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Supplier Selection Decision Based on Fuzzy Delphi Method with Z-Number Valuation

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ABSTRACT
Supplier selection problem is interesting many researchers. For years, the problem has drawn contentious debates among the practitioners and decision makers (DMs) mostly due to the uncertainty of input data involved and incomplete information. The study proposes Fuzzy Delphi Method (FDM) to minimize the problem. It focuses on the ways FDM can deal efficiently with incomplete information and uncertain data related to the supplier selection using Z-number valuation. A synthesis process was carried out to construct the decision matrix and derive the fuzzy average before applying the defuzzification process. A related illustrative example was employed to justify the beneficial and reliability of FDM. Based on the result of the calculation, it was found that by using Z-number in FDM, it had provided clear advantage in terms of evaluation approach due to its structure having the so-called restriction (constraint) and reliability (certainty) for component A and B, respectively. While component A described the real situation by linguistic measures with efficiency, component B provided the certainty of A consistently throughout the evaluation process. Thus, the uncertain data and incomplete information, which this study evaluated, were handled more effectively while the decision-making process was made easier.

Keywords: Decision Making; Fuzzy Delphi Method; Supplier Selection; Triangular Fuzzy Number; Z-Number

INTRODUCTION

Supplier selection is a decision-making process with the purpose of defining an order of preference among potential suppliers based on a set of evaluation criteria. This is the most important activity in purchasing to optimize the quality, delivery and cost of the services and manufactured products. It outlines four steps involved in supplier selection. They are problem definition, formulation of criteria, qualification and final choice (Lima-Junior et.al, 2016).

The supplier selection process appears to be the most significant variable as it helps in achieving high quality products and customer satisfaction. Due to the presence of various criteria, which should be considered in any decision-making process of supplier selection, a technique that allows process automation and brings the efficiency and rationality to the decision-making process is needed (González et al.,2004). A research done lists 23 criteria for supplier selection according to their importance (Dickson, 1966 and Simic et al., 2017).

Various methods have been applied to supplier selection problem. They can be grouped into two major approaches: (a) individual approach and (b) integrated approach. Mathematics, Statistical Model and Artificial Intelligence are grouped in the individual approach while fuzzy set theory (FST), Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) are grouped in the integrated approach (they are integrated with other methods). Many researchers have dealt with integrated fuzzy approach, such as fuzzy AHP, fuzzy ANP, fuzzy TOPSIS, fuzzy VIKOR and fuzzy DEMATEL and many others.

The fuzzy DEMATEL method used to evaluate supplier performance to find the key factor criteria and provides a novel approach of decision-making information in supply chain supplier selection (Chang et al., 2011). Also provides a model using fuzzy DEMATEL method to examine the relationship and the impact of indices related to the selection of suppliers (Mirmousa et al., 2016). The study proposed uses the fuzzy ANP (FANP) approach to address the multiple criteria and the inherent uncertainty in supplier selection. FANP is then integrated with fuzzy multi-objective linear programming (FMOLP) in selecting the best suppliers (Lin, 2012).

FANP used to determine the importance level of the elements effective in resilient supplier selection. Using these elements, the resiliency level of the suppliers of the company is specified through the grey VIKOR method (Parkouhi et al., 2017). The new fuzzy hybrid approaches for the strategic supplier selection problem presented. The approach combines the fuzzy consensus-based possibility measure and fuzzy TOPSIS method (Igoulalene et al., 2015). A comparison between the performance of three fuzzy multi-criteria decision making (MCDM) methods, including fuzzy TOPSIS, fuzzy VIKOR and fuzzy GRA (Banaeian et al., 2018).

Many authors recommend using FST to model uncertainty in selection decision problems. However, most of the existing methods only focus on the single method and in combination with other ordinary fuzzy methods. Therefore, this study seeks to apply FDM with the Z-number valuation approach to deal with the ambiguity of the criteria and derive more confidence decision, particularly in supplier selection problems. This paper begins with the introduction and brief of literature reviews, followed by discussion of the methodology i.e. definitions and the proposed methodology of decision-making using the integrated FDM and Z-number valuation, results and discussion of an illustrative example related to supplier selection and lastly, the conclusion.

METHDOLOGY

Preliminaries

A brief of fuzzy set theory, *Triangular Fuzzy Number* (TFN), Z-number definition and FDM concept will be reviewed for reference purposes.

Definition 1:

A fuzzy set $\tilde{A}$ in a universe of discourse ***X*** is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element *x* in ***X*** that takes the value in the real number in the interval [0,1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of *x* in $\tilde{A}$.

Definition 2:

A TFN $\tilde{A}$ can be written as (1), and can be defined by a triplet (a_1, a_2, a_3). The membership function $\mu_{\tilde{A}}(x)$ is defined as:

$$\mu_{\tilde{A}}(x)=\begin{cases} 0, & x<a_1, \\ \dfrac{x-a_1}{a_2-a_1}, & a_1 \le x \le a_2, \\ \dfrac{x-a_3}{a_2-a_3}, & a_2 < x \le a_3, \\ 0, & x>a_3 \end{cases} \tag{1}$$

Definition 3:
A Z-number is an order paired of fuzzy numbers denote as $Z = (A, B)$, with the first component *A*, a restriction on the values, is a real-valued uncertain variable. The second component *B* is measure of reliability or certainty for the first component (*A*) (Zadeh, 2011).

Based on definition 3 above, a Z-number concept is intended to provide basic calculations with numbers that are not quite reliable. It also can be used to represent information about the variable uncertainty of the type where *A* represents the value of variable *X*, and the second component, *B* represents the idea of certainty or probability such as the concept of certainty, reliability, strength of trust, level of confidence and possibility. For example, the evaluation can be given such as; (*quality of service is good, very sure*), (*price of fuel RON 95 increase to RM2/liter for incoming week, sure*), etc. It can be clearly seen that the Z-number approach gives a compound benefit in terms of how the attributes are evaluated more precisely and certainty along the decision process. Therefore, this advantage has been utilized by integrating them into the decision matrix.

There are several methods available in recent decades to solve the decision-making problem. One of the simple methods that can be employed and able to deal efficiently the uncertain data is FDM. Dalkey and Helmer first developed the Delphi Method (Dalkey et al., 1963). It was later extended to FDM, which was introduced by Kaufman and Gupta (Kaufman et al., 1988). The main task of FDM is to structure the decision matrix based on the nature of the input datasets. The method has been quite successful in various applications such as personal presentation content (Kardaras et al., 2013), road safety performance indicators (Ma et al., 2011), prediction of dry bulk freights (Duru et al., 2012), etc. Usually, the evaluation involves uncertain and imprecise datasets, where experts' opinions or DMs are often subjective and solely based on their competencies. The TFNs are usually used because they can represent the information with more flexible and precision. The TFNs are based on seven linguistic variables and five degree of certainty is prior defined and given in Table 1 and Table 2, respectively.

Table 1: Seven Linguistic Variables in TFNs Form

Linguistic Variables	TFNs
Very High (*VH*)	(0.8,0.9,1.0)
High (*H*)	(0.7,0.8,0.9)
Medium High (*MH*)	(0.6,0.7,0.8)
Medium (*M*)	(0.3,0.5,0.7)
Medium Low (*ML*)	(0.2,0.3,0.4)
Low (*L*)	(0.1,0.2,0.3)
Very Low (*VL*)	(0,0.1,0.2)

Table 2: Five Types of Degree of Certainty

Degree of Certainty	TFNs
Very Sure (*VS*)	(0.9,1.0,1.0)
Sure (*S*)	(0.5,0.7,0.9)
Neutral (*N*)	(0.3,0.5,0.7)
Not Sure (*NS*)	(0.1,0.3,0.5)
Very Unsure (*VU*)	(0,0, 0.1)
Respective Degree of Certainty	The range of value in TFNs

Proposed Methodology
In this study, the proposed approach is based on the integrating FDM and Z-number valuation in decision matrix. The FDM method was initially verified to determine the compatibility with the Z-number (Zadeh, 2011). A modification was proposed by inserting each entry in decision matrix with Z-number valuation approach. The method involved five steps, as follow.

Step 1: Categorize and Identify the Nature of Input Datasets
In the first step, the input datasets were categorized based on the nature of the data. Then, the identification approach was applied to ensure the input data suit the measure tools.

Step 2: Establish the Decision Matrix Integrate With the Z-Number Valuation
In this step, an integrated Z-number and linguistic variables (i.e. TFNs) were synthesized comprehensively to establish a decision matrix, $\widetilde{D}$ given as:

$$\widetilde{D} = \begin{bmatrix} \overline{A}_{11} & \cdots & \overline{A}_{1n} \\ \vdots & \ddots & \vdots \\ \overline{A}_{m1} & \cdots & \overline{A}_{mn} \end{bmatrix}$$

where $\overline{A}_{m\times n} = \left(a_1, a_2, a_3; \text{degree of certainty}\right)_{m\times n}$

Step 3: Calculate the Fuzzy Average
Calculate the fuzzy average to derive an overall of aggregated scores obtained from previous step (i.e., Step 2).

Step 4: Defuzzification Process
The defuzzification process then be calculated based on Chen method (Chen, 1996) with modification to suit the Z-number structure given as:

$$\widetilde{\widetilde{F}}_A = \left\{ \frac{1}{4}\left[\left(a_1 + 2a_2 + a_3\right); \left(b_1 + 2b_2 + b_3\right)\right] \right\} \quad (2)$$

where a_1, a_2, a_3 and b_1, b_2, b_3 are left, middle and right foot values of TFNs, respectively.
For instance, if the attribute evaluated as (*Medium high* (*MH)*, *Very sure*), where *MH* is a component *A* using TFNs and *Very sure* is the degree of certainty of *MH*, then the defuzzification can easily be calculated as:

$$\widetilde{\widetilde{F}} = \left(\frac{1}{4}\left[\left(0.6 + 2(0.7) + 0.8\right); (0.9 + 2(0.9) + 1.0)\right] \right) = (0.7; 0.925 \approx \textit{Very sure}) .$$

Step 5: **Ranking and the Results**
Finally, the ranking process of the alternative (S_n) was carried out by descending order. If the results given as $S_1 \supset S_2 \supset S_3 \supset ... \supset S_n$, then S_1 is the best option, followed by S_2 and S_3 and lastly was S_n where symbol '$\supset$' is more preferred than or better than. The above entire procedure is visualized in Figure 1.

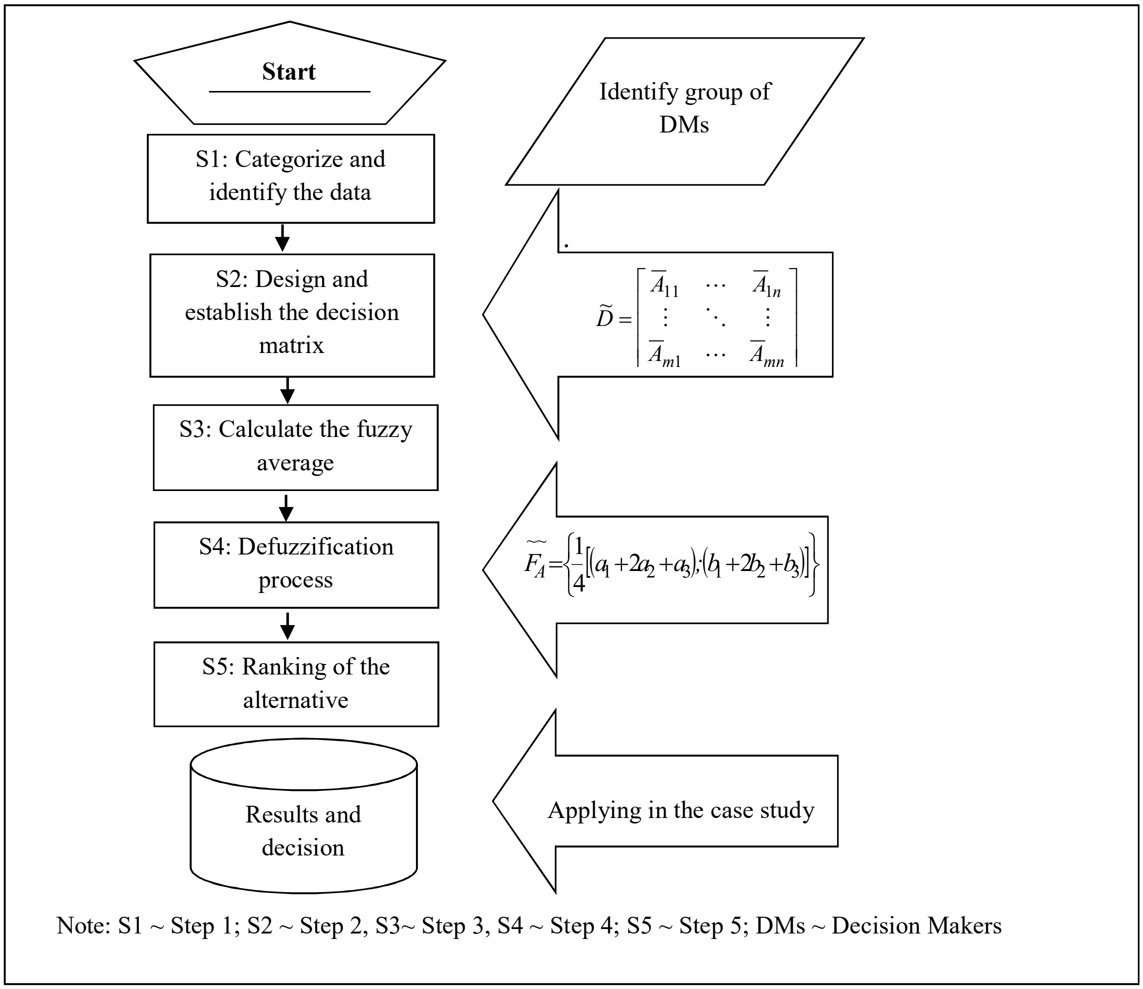

Figure 1: Systematic Procedure of the Proposed Method

RESULT AND DISCUSSIONS

For illustrative example, a study of supplier selection was adopted to justify the beneficial and reliability of the proposed method (Chan et al., 2007). The problem consists of four alternatives $(S_i; i=1,2,3,4)$ with five criteria $(C_i; i=1,2,3,4,5)$. Here, the following 5 steps have been utilized as proposed from the previous section.

Step 1: Categorize and Identify the Nature of Input Datasets

Based on the nature of the problem and thoroughly investigated, the main goal is to choose the best supplier based on five identified criteria from four alternatives available.

Step 2: Establish the Decision Matrix Integrate With the Z-Number Valuation
The decision matrix, $\widetilde{D}$ given as shown in Table 3 and Table 4 below.

Table 3: Decision Matrix Based on Z-number Valuation Approach

	C_1	C_2	C_3	C_4	C_5
S_1	(VH; *S*)	(L; *S*)	(VH; *N*)	(ML; *N*)	(H; *NS*)
S_2	(M; *VS*)	(M; *S*)	(MH; *S*)	(MH; *VS*)	(ML; *S*)
S_3	(ML; *VS*)	(M; *N*)	(ML; *VS*)	(ML; *N*)	(L; *N*)
S_4	(H; *NS*)	(MH; *NS*)	(H; *N*)	(MH; *S*)	(M; *S*)

Table 4: Decision Matrix in TFNs

	C_1	C_2	C_3	C_4	C_5
S_1	(0.8,0.9,1; *0.5,0.7,0.9*)	(0.1,0.2,0.3; *0.5,0.7,0.9*)	(0.8,0.9,1; *0.3,0.5,0.7*)	(0.2,0.3,0.4; *0.3,0.5,0.7*)	(0.7,0.8,0.9; *0.1,0.3,0.5*)
S_2	(0.3,0.5,0.7; *0.9,1,1*)	(0.3,0.5,0.7; *0.5,0.7,0.9*)	(0.6,0.7,0.8; *0.5,0.7,0.9*)	(0.6,0.7,0.8; *0.9,1,1*)	(0.2,0.3,0.4; *0.5,0.7,0.9*)
S_3	(0.2,0.3,0.4; *0.9,1,1*)	(0.3,0.5,0.7; *0.3,0.5,0.7*)	(0.2,0.3,0.4; *0.9,1,1*)	(0.2,0.3,0.4; *0.3,0.5,0.7*)	(0.1,0.2,0.3; *0.3,0.5,0.7*)
S_4	(0.7,0.8,0.9; *0.1,0.3,0.5*)	(0.6,0.7,0.8; *0.1,0.3,0.5*)	(0.7,0.8,0.9; *0.3,0.5,0.7*)	(0.6,0.7,0.8; *0.5,0.7,0.9*)	(0.3,0.5,0.7; *0.5,0.7,0.9*)

For simplicity of the calculation, each of the DMs has an equal of weights and the total must be satisfied $\sum_{i=0}^{n} W_i = 1$.

Step 3: Calculate the Fuzzy Average
An overall of aggregated scores can be obtained after fuzzy average process given as shown in Table 5 below.

Table 5: Fuzzy Average of Aggregated Score

	Aggregated Score
S_1	(0.52,0.62,0.72; *0.34,0.54,0.74*)
S_2	(0.40,0.54,0.68; *0.66,0.82,0.94*)
S_3	(0.20,0.32,0.44; *0.54,0.70,0.82*)
S_4	(0.58,0.70,0.82; *0.30,0.50,0.70*)

Step 4: Defuzzification Process
The defuzzification process will take place to convert back to the crisp values. The overall performance scores of criteria can be derived by (2) as shown in Table 6 below.

Table 6: Overall Performance Score After Defuzzification Process

	S_1	S_2	S_3	S_4
Overall performance score	(0.62;*0.54* $\approx$ *Neutral*)	(0.54;*0.81* $\approx$ *Sure*)	(0.37;*0.69* $\approx$ *Sure*)	(0.70;*0.50* $\approx$ *Neutral*)

Step 5: **Ranking and the Results**

Apparently, the best alternative is supplier fourth (S_4) with degree of certainty is *neutra*l, followed by supplier 1 (S_1) also with *neutral* of degree of certainty, and alternative 3 and 4 are both second supplier (S_2) and third supplier (S_3) with same level of certainty (i.e. *sure*), respectively.

Table 7: Ranking of the Alternatives

	Overall score	Order	Ranking
S_1	(0.62; *0.54* ≈ *Neutral*)	2	S_4(*Neutral*) ⊃ S_1 (*Neutral*) ⊃ S_2 (*Sure*) ⊃ S_3 (*Sure*)
S_2	(0.54; *0.81* ≈ *Sure*)	3	
S_3	(0.37; *0.69* ≈ *Sure*)	4	
S_4	(0.70; *0.50* ≈ *Neutral*)	1	

Note: The symbol "⊃" means more preferred than or better than.

CONCLUSION

This article discusses how FDM integrated with the Z-number valuation can minimize the ambiguity of the input data specifically in supplier selection decision process. Since the nature of supplier selection usually involves the uncertainty and lack of information, the proposed approach is presented as an alternative way to deal with such. The FDM was employed by integrating with the Z-number valuation in the decision matrix. Also, the proposed approach offers a great advantage even though in the case where the overall score is equal, the decision-makers (DMs) still can easily distinguish the best alternative by choosing the highest degree of certainty. Hence, not only the proposed method can deal with the uncertain data and incomplete information more effectively, it also makes the decision-making process to be easier and thereby gives decision makers more confidence to make decision.

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