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A Fuzzy-Based Approach to Selecting Successful Contractor for Public Procurement

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Abstract

Public procurement contracts are awarded by tendering procedures to the most advantageous candidates. In this paper we propose multiple criteria decision making method for selecting successful contractor. The proposed formalism involves rating and ranking of the alternatives. Decision makers express the ratings of the alternatives with respect to various criteria using linguistic variables, represented with triangular fuzzy numbers. Fuzzy preference matrix is constructed by calculating the difference of evaluation values for each pair of alternatives. We created an application for selecting successful contractor based on the proposed elicitation and ranking techniques in a fuzzy environment.

Keywords: *Fuzzy decision making, linguistic variables, ranking of the alternatives.*

Introduction

Public procurement contracts are awarded by public call for tenders. By the tendering procedure the public entity selects the successful candidate on the basis of objective criteria, made known to the candidates in advance. While price has been traditionally considered as the only important factor, it has been agreed upon that evaluation process has to include other factors [6], such as quality, financial standing of the companies, date of delivery, mode of payment, guarantee, etc. The selection of an appropriate candidate for public procurement on the basis of more factors is a multi criteria decision making problem [4].

In many situations the values for the criteria are imprecisely defined for the decision-makers. The desired value and importance weight of criteria are usually expressed in linguistic terms, such as 'high', 'fair', 'low', etc. It is not easy to precisely quantify the rating of each candidate. This fuzziness motivated us to propose a decision model that includes processes for measuring and combining criteria and alternatives in fuzzy environment.

Bellman and Zadeh define the process of decision making in fuzzy environment as 'a decision process in which the goals and/or the constraints, but not necessarily the system under control, are fuzzy in nature. This means that the goals and/or the constraints constitute classes of alternatives whose boundaries are not sharply defined'[1]. Fuzzy set theory is based on the idea that the key elements in human thinking are not numbers, but linguistic terms or labels of fuzzy sets [7].

We use fuzzy multi criteria decision making to combine linguistic assessments and weights during evaluation of the candidates and selecting the best alternative. The decision criteria are divided into quantitative and qualitative in our method. The importance weights of the criteria and the ratings of the alternatives are expressed as linguistic variables, described by triangular fuzzy numbers. We aggregate the ratings and calculate the final evaluation values for the candidates. After creating a preference relation which indicates the over degree of preference for each pair of candidates we create a preference relation matrix and use a ranking procedure to determine the ranking order of the alternatives.

Next section introduces basic notions of fuzzy multi criteria decision making. Then we define a fuzzy preference relation and propose a ranking procedure for the alternatives. The approach is illustrated by an example where we infer the appropriate candidate for public procurement. The paper ends with a brief discussion and conclusions.

Theoretical Framework for Fuzzy Multi Criteria Decision Making

In this section, we describe our approach to the problem of selecting appropriate candidate for public procurement based on the concepts of fuzzy set theory and multiple-criteria decision making. The decision model includes measuring and combining criteria and alternatives for evaluation in fuzzy environment. The important aspect of the contractor selection problem is to provide mechanism for handling imprecise and vague information. For that purpose the importance weights of the criteria and the ratings of the alternatives with respect to various criteria are considered as linguistic variables.

The linguistic variables used in this paper are represented as triangular fuzzy numbers – given in Tables 1 and 2.

Table 1. Linguistic variables for the importance weight of criterions

Very unimportant (VU)	(0, 0, 0.1)
Unimportant (U)	(0, 0.1, 0.3)
Medium unimportant (MU)	(0.1, 0.3, 0.5)
More or less important (MLI)	(0.3, 0.5, 0.7)
Medium important (MI)	(0.5, 0.7, 0.9)
Important (I)	(0.7, 0.9, 1.0)
Very important (VI)	(0.9, 1.0, 1.0)

Table 2. Linguistic variables for the ratings

Very low (VL)	(0, 0, 1)
Low (L)	(0, 1, 3)
Medium low (ML)	(1, 3, 5)
Medium (M)	(3, 5, 7)
Medium high (MH)	(5, 7, 9)
High (H)	(7, 9, 10)
Very high (VH)	(9, 10, 10)

Fuzzy operation addition is defined as $(\underline{A}+\underline{B})(z) = \sup_{z=x+y} \min[A(x), B(y)]$, where $\underline{A},\underline{B}$ are fuzzy numbers and min is operation between membership functions.

If we assume that there are K decision makers, the importance of the criteria and the ratings of alternatives are calculated as:

$$\underline{x}_{ij} = [\underline{x}_{ij}^{1}(+)\underline{x}_{ij}^{2}(+)\ldots(+)\underline{x}_{ij}^{K}]/K, \quad (1)$$
$$\underline{w}_{j} = [\underline{w}_{j}^{1}(+)\underline{w}_{j}^{2}(+)\ldots(+)\underline{w}_{j}^{K}]/K, \quad (2)$$

where $\underline{x}_{ij}^{K}$ and $\underline{w}_{j}^{K}$ are the rating and the importance weight for the j-th criterion of the *K-th* decision maker.

Let $A_1, \ldots, A_m$ be possible alternatives (number of candidates) and $C_1, \ldots, C_n$ be criteria with which alternative performances are measured. As stated above, a fuzzy multi-criteria decision-making method for the contractor selection problem can be concisely expressed in matrix format as:

$$\underline{D} = \begin{bmatrix} \underline{x}_{11} & \underline{x}_{12} & \cdots & \underline{x}_{1n} \\ \underline{x}_{21} & \underline{x}_{22} & \cdots & \underline{x}_{2n} \\ \vdots & \vdots & \cdots & \\ \underline{x}_{m1} & \underline{x}_{m2} & \cdots & \underline{x}_{mn} \end{bmatrix} \quad \underline{W}=[\underline{w}_1, \underline{w}_2, \ldots, \underline{w}_n]$$

where $\underline{x}_{ij}$, $\forall i,j$ is the fuzzy rating of alternative A_i $(i=1, 2, \ldots,m)$ with respect to criterion C_j and $\underline{w}_j$ $(j=1, 2, \ldots,n)$ is the weight of criterion C_j. These fuzzy ratings and the weights of each criterion are linguistic variables which can be described by triangular fuzzy numbers, $\underline{x}_{ij}=(a_{ij}, b_{ij}, c_{ij})$ and $\underline{w}_j=(w_{j1}, w_{j2}, w_{j3})$.

Therefore, we can obtain the normalized fuzzy decision matrix denoted by $\underline{\boldsymbol{R}}$ as:

$$\underline{R}=[\underline{r}_{ij}]_{m \times n}$$
$$\underline{r}_{ij} = (a_{ij}/c_j^{*}, b_{ij}/c_j^{*}, c_{ij}/c_j^{*}), j \in B$$
$$\underline{r}_{ij} = (a_j/c_{ij}, a_j/b_{ij}, a_j/a_{ij}), j \in C \quad (3)$$
$$c_j^{*}=\max_i c_{ij}, \text{ if } j \in B, \quad a_j=\min_i a_{ij}, \text{ if } j \in C$$

where B and C are the set of benefit criteria and cost criteria, respectively.

The normalization method mentioned above is to preserve the property that the ranges of normalized fuzzy numbers belong to [0, 1].

Considering the different importance of each criterion, we calculate the final fuzzy evaluation value of each alternative as:

$$\underline{P}_i = \sum_{j=1}^{n} \underline{r}_{ij}(\cdot)\underline{w}_j \text{ , } i=1, 2, ..., m \qquad (4)$$

where $\underline{P}_i$ is the final fuzzy evaluation value of alternative A_i.

After the calculation of the final fuzzy evaluation value of each alternative, the pairwise comparison of the preference relationship between the alternatives A_i and A_j can be established as stated in the following section.

The α-cut of a fuzzy number $\underline{n}$ is defined as $\underline{n}^{\alpha} = \{x_i: \mu_n(x_i) \geq \alpha, x_i \in X\}$; where $\alpha \in [0; 1]$.

To define a preference relation of alternative A_i over alternative A_j we do not directly compare the membership function of $\underline{P}_i$ and $\underline{P}_j$. Instead, we use the membership function of $\underline{P}_i(-)\underline{P}_j$ to indicate the preferability of alternative A_i over alternative A_j and then compare $\underline{P}_i(-)\underline{P}_j$ with zero. The difference $\underline{P}_i(-)\underline{P}_j$ here is the fuzzy difference between two fuzzy numbers. Using the fuzzy number, $\underline{P}_i(-)\underline{P}_j$, one can compare the differences between $\underline{P}_i$ and $\underline{P}_j$ for all possibly occurring combinations of $\underline{P}_i$ and $\underline{P}_j$.

Here, the final fuzzy evaluation values $\underline{P}_i$ and $\underline{P}_j$ are triangular fuzzy numbers. The difference between $\underline{P}_i$ and $\underline{P}_j$ is also a triangular fuzzy number and can be calculated as:

$$\underline{Z}_{ij} = \underline{P}_i(-)\underline{P}_j \qquad (5)$$

$$\underline{Z}^{\alpha}_{ij} = [z^{\alpha}_{ijl}, z^{\alpha}_{iju}] \qquad (6)$$

$$\underline{P}_i^{\alpha} = [p^{\alpha}_{il}, p^{\alpha}_{iu}], \ \underline{P}_j^{\alpha} = [p^{\alpha}_{jl}, p^{\alpha}_{ju}],$$

$$z^{\alpha}_{ijl} = p^{\alpha}_{il} - p^{\alpha}_{ju}, \quad z^{\alpha}_{iju} = p^{\alpha}_{iu} - p^{\alpha}_{jl}$$

If $z^{\alpha}_{ijl}>0$ for $\alpha \in [0, 1]$, then alternative A_i is absolutely preferred to A_j. If $z^{\alpha}_{ijl}<0$ for $\alpha \in [0, 1]$, then alternative A_i is not absolutely preferred to A_j. If $z^{\alpha}_{ijl}<0$ and $z^{\alpha}_{ijl}>0$ for some α values, we define e_{ij} as a fuzzy preference relation between alternatives A_i and A_j to represent the degree of preference of alternative A_i over alternative A_j. The e_{ij} is defined as:

$$e_{ij} = S_1/S, \ S>0 \qquad (7)$$

$$S_1 = \int_{x>0} \mu_{Zij}(x)dx, \ S_2 = \int_{x<0} \mu_{Zij}(x)dx,$$

$$S = S_1 + S_2$$

The value of e_{ij} is the degree of preference of alternative A_i over alternative A_j and $\mu_{Zij}(x)$ is the membership function of $\underline{P}_i(-)\underline{P}_j$.

Intuitively, S_1 indicates the portion where alternative A_i is preferred to alternative A_j in the most favorable situation. The e_{ij} indicates the over degree of preference of alternative A_i over alternative A_j. An illustration of calculating e_{ij} is shown on Fig.1. Therefore, $e_{ij}>0.5$ indicates the alternative A_i is preferred to alternative A_j. If $e_{ij}=0.5$ then there is no difference between alternatives A_i and A_j. If $e_{ij}<0.5$ then alternative A_j is preferred to alternative A_i.

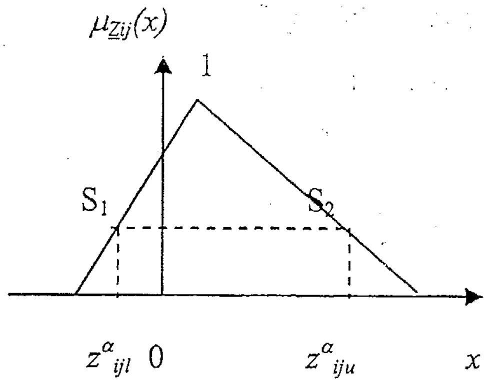

Fig. 1. An illustration of calculating e_{ij}

Using the fuzzy preference relation, we can construct a fuzzy preference relation matrix as:

$$\boldsymbol{E} = [e_{ij}]_{m \times m} \tag{8}$$

The fuzzy preference relation matrix represents the degree of preference of each pair alternatives. According to the fuzzy preference relation matrix $\boldsymbol{E}$, the fuzzy strict preference relation matrix can be defined as:

$$\boldsymbol{E}^S = [e^S_{ij}]_{m \times m} \tag{9}$$

$$e^S_{ij} = \begin{cases} e_{ij} - e_{ji}, when \ e_{ij} \geq e_{ji} \\ 0, \quad otherwise \end{cases} \tag{10}$$

The value of e^S_{ij} is a degree of strict dominance of alternative A_i over alternative A_j. Then, the non-dominated degree of each alternative A_i $(i=1, 2, \ldots, m)$, can be determined by using the fuzzy strict preference relation matrix as:

$$\mu^{ND}(A_i) = min_{j \in \Omega} \{1 - e^S_{ji}\} = 1 - max_{j \in \Omega} e^S_{ji} \tag{11}$$

where $\mu^{ND}(A_i)$ is the non-dominated degree of each alternative A_i and Ω is a set of alternatives.

A large value of $\mu^{ND}(A_i)$ indicates that the alternative A_i has a higher non-dominated degree than others. Therefore, we can use the $\mu^{ND}(A_i)$ values to rank a set of alternatives. The ranking procedure is described as follows:

(i) Set K=0 and $\Omega=\{A_1, \ldots, A_m\}$.

(ii) Select the alternatives which have the highest non-dominated degree, say A_h, $\mu^{ND}(A_h) = max_i\{\mu^{ND}(A_i)\}$. Set the ranking for A_h as $r(A_h) = K+1$.

(iii) Delete the alternatives A_h from Ω, i.e. $\Omega=\Omega \backslash A_h$. The corresponding row and column of A_h are deleted from the fuzzy strict preference relation matrix.

(iv) Recalculate the non-dominated degree for each alternative A_i, $A_i \in \Omega$. If $\Omega=\varnothing$, then stop. Otherwise, set $K=K+1$, and return to step (ii).

Experimental Results

In this section we illustrate the presented method that enables selection of an appropriate contractor for public procurement. The experimental setting includes three decision-makers D_1, D_2 and D_3, three alternatives or candidates, and five decision criteria. After preliminary screening, three candidates A_1, A_2 and A_3 remain for further evaluation. The public entity considers following five criteria for selecting the most suitable candidate:

(1) price (C_1)
(2) solvency of the company (C_2)
(3) date of delivery (C_3)
(4) mode of payment (C_4)
(5) guarantee (C_5)

The benefit and cost criteria sets are $B=\{C_2, C_3, C_4, C_5\}$ and $C=\{C_1\}$, respectively.

The proposed method is applied to solve this problem. The computational procedure is summarized as follows:

Step 1: Linguistic variables (from Table 1) are used to assess the importance of the criteria and they are represented in Table 3. The importance of the criteria is established in advance. The calculated fuzzy weights for criteria are shown in Table 4.

Table 3. The importance weight of the criteria

C_1	VI
C_2	I
C_3	VI
C_4	MI
C_5	MLI

Table 4. The fuzzy weights of the criteria

	C_1	C_2	C_3	C_4	C_5
Weight	(0.9, 1.0, 1.0)	(0.7, 0.9, 1.0)	(0.9, 1.0, 1.0)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)

Step 2: The decision-makers use the linguistic variables (shown in Table 2) to evaluate the ratings of alternatives with respect to each criterion given in Table 5.

Step 3: According to Table 4, the fuzzy decision matrix is constructed as shown in Table 6.

Step 4: Fuzzy normalized decision matrix is shown in Table 7.

Step 5: The final fuzzy evaluation values of three alternatives are calculated as:

$$\underline{P_1}=(1.98, 3.18, 4.27)$$
$$\underline{P_2}=(1.88, 2.94, 3.85)$$
$$\underline{P_3}=(1.98, 3.01, 3.87)$$

Step 6: The differences between each two final fuzzy evaluation values are calculated as:

$$\underline{P_1}\,(-)\,\underline{P_2}=(-1.87, 0.24, 2.39)$$

$$\underline{P}_1 (-) \underline{P}_3 = (-1.89, 0.17, 2.29)$$
$$\underline{P}_2 (-) \underline{P}_3 = (-1.99, -0.07, 1.87)$$

Step 7: Fuzzy preference relation matrix is calculated as:

$$E = \begin{bmatrix} 0.50 & 0.61 & 0.59 \\ 0.39 & 0.50 & 0.47 \\ 0.41 & 0.53 & 0.50 \end{bmatrix}$$

Step 8: Fuzzy strict preference relation matrix is shown below:

$$E^S = \begin{bmatrix} 0 & 0.22 & 0.18 \\ 0 & 0 & 0 \\ 0 & 0.06 & 0 \end{bmatrix}$$

Step 9: The non-dominated degree of each alternative A_i (i=1, 2, 3) is computed as:
$\mu^{ND}(A_1) = 1.00$; $\mu^{ND}(A_2) = 0.78$; $\mu^{ND}(A_3) = 0.82$;

Table 5. The ratings of the three candidates by decision-makers under all criteria

Criteria	Candid.	D_1	D_2	D_3
	A_1	Ml	MH	H
C_1	A_2	H	H	H
	A_3	VH	H	VH
	A_1	MH	M	H
C_2	A_2	M	ML	MH
	A_3	H	H	H
	A_1	M	VH	M
C_3	A_2	VH	VH	VH
	A_3	MH	H	VH
	A_1	VH	H	VH
C_4	A_2	H	H	M
	A_3	H	VH	M
	A_1	VH	H	VH
C_5	A_2	H	VH	M
	A_3	ML	M	MH

Table 6. The fuzzy decision matrix

C_1	C_2	C_3	C_4	C_5
A_1 (5,7,8.7)	(5,7,8.7)	(5,6.7,8)	(8.3,9.7,10)	(8.3,9.7,10)
A_2 (7,9,10)	(3,5,7)	(9,10,10)	(4.3,7.7,9)	(6.3,8,9)
A_3 (8.3,9.7.10)	(7, 9,10)	(7,8.7,9.7)	(6.3,8,9)	(3,5,7)

Table 7. The fuzzy normalized decision matrix

	C_1	C_2	C_3	C_4	C_5
A_1	(0.57,0.71,1)	(0.5,0.7,0.87)	(0.5,0.67,0.8)	(0.83,0.97,1)	(0.83,0.97,1)
A_2	(0.5,0.55,0.71)	(0.3,0.5,0.7)	(0.9, 1, 1)	(0.43,0.77,0.9)	(0.63,0.8,0.9
A_3	(0.5,0.52,0.6)	(0.7,0.9,1)	(0.7,0.87,0.97)	(0.63,0.8,0.9)	(0.3,0.5,0.7)

Step 10: The alternative A_1 has the highest non-dominated degree and set $r(A_1)=1$.

Step 11: Delete the alternative A_1 from the fuzzy strict preference relation matrix.

Step 12: After deleting the alternative A_1, the new fuzzy strict preference relation matrix is:

$$E^S = \begin{array}{c} \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{cc} A_2 & A_3 \end{array} \\ \begin{bmatrix} 0 & 0 \\ 0.06 & 0 \end{bmatrix} \end{array}$$

The non-dominated degree of alternatives A_3 and A_2 are 1.0 and 0.94 respectively. Therefore, $r(A_3)=2$ and $r(A_2)=3$. The ranking order of the three alternatives is $\{A_1\}>\{A_3\}>\{A_2\}$. Therefore, the candidate A_1 is the best alternative. We can see that the proposed method not only allows decision-makers to determine the ranking order of alternatives but also can indicate the degree of preference of each pair of alternatives. Therefore, it is more suitable and effective in dealing with subjective judgments in an imprecise environment.

Conclusion

In this paper we propose a fuzzy multi criteria decision making method for evaluating the candidates applying for public procurement. In this method the importance weights of the criteria and the assessment of the alternatives are given with linguistic variables. Seven levels of linguistic values are used but this number can be adjusted based on the characteristics of the data. We described a stepwise and objective method for determining the ranking order of fuzzy numbers.

The proposed method can be used by the public entity for selecting the appropriate candidate on the basis of how well the candidates meet a variety of specific criteria, such as price, solvency of the company, date of delivery, quality, etc. In addition, instead of the presented method other aggregation techniques can be used to combine the fuzzy ratings of the decision makers [3][5].

The application of this approach is demonstrated by an illustrative example with three decision makers, three candidates, and five decision criteria.

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