Evaluation of construction contractors in developing countries using fuzzy SAW method

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Abstract
Choosing an appropriate contractor for a construction project is a major concern in many developing countries, including Iran. The development of a computational method for selecting the right contractor among those who participated in the tender process could provide a solution to such concerns. Making the decision to select a contractor is a very complicated process, involving the consideration of numerous criteria. Despite the existence of a gamut of very important criteria for the selection procedure, decisions by most Iranian owners are still minimum-price oriented. This paper proposes a simple multi-criteria system to assist in the decision process of ranking contractors; this system uses methods that are based on the theory of fuzzy logic. This suggested model, which introduces various criteria for the evaluation of contractors, first calculates each criterion’s fuzzy weight. Then, to evaluate the contractors’ suitability with regard to each criterion, the model utilizes triangular and trapezoidal fuzzy numbers. Next, it uses the fuzzy simple adaptive weighting (SAW) method to rank the contractors. Finally, the sensitivity of the proposed model is analyzed by implementing it in a real construction project.

Keywords: prequalification, criteria, owner, contractor, fuzzy SAW

1 Introduction
Owing to the important role of contractors in construction projects, selecting a contractor, which involves a substantial amount of risk, is one of the most important initial decisions taken by owners. Therefore, owners usually attempt to reduce this risk by following a suitable strategy (Hatush and Skimore, 1997a).

Recently, the delay or stoppage of construction activities because of the disqualification of contractors has wasted a considerable amount of resources in Iran. Statistics show that a large portion of resource impairment is a consequence of choosing the wrong contractors. Usually when choosing a contractor, the focus is on the minimum price. However, this creates tremendous problems in the construction phases. Thus, Iranian public sector owners have concluded that it is insufficient to merely use the lowest bid as the sole criterion for selecting a contractor. Thus, it seems to be necessary to utilize models that consider other necessary criteria. This paper proposes a fuzzy model that totals the scores of the participating contractors in order to prequalify them.
2 Background

The tender system of basing decisions on the minimum price has been utilized in the U.S. since the nineteenth century. Hatush pointed out that this system had been used since 1848 for highway and bridge tenders in New York (Hatush and Skimore, 1997b). The main idea of such a method (determining the winner by the lowest bid) was to save financial resources and create equal competition for all participating contractors. This method also prevented the impact of external factors and political pressures on the owner. After many years, picking a contractor underwent changes. For example, other parameters were added to select and the rest of the criteria were included along with the bidding price. The ideals of the nineteenth century have not changed, although it is interesting to mention that all countries have challenged this tender-based way of choosing (Holt, 1998).

Very few countries, such as Italy, Portugal, and Peru, utilize systems in which the winner of a construction contract does not necessarily offer the lowest price. The philosophy in these countries is that the best offer, and not necessarily the lowest one, is the one that should be accepted. The best bid is usually close to the average of all the offers (Holt, 1998). Selecting the company that bids the lowest amount can create problems in terms of the project’s desired duration, quality, etc. As a result, a multi-parameter system was devised that involved other criteria in addition to the price. This method is based on the belief that only a contractor that possesses a good combination of all the criteria can perform a project well. Therefore, due to the problems mentioned above, multi-criteria methods have come into use to qualify contractors. This issue is investigated by researchers under various conditions. Diekmann introduced an innovative, functional method for selecting a contractor in Cost Plus contracts (Diekmann, 1981).

The most famous method was created by Jeffrey S. Russell, who helped his partners in 1990 with a program called “Qualifier-1,” which is software that uses a linear combination of decision weighted criteria. This program calculates the weighted proportions of each contractor and outputs his rank. Because of its systematic structure, it can be said that this software is a good means for the client to pick the best contractor (Russell and Skibniewski, 1990), (Russell, 1990). In addition, Russell went on to design “Qualifier-2,” a model based on expert systems (Russell et al., 1990).

A multitude of other research has been performed on this subject. Singh gave a fuzzy framework for selecting contractors (Singh and Tiong, 2005). In addition, Elazouni applied a neural network model to aid in the prequalification process by classifying contractors into groups based on similarity in performance (Elazouni, 2006). Yawei Li utilized a fuzzy approach to prequalify construction contractors (Li et al., 2007). Palaneeswaran developed a model for the selection of contractors for designing/building projects (Palaneeswaran and Kumaraswamy, 2000). Bendaña presented a fuzzy logic based system for the selection of contractors for private sector clients in traditional design-bid-build projects (Bendaña et al., 2008).

Despite the existence of many research models for prequalification and for the selection of contractors, the interesting characteristic of the model proposed in the present paper is its simplicity in comparison with the others. This will make it very practical for both public and private sector owners in Iran. At the same time, the amount of computation required in this model is quite low in cases where the number of criteria and the number of contractors are limited. Therefore, it is compatible with most Iranian construction tenders.

3 Introduction to fuzzy sets theory

In 1965, Zadeh introduced fuzzy sets for measuring qualifications with neither sharp nor vivid boundaries (Zadeh, 1965). While in a classic set, having sharp boundaries, each element is either a member or not, borders in fuzzy sets are not sharp or clear. In other words, for an element to be a member of a set or not to be a member of a set, it is not necessary for it to be completely included in it or excluded from it, respectively. The element could bear, more or less, a membership degree in
comparison to other elements of the set. In order to be better acquainted with the fuzzy set theory, first a set of concepts and terminology is required (Zimmermann, 1996).

**Definition 1:** Fuzzy set: Assume that $X$ is a classic set of possible space, each of whose members is indicated as $x$. The membership degree in a fuzzy sub-set of $X$ is often shown as $\mu_A$ of $X$ to $[0, 1]$. Thus:

$$\tilde{A} = \{(x, \mu_A(x)) | x \in X\}$$  \hspace{1cm} (1)

**Definition 2:** The $\tilde{A}$ fuzzy set is convex only if for each $x_1$ and $x_2$ there is a $\lambda$ number that:

$$\mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \text{Min}(\mu_A(x_1), \mu_A(x_2))$$   \hspace{1cm} (2)

**Definition 3:** The $\tilde{A}$ fuzzy set is normal only if there is at least one $x_i$ as a member of $\tilde{A}$ in which:

$$\mu(x_i) = 1$$   \hspace{1cm} (3)

**Definition 4:** The fuzzy set of $\tilde{A}$, both convex and normal, introduced in $\tilde{X}$ reference set, is defined as $\tilde{A}$ fuzzy number.

**Definition 5:** An $\alpha$-cut of $\tilde{A}$ is a non-fuzzy sub-set of $\tilde{A}$ and is defined as follows:

$$\tilde{A} = \{x | \mu_\lambda(x) \geq \alpha, x \in A\}$$   \hspace{1cm} (4)

**Definition 6:** A trapezoidal fuzzy number of $\tilde{A}$ is shown as $\tilde{A}=(a_1,a_2,a_3,a_4)$ and its diagram is as below:

![Trapezoidal fuzzy number](image)

**Definition 7:** The distance between $\tilde{A}=(a_1,b_1,c_1,d_1)$ and $\tilde{B}=(a_2,b_2,c_2,d_2)$ then:

$$\tilde{A} + \tilde{B} = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2)$$   \hspace{1cm} (5)

$$\tilde{A} - \tilde{B} = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2)$$   \hspace{1cm} (6)

$$r \otimes \tilde{A} = (ra_1, rb_1, rc_1, rd_1)$$   \hspace{1cm} (7)

$$\tilde{A} \otimes \tilde{B} = (a_1a_2, b_1b_2, c_1c_2, d_1d_2)$$   \hspace{1cm} (8)
\[ d(A,B) = \sqrt{\frac{1}{4}[(a_1-b_1)^2+(a_2-b_2)^2+(c_1-c_2)^2+(d_1-d_2)^2]} \] 

4 Suggested model to evaluate contractors via fuzzy SAW method

The general structure of this suggested model is presented in Figure 2.

![Diagram of the suggested model](image)

Figure 2- Stepwise stages of the suggested model

The steps of the model are as follows:

Step 1: After analyzing Iranian & non-Iranian standards for the selection of contractors and gathering the opinions of construction industry experts, the main criteria to prequalify contractors should be verified (Bubshait and Al-Gobali, 1996), (Liker, 2004), (Tzeng et al., 2006).

Step 2: Experts must make a pairwise comparison of the criteria to weigh them. Each of their weights is indicated by the matrix of pairwise comparisons. This method utilizes fuzzy numbers, shown in Table 1, to compare the criteria’s priorities.
### Table 1- Equivalent fuzzy numbers for different pair wise comparison status

<table>
<thead>
<tr>
<th>Pair wise comparison</th>
<th>Fuzzy number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Equal priority or importance</td>
<td>(1,1,1,1)</td>
</tr>
<tr>
<td>2 Poor priority or importance</td>
<td>(\left(\frac{2}{3},1,1,\frac{3}{2}\right))</td>
</tr>
<tr>
<td>3 Average priority or importance</td>
<td>(\left(\frac{3}{2},2,2,\frac{5}{2}\right))</td>
</tr>
<tr>
<td>4 Strong priority or importance</td>
<td>(\left(\frac{5}{2},3,3,\frac{7}{2}\right))</td>
</tr>
<tr>
<td>5 Absolute priority or importance</td>
<td>(\left(\frac{7}{2},4,4,\frac{9}{2}\right))</td>
</tr>
</tbody>
</table>

Step 3: Once experts make pairwise comparisons of the criteria and the matrix is created, based on Buckley’s method, the geometrical average of the rows of each matrix can be calculated by means of this formula (Buckley, 1985):

\[
\bar{z}_i = (\bar{a}_1, \bar{a}_2, \ldots, \bar{a}_n)
\]  

(10)

Afterward, each standard’s fuzzy weight can be calculated with this formula:

\[
\bar{w}_i = \frac{\bar{z}_i}{\bar{z}_1 + \bar{z}_2 + \cdots + \bar{z}_n}
\]  

(11)

If there are k choosers and each criterion is fuzzily weighted, the total weight is obtained as follows.

If the \(j^{th}\) criterion weight of each chooser is like below:

\[
w_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \quad l = 1,2,\ldots,k
\]  

(12)

The total weight might be presented in this way:

\[
w_{j1} = \frac{1}{k} \sum_{i=1}^{k} w_{j1} \quad l = 1,2,\ldots,k
\]

\[
w_{j2} = \frac{1}{k} \sum_{i=1}^{k} w_{j2} \quad l = 1,2,\ldots,k
\]

\[
w_{j3} = \frac{1}{k} \sum_{i=1}^{k} w_{j3} \quad l = 1,2,\ldots,k
\]

\[
w_{j4} = \frac{1}{k} \sum_{i=1}^{k} w_{j4} \quad l = 1,2,\ldots,k
\]

(13)

Step 4: Each contractor’s condition in each criterion is conveyed qualitatively according to the analyzer experts’ opinions. Finally, the decision matrix is created. Once the criteria are weighted by the formula below, the scores of the contractors can be fuzzily calculated.

\[
\bar{U}_i = \sum_{j=1}^{n} \bar{w}_j \bar{x}_j
\]  

(14)

In which,

\(\bar{U}_i\) is the score of the \(i^{th}\) contractor.

\(\bar{w}_j\) is the weight of the \(j^{th}\) criterion.

\(\bar{x}_j\) is the score of the points the \(i^{th}\) contractor gets in relation to the \(j^{th}\) criterion.

In a case where the criteria were weighted with pairwise comparisons and the fuzzy numbers evaluating them are trapezoidal, the calculation is as follows.
\[
\tilde{w} = (a_1, b_1, c_1, d_1)
\]
\[
\tilde{r} = (a_2, b_2, c_2, d_2)
\]

Then,
\[
\tilde{w}\tilde{r} = (a[L_1, L_2], b, c, d[R_1, R_2])
\]

In which,
\[
a = a_1, a_2, \quad b = b_1, b_2, \quad c = c_1, c_2, \quad d = d_1, d_2
\]
\[
L_1 = (b_1 - a_1)(b_2 - a_2)
\]
\[
L_2 = a_2(b_1 - a_1) + a_1(b_2 - a_2)
\]
\[
R_1 = (d_1 - c_1)(d_2 - c_2)
\]
\[
R_2 = -[d_2(d_1 - c_1) + d_1(d_2 - c_1)]
\]

A fuzzy number, obtained by multiplying two trapezoidal fuzzy numbers, is not, itself, a fuzzy trapezoidal number. Provided that \( \tilde{M} = \tilde{w} \times \tilde{r} \), its membership function is:

\[
\mu_{\tilde{M}}(x) = \begin{cases} 
0 & x \leq a \\
0 & x \geq d \\
1 & b \leq x \leq c \\
\alpha & a \leq x \leq b \\
\alpha & c \leq x \leq d
\end{cases}
\]

If \( c \leq x \leq d \) and \( a \leq x \leq b \), then:
\[
x = L_1 \alpha^2 + L_2 \alpha + a \quad ; \alpha \in [0,1] \quad a \leq x \leq b
\]
\[
x = R_1 \alpha^2 + R_2 \alpha + d \quad ; \alpha \in [0,1] \quad c \leq x \leq d
\]

For fuzzy numbers, the addition function is:
\[
\tilde{M}_1 = (a_1[L_1, L_2], b_1, c_1, d_1) \quad \tilde{M}_2 = (a_2[L_2, L_2], b_2, c_2, d_2)
\]

With n fuzzy numbers, as presented above, their sum might be reported as follows:
\[
\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \quad l = 1, 2, \cdots, k
\]
\[
\tilde{N} = \sum_{j=1}^{n} \tilde{M}_j = (a[L_1, L_2], b, c, d[R_1, R_2])
\]

In which,
\[
a = \sum_{j}^n a_j, \quad b = \sum_{j}^n b_j, \quad c = \sum_{j}^n c_j, \quad d = \sum_{j}^n d_j
\]
\[
L_1 = \sum_{j}^n L_{j1}, \quad L_2 = \sum_{j}^n L_{j2}, \quad R_1 = \sum_{j}^n R_{j1}, \quad R_2 = \sum_{j}^n R_{j2}
\]
Step 5: In this stage, while having fuzzy numbers as above, their final utility is calculated with Chen’s method, as shown below (Chen, 1985):

\[
U_{(x)} = \frac{1}{2} \{U_R(x) + 1 - U_L(x)\}  \tag{31}
\]

In which, \(U_R\) and \(U_L\) are right and left side utilities and defined as below:

\[
U_R(x) = \max \{\min(\mu_M(x), \mu_A(x))\}  \tag{32}
\]

\[
U_L(x) = \max \{\min(\mu_G(x), \mu_A(x))\}  \tag{33}
\]

Where:

\[
\mu_M(x)=\begin{cases}
\frac{(x-x_{\text{MIN}})/(x_{\text{MAX}}-x_{\text{MIN}})}{x_{\text{MIN}} \leq x \leq x_{\text{MAX}}} \\
0 & \text{otherwise}
\end{cases}
\tag{34}
\]

\[
\mu_G(x)=\begin{cases}
\frac{(x-x_{\text{MAX}})/(x_{\text{MIN}}-x_{\text{MAX}})}{x_{\text{MIN}} \leq x \leq x_{\text{MAX}}} \\
0 & \text{otherwise}
\end{cases}
\tag{35}
\]

5 Numerical Example

The mentioned method was utilized in a real construction project in Iran: a large structure stadium accommodating about 10,000 spectators in Semnan. The project client was Iran’s Physical Education Organization. Seven contractors participated in the tender, referred to by the letters A to G. Table 2 shows their bids.

Table 2- Different contractors’ bids

<table>
<thead>
<tr>
<th>No.</th>
<th>Contractor</th>
<th>Proposed Price ( million Rial )</th>
<th>Difference with Ave.( % )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>85,200</td>
<td>7.46</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>90,200</td>
<td>13.77</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>78,460</td>
<td>-1.04</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>76,870</td>
<td>-3.05</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>69,940</td>
<td>-11.79</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>71,800</td>
<td>-9.44</td>
</tr>
<tr>
<td>7</td>
<td>G</td>
<td>82,530</td>
<td>4.09</td>
</tr>
<tr>
<td></td>
<td><strong>Average Proposed Price</strong></td>
<td><strong>79286</strong></td>
<td></td>
</tr>
</tbody>
</table>

The stages where this model was used are discussed below:
Initially, and after analyzing various nations’ standards for selecting contractors and receiving the opinions of the owner’s managers for this project, the following eight criteria were set to evaluate the contractors:

- C1. Experience
- C3. Financial stability
- C5. The number of projects currently being handled by the company
- C6. Safety and health standards
- C8. Technical ability
- C2. Management capability
- C4. Previous experience in similar or related work
- C7. Technical and management personnel
After setting these criteria, they were weighted according to the opinions of the owner's managers, and if necessary, according to the opinions of other construction experts. The criteria were then conveyed as fuzzy numbers, as shown in Table 3, by means of the afore-mentioned methods.

Table 3- Fuzzy weights of the criteria

<table>
<thead>
<tr>
<th>Pre-qualification criteria</th>
<th>Fuzzy weights of criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>(0/12, 0/19, 0/19, 0/28)</td>
</tr>
<tr>
<td>C2</td>
<td>(0/07, 0/12, 0/19, 0/28)</td>
</tr>
<tr>
<td>C3</td>
<td>(0/08, 0/14, 0/14, 0/22)</td>
</tr>
<tr>
<td>C4</td>
<td>(0/07, 0/1, 0/1, 0/16)</td>
</tr>
<tr>
<td>C5</td>
<td>(0/07, 0/12, 0/12, 0/20)</td>
</tr>
<tr>
<td>C6</td>
<td>(0/08, 0/13, 0/13, 0/22)</td>
</tr>
<tr>
<td>C7</td>
<td>(0/01, 0/14, 0/14, 0/22)</td>
</tr>
<tr>
<td>C8</td>
<td>(0/05, 0/08, 0/08, 0/12)</td>
</tr>
</tbody>
</table>

Experts then used lingual phrases to give scores and quantify the criteria. To do so, they utilized triangular and trapezoidal fuzzy numbers. The equivalent fuzzy numbers for each of the following lingual phrases are shown in Figure 3.

Very good or very important: (VG/VI), fuzzy number: (0/8, 0/9, 1, 1)
Good or Important (G/V), fuzzy number: (0/6, 0/7, 0/8, 0/9)
Above Average (AA), fuzzy number: (0/5, 0/6, 0/7, 0/8)
Average (A), fuzzy number: (0/4, 0/5, 0/5, 0/6)
Below Average (BA), fuzzy number: (0/2, 0/3, 0/4, 0/5)
Poor or low importance (P/LI), fuzzy number: (0/1, 0/2, 0/3, 0/4)
Very poor or very low importance (VP/VL), fuzzy number: (0, 0, 0/1, 0/2)

Figure 3- Fuzzy Numbers for each lingual phrase

After the lingual phrases were verified and the criteria were weighted, one condition could be appointed to each contractor for each criterion. This research evaluated 7 contractors. A lingual phrase was appointed to each contractor in accordance with the terms used by the experts, owners, and professionals, as shown in Table 4.

Having put the fuzzy equivalents of the lingual phrases in the above matrix, the researchers created the decision matrix. This, along with the weights of the criteria, underwent the aforementioned procedure to give a final score to each contractor as a fuzzy trapezoidal number. Figure 4 shows the diagrams for the first two contractors.
Table 4- Conditions of different participating contractors for different criteria

<table>
<thead>
<tr>
<th>contractor</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>G</td>
<td>A</td>
<td>VG</td>
<td>VG</td>
<td>L</td>
<td>G</td>
<td>G</td>
<td>AA</td>
</tr>
<tr>
<td>B</td>
<td>A</td>
<td>BA</td>
<td>BA</td>
<td>G</td>
<td>A</td>
<td>VP</td>
<td>BA</td>
<td>P</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
<td>P</td>
<td>G</td>
<td>BA</td>
<td>H</td>
<td>AA</td>
<td>G</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>AA</td>
<td>BA</td>
<td>G</td>
<td>G</td>
<td>A</td>
<td>A</td>
<td>G</td>
<td>A</td>
</tr>
<tr>
<td>E</td>
<td>G</td>
<td>BA</td>
<td>BA</td>
<td>VG</td>
<td>AA</td>
<td>A</td>
<td>AA</td>
<td>A</td>
</tr>
<tr>
<td>F</td>
<td>VG</td>
<td>P</td>
<td>VP</td>
<td>G</td>
<td>VH</td>
<td>BA</td>
<td>G</td>
<td>VG</td>
</tr>
<tr>
<td>G</td>
<td>A</td>
<td>VP</td>
<td>P</td>
<td>G</td>
<td>VL</td>
<td>BA</td>
<td>G</td>
<td>VP</td>
</tr>
</tbody>
</table>

Figure 4- Evaluating contractors’ A & B membership functions

The membership functions of the various contractors were compared by means of Chen’s method. To do so, they had to be drawn in a unique diagram and their right and left side utilities obtained. Figure 5 shows the diagram.

Figure 5- Right and left utilities for different contractors

Eventually, with the use of the right and left side utilities of each contractor, their final scores were calculated based on Chen’s method, as shown in Table 5.
Table 5- The final score of the contractors, taking part in the tender

<table>
<thead>
<tr>
<th>CONTRACTOR</th>
<th>Final Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0/512</td>
</tr>
<tr>
<td>B</td>
<td>0/262</td>
</tr>
<tr>
<td>C</td>
<td>0/362</td>
</tr>
<tr>
<td>D</td>
<td>0/414</td>
</tr>
<tr>
<td>E</td>
<td>0/380</td>
</tr>
<tr>
<td>F</td>
<td>0/350</td>
</tr>
<tr>
<td>G</td>
<td>0/324</td>
</tr>
</tbody>
</table>

By comparing the contractors’ scores with their offered prices, it can be concluded that the contractors with the highest scores (here companies A and D) do not necessarily offer the lowest prices. Still, their prices are approximately near the average of all the contractors’ prices.

6 Analysis of model’s sensitivity

In order to evaluate the influence of the criterion weights, this part of the study analyzes their effect on contractors’ scores by varying them. Figure 6 shows how each contractor’s score changes if the weights of the first 2 criteria differ (C1 to C2). The following diagrams prove that changing the criterion weights does not make much difference in a contractor’s final score, i.e., in this method, the contractors’ scores are not very sensitive to the criteria weights.

7 Discussion and conclusion

This paper proposed a fuzzy multiple criteria decision model to evaluate contractors based on the chosen criteria. The given model was implemented in a real environment. The summary of the results is as follows:

Contractors with the highest scores did not necessarily offer the lowest prices. Their prices, however, were near the average of all the offered prices, i.e., the prices bid by these contractors are more logical.

The results of the model’s sensitivity toward the criteria proved that when using the fuzzy SAW method, the contractors’ final scores are not very sensitive to the weights (especially in lower weighted criteria). Therefore, this method is especially recommended for cautious clients.

Because Iranian owners in the public sector still tend to select the contractors who offer the lowest prices and because the proposed method is problematic, a two-staged method is more highly recommended. In this method, the above model is first used to select interested contractors with higher scores; those with low scores in the multi-criteria ranking are not considered. In the second level, the company that bids the lowest amount is selected.
References


