\ 7.35,\ 9.24) & (4.42,\ 6.90,\ 9.00) & (4.25,\ 6.79,\ 8.95) \\ S_3 & (4.83,\ 7.13,\ 9.15) & (4.25,\ 6.80,\ 8.95) & (5.00,\ 7.24,\ 9.20) \\ S_4 & (4.92,\ 7.23,\ 9.15) & (4.88,\ 7.24,\ 9.17) & (5.67,\ 7.80,\ 9.43) \end{array}$ $\tilde{R} = \begin{bmatrix}R_1\\ R_2\\ R_3\\ R_4\end{bmatrix} = \begin{bmatrix}(10.04, & 19.22, & 27.10)\\ (7.95, & 17.13, & 25.99)\\ (8.15, & 17.23, & 26.09)\\ (8.56, & 18.14, & 26.53)\end{bmatrix}$	$\bar{x}(\tilde{R}) = \begin{array}{c} S_1\\ S_2\\ S_3\\ S_4\end{array}\begin{bmatrix}18.79\\ 17.02\\ 17.16\\ 17.88\end{bmatrix}$
***G*₁**	$\tilde{W} = \begin{bmatrix}\tilde{w}_1\\ \tilde{w}_2\\ \tilde{w}_3\end{bmatrix} = \begin{bmatrix}(0.48, & 0.78, & 0.93\\ (0.51, & 0.82, & 0.95)\\ (0.51, & 0.82, & 0.95)\end{bmatrix}$ $\tilde{G} = \begin{array}{cccc} & X_1 & X_2 & X_3 \\ S_1 & (4.79,\ 7.85,\ 9.39) & (4.15,\ 7.27,\ 9.00) & (4.75,\ 7.95,\ 9.42) \\ S_2 & (4.38,\ 7.17,\ 9.11) & (3.94,\ 6.71,\ 8.79) & (3.90\ 6.60,\ 8.75) \\ S_3 & (4.21,\ 6.94,\ 9.01) & (3.90,\ 6.60,\ 8.75) & (4.25,\ 7.05,\ 9.05) \\ S_4 & (4.07,\ 7.04,\ 8.92) & (4.24,\ 7.06,\ 9.00) & (4.63,\ 7.62,\ 9.29) \end{array}$ $\tilde{R} = \begin{bmatrix}R_1\\ R_2\\ R_3\\ R_4\end{bmatrix} = \begin{bmatrix}(6.84 & 18.61, & 26.23)\\ (6.10, & 16.52 & 25.14)\\ (6.18, & 16.62, & 25.29)\\ (6.48, & 17.53, & 26.67)\end{bmatrix}$	$\bar{x}(\tilde{R}) = \begin{array}{c} S_1\\ S_2\\ S_3\\ S_4\end{array}\begin{bmatrix}17.22\\ 15.92\\ 16.03\\ 16.56\end{bmatrix}$
***G*₂**	$\tilde{W} = \begin{bmatrix}\tilde{w}_1\\ \tilde{w}_2\\ \tilde{w}_3\end{bmatrix} = \begin{bmatrix}(0.59, & 0.79, & 0.95\\ (0.63, & 0.83, & 0.96)\\ (0.63, & 0.83, & 0.96)\end{bmatrix}$ $\tilde{G} = \begin{array}{cccc} & X_1 & X_2 & X_3 \\ S_1 & (5.92,\ 8.07,\ 9.54) & (5.33,\ 7.49,\ 9.25) & (6.17,\ 8.18,\ 9.58) \\ S_2 & (5.08,\ 7.39,\ 9.29) & (4.50,\ 7.92,\ 9.04) & (4.33,\ 6.81,\ 9.00) \\ S_3 & (4.83,\ 7.16,\ 9.21) & (4.33,\ 6.81,\ 9.00) & (5.00,\ 7.27,\ 9.25) \\ S_4 & (5.00,\ 7.26,\ 9.17) & (4.92,\ 7.26,\ 9.21) & (5.67,\ 7.89,\ 9.46) \end{array}$ $\tilde{R} = \begin{bmatrix}R_1\\ R_2\\ R_3\\ R_4\end{bmatrix} = \begin{bmatrix}(10.66, & 19.38, & 27.19)\\ (8.51, & 17.23, & 26.19)\\ (8.67, & 17.34, & 26.31)\\ (9.55, & 18.28, & 26.68)\end{bmatrix}$	$\bar{x}(\tilde{R}) = \begin{array}{c} S_1\\ S_2\\ S_3\\ S_4\end{array}\begin{bmatrix}19.08\\ 17.31\\ 17.44\\ 18.17\end{bmatrix}$

Table 8: Ranking Order by Incorporating Fuzzy Numbers based on Different Groups of Respondents

Criterion / Group	Background of Supplier X_1	Product Performance X_2	Supplier Performance X_3	Final Ranking
G_1	$S_1 \succ S_2 \succ S_4 \succ S_3$	$S_1 \succ S_4 \succ S_2 \succ S_3$	$S_1 \succ S_4 \succ S_3 \succ S_2$	$S_1 \succ S_4 \succ S_3 \succ S_2$
G_2	$S_1 \succ S_2 \succ S_3 \succ S_4$	$S_1 \succ S_4 \succ S_2 \succ S_3$	$S_1 \succ S_4 \succ S_3 \succ S_2$	$S_1 \succ S_4 \succ S_3 \succ S_2$
G_3	$S_1 \succ S_2 \succ S_4 \succ S_3$	$S_1 \succ S_4 \succ S_2 \succ S_3$	$S_1 \succ S_4 \succ S_3 \succ S_2$	$S_1 \succ S_4 \succ S_3 \succ S_2$

Based on Table 8, the final ranking results are the same for all groups which produce $S_1 \succ S_4 \succ S_2 \succ S_3$. For criterion X_2 (product performance), the ranking order is obtained as $S_1 \succ S_4 \succ S_2 \succ S_3$. While for criterion X_3 (supplier performance), the ranking order yields $S_1 \succ S_4 \succ S_3 \succ S_2$. However, the ranking result varies for criterion X_1 (background of supplier), particularly for fuzzy numbers based on G_2, that produces the ranking result as $S_1 \succ S_2 \succ S_3 \succ S_4$, and this is different with the other two groups with ranking order $S_1 \succ S_2 \succ S_4 \succ S_3$.

The largest difference in spread for importance weights and performance ratings of X_1 occur mostly in group G_2. The spread of fuzzy numbers is one of the factors that can affect the ranking results (Wang et al., 2009), thus leading to the ranking variation in criterion X_1. This indicates that different outcomes may be obtained when using fuzzy numbers based on different groups of respondents. Although the final ranking is the same, there is an indication that the ranking result for main criteria can be affected. This could be significant to decision makers who are interested in focusing on certain aspects of the evaluation.

6 Conclusion

Supplier selection depends on human evaluation which is subjective and vague in nature. Thus, fuzzy approach is deemed appropriate to represent these measurements rather than using real or crisp values. Evidence from previous literature suggested that fixed triangular or trapezoidal fuzzy numbers were used corresponding with fuzzy linguistic terms. Hence, this study proposed to develop triangular fuzzy numbers based on respondents' opinions. The developed fuzzy numbers were then adopted into an existing fuzzy evaluation method in IT supplier selection problem. Comparison was made between the ranking results using fuzzy numbers based on different groups of respondents. The results showed that there is a difference in adopting different sets of fuzzy numbers. Therefore, this indicates the importance of considering fuzzy numbers based on respondents during the decision making process, as it may affect the final evaluation. It is suggested that fuzzy numbers should be developed based on respondents, rather than assuming fixed values as practised in previous studies.

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