Contractor selection using extended TOPSIS technique with interval-valued triangular fuzzy numbers

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Abstract
Today, outsourcing plays an important role in the success of organizations and is used as a tool to create business advantages and capabilities. One of the risks that outsourcing faced is inappropriate contractor selection which would have a significant effect on the implementation of project in terms of time, quality and cost. This study aimed to identify important criteria of contractor selection, determine the significance of them and design a framework for an appropriate contractor selection. Important criteria for selecting contractors were extracted from the literature, and then experts' views were collected using questionnaire and six criteria were selected which were more significant from the experts' views and their weights were determined. Finally, contractors were ranked and final contractor was selected using extended fuzzy TOPSIS technique with interval-valued triangular fuzzy numbers.

Keywords: contractor selection, multi-criteria decision making, interval-valued triangular fuzzy numbers
1. INTRODUCTION

All organizations don’t profit from outsourcing their activities and disadvantages of outsourcing can create serious problems and risks for the organization. Disadvantages of outsourcing include selecting improper contractor, poorly written contracts, ignoring staff's problems, losing control over the outsourced activities, disregarding the hidden costs of outsourcing, lack of appropriate planning for an exit strategy. In any outsourcing contractors play an important role and we can say that contractor selection is the main decision before the outsourcing. Due to the diversity and variety of contractors who potentially have the required qualifications and capabilities to perform the contract and project, so inevitably, contractors should first be evaluated, ranked and then selected in order to ensure the project implementation to the best way.

Due to the increasing importance and role of contractors in the design and implementation of various projects, several procedures are designed and used for contractor selection process by governments and large employer organizations in the world which among them Multi Criteria Decision Making (MCDM) techniques may be mentioned that is one of the most important decision-making tools to help organizations.

In this study, extended TOPSIS method and interval triangular fuzzy numbers is used to rank contractors based on six technical capacity, experience, offered cost and price, reputation, financial stability and administrative capacity.

2. LITERATURE REVIEW

Most real-world problems have different, conflicting and multiple measurement criteria and if different and contradictory qualitative factors are evaluated in decision-making and suitable solutions are selected among several alternatives, this is called multi criteria decision making.

Analytic Hierarchy Process (AHP) (Fong and Choi, 2000), Analytic Network Process (ANP) (Cheng and Li, 2004), TOPSIS (Boran et al., 2009), Promethee (Araz et al., 2007), graph theory and matrix approach (Darvish et al., 2009) are MCDM techniques which are used to prioritize contractors.

Other methods that can be used for contractor selection are as follows: Multi Attribute Analysis (MAA) (Kashiwhgi & Byfield, 2002; Topcu, 2004), Data Envelopment Analysis (DEA) (McCabe et al., 2005; Juan, 2009), Multi Attribute Utility Theory (MAUT) (Wong et al., 2003; Louw et al., 2006), Multiple Regression (MR) (Doloi, 2009), Fuzzy Set Theory (FST) (Plebankiewicz, 2012; Nieto-Morote & Ruz-Vila., 2012), Multivariate discriminant
Analysis (MDA) (Kashiwhgi & Byfield, 2002), etc. In various studies, different criteria are used to select contractors in domestic and international level.

At the international level, much work has been done on contractors' selection and several criteria are used to assess them. For example, Mahdi et al (2002) used Delphi method to identify assessment criteria of contractors and obtain the priority of them. Criteria identified by them are divided into two qualifying criteria and final criteria. They introduced specific project criteria, financial stability, past performance and experience as qualifying criteria and the following criteria as final contractor selection factors: Managerial capability, cash flows, contractor's business strategy, equipment accessibility, workforce scheduling, organizational structure and staff's professional capabilities, access to the workforce, supply scheduling, the type and percentage of work that is deposited to the contractor, logistics capability, equipment scheduling, guarantee program and quality control.

Singh and Tiong (2006) studied the state of construction industry in Singapore through a questionnaire survey and they sought to identify the important criteria of contractor selection and the importance of these criteria from the perspective of construction industry's practitioners. They classified the contractor selection criteria into five general categories, the characteristics of the contractor's company, contractor's past performance, contractor's financial capabilities, contractor's potential performance and specific project criteria. According to Hafeez et al. (2007), physical assets, intellectual properties and cultural capitals are the most important criteria for selecting the best contractor. In another study, three criteria: cost, quality and delivery time are introduced to select a contractor which the cost itself includes three sub-criteria, order costs, transportation costs and unit costs.

Delivery time contains two sub-criteria of product's timely delivery and order delivery time. Quality also includes three sub-criteria, the percentage of defective goods, the percentage of guarantee's demand, and average response time of each demand (Faez et al., 2009). Darvish et al. (2009) used work experience, technology and equipment, experience and knowledge of the operations team, financial stability, quality, being familiar with the area or domestication, reputation, creativity and innovation to evaluate the contractors.

In a study, Watt et al. (2009) identified and classified criteria used to evaluate bids and contractors' selection between Australian employers. They first reviewed the literature of contractor selection and identified criteria found in the literature. In the next step, they identified and classified the criteria used by Australian employers using a questionnaire survey. Categories created by them are working capacity, financial status, health, safety and the environment, key personnel of the company location, skills in project management, social
and political standards, organizational experiences, performance in previous projects, company reputation, offered price, quality control, employer and contractor relationships, technical skills and the proposed method. Based on the results of another study that was carried out by Watt et al. (2010), it was found that past performance, technical expertise, and cost are the most important criteria in contractor selection and organizational criteria is less important.

According to Jaskowski et al (2010), five criteria were identified for a contractor to study the contractor's qualification in bid procedures which included:

1. Labor and equipment
2. Financial capacity
3. Performance in the previous projects
4. Organizational experience
5. Managerial systems (quality system and safety policy)

In another study, Lam and Yu divided contractor selection criteria into two categories: quantitative criteria and qualitative criteria and they introduced human resources, financial capacity and current workload as quantitative criteria and equipment resources, environmental concerns, complaints and claims history, management capacity, potentialities of quality management, safety and health aspects, previous experience on similar tasks and past performance were considered as qualitative criteria (Lam and Yu, 2011). Some other important criteria for contractor selection which have been studied including safety, quality, past performance, environment, management and technical aspects, resources, organization, experience, size / type of previous projects, finance (Alzahrani & Emsley, 2012).

According to another research, the main contractor selection criteria included technical capacity with sub-criteria of staff's qualification, employees' experience, innovation in method, labor and equipment, experience with the sub-criteria of previous completed projects types, the size of previous completed projects, the number of previous completed projects and the experience in local areas, managerial capacity with sub-criteria of organizational culture, management knowledge and quality management system, financial stability with sub-criteria of financial capability, credit and liquidity, past performance with sub-criteria of performance quality of projects, on time completed projects and projects completed based on budget, previous relationships with sub-criteria of relationships with sub-contractors, customer satisfaction and relationship with suppliers, reputation with sub-criteria of past failures in completed projects, the number of years working in the industry, legal claims and complaints,
job health and safety with sub-criteria of safety management and secure performance (Nieto-Morote and Ruz-Vila, 2012).

3. FUZZY TOPSIS

In this study, fuzzy extended TOPSIS method is used to solve multi-criteria problems in which criteria's values are expressed in the form of linguistic variables within interval-valued triangular fuzzy numbers.

Interval-valued triangular fuzzy number was first presented by Gorzalczany (1987), Turksen (1996) and Cornelis et al. (2006). The reason for offering these numbers was that it was difficult to express linguistic variables in the form of simple fuzzy numbers and wasn’t transparent enough. Interval fuzzy numbers are widely used in the real world.

![Figure 1. An interval-valued triangular fuzzy number](image)

The steps of this method are as follows (Ashtiani et al., 2009):

**Step 1:** Calculate the normalized decision matrix \( \tilde{R} \). We obtain following equation for given \( \tilde{x}_{ij} = [(a_{ij}, a'_{ij}) b_{ij} (c'_{ij}, c_{ij})] \).

\[
\tilde{r}_{ij} = \left[ \frac{a_{ij}}{c'_{ij}}, \frac{a'_{ij}}{c'_{ij}} \right] \frac{b_{ij}}{c'_{ij}} \left[ \frac{c'_{ij}}{c_{ij}}, \frac{c_{ij}}{c_{ij}} \right], \quad i = 1, 2, \ldots, m
\]

\[
j = 1, 2, \ldots, n \quad \text{for} \quad j \in \Omega_b
\]

\[
x_{ij} = \left[ \frac{a_{ij}}{c'_{ij}}, \frac{a'_{ij}}{c_{ij}} \right] \frac{a_{ij}}{b_{ij}} \left[ \frac{a'_{ij}}{a_{ij}}, \frac{a_{ij}}{a_{ij}} \right], \quad i = 1, 2, \ldots, m
\]

\[
j = 1, 2, \ldots, n \quad \text{for} \quad j \in \Omega_c
\]

\[
c_j = \max_j c_{ij}, \quad j \in \Omega_b
\]

\[
a'_j = \min_j a'_{ij}, \quad j \in \Omega_c
\]

**Step 2:** Considering the importance of each criterion, we formed weighted normalized fuzzy decision matrix \( \tilde{V} = [\tilde{v}_{ij}]_{nm} \) which is as \( \tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{w}_{ij} \). We have:
\[ \vec{v}_j = [\vec{v}_1 \times \vec{v}_j', \vec{v}_2 \times \vec{v}_j', \vec{v}_3 \times \vec{v}_j', \vec{v}_4 \times \vec{v}_j', \vec{v}_5 \times \vec{v}_j', \vec{v}_6 \times \vec{v}_j', \vec{v}_7 \times \vec{v}_j', \vec{v}_8 \times \vec{v}_j'] \] 

(3)

For convenience, we show \( \vec{v}_j \) as follows:
\[ \vec{v}_j = [(g_{ij}, g_{ij}'); h_{ij}; (l_{ij}, l_{ij}')] \]

**Step 3:** positive and negative ideal are defined as follows:
\[ A^+ = [(1,1);(1,1)], \quad j \in \Omega_x \]
\[ A^- = [(0,0);(0,0)], \quad j \in \Omega_x \]  

(4)

**Step 4:** Calculate the normalized Euclidean distance.

If \( N_x = [N_x^-; N_x^+], \quad M_x = [M_x^-; M_x^+] \) are two interval fuzzy numbers, we have:
\[ D(\vec{N}_x, \vec{M}_x) = \sqrt{\frac{1}{6} \sum_{i=1}^{8} [(N_{x_i}^- - M_{x_i}^-)^2 + (N_{x_i}^+ - M_{x_i}^+)^2]} \] 

(5)

\[ D^-(\vec{N}_x, \vec{M}_x) = \sqrt{\frac{1}{3} \sum_{i=1}^{4} [(N_{x_i}^- - M_{x_i}^-)^2]} \]
\[ D^+(\vec{N}_x, \vec{M}_x) = \sqrt{\frac{1}{3} \sum_{i=5}^{8} [(N_{x_i}^+ - M_{x_i}^+)^2]} \] 

(6)

Similarly, the interval of each alternative to positive ideal is calculated as follows:
\[ D^+_{i1} = \sum_{j=1}^{8} \sqrt{\frac{1}{3} [(g_{ij} - 1)^2 + (h_{ij} - 1)^2 + (l_{ij} - 1)^2]} \]
\[ D^+_{i2} = \sum_{j=1}^{8} \sqrt{\frac{1}{3} [(g_{ij} - 1)^2 + (h_{ij} - 1)^2 + (l_{ij} - 1)^2]} \] 

(7)

And the interval of each alternative to positive ideal is calculated as follows:
\[ D^-_{i1} = \sum_{j=1}^{8} \sqrt{\frac{1}{3} [(g_{ij} - 0)^2 + (h_{ij} - 0)^2 + (l_{ij} - 0)^2]} \]
\[ D^-_{i2} = \sum_{j=1}^{8} \sqrt{\frac{1}{3} [(g_{ij} - 0)^2 + (h_{ij} - 0)^2 + (l_{ij} - 0)^2]} \] 

(8)

Equations (1) and (2) are used to determine the interval to positive and negative ideals. In this case, we lose less information compared when we immediately convert the numbers into crisp numbers.

**Step 5:** relative closeness is calculated as follows:
\[ RC_1 = \frac{D^+_{i2}}{D^+_{i1} + D^+_{i2}}, \quad RC_2 = \frac{D^-_{i2}}{D^-_{i1} + D^-_{i2}} \] 

(9)
$RC_i^+$ is calculated as follows:

$$RC_i^+ = \frac{RC_i + RC_j}{2}$$  \hspace{2cm} (10)

And Rank alternatives in terms of their relative closeness’s.

If we have a group decision making environment with $k$-decision, we average decision makers' views as such:

$$\bar{x}_{ij} = \frac{1}{k} \left[ \bar{x}_{ij}^1 + \bar{x}_{ij}^2 + \cdots + \bar{x}_{ij}^k \right]$$  \hspace{2cm} (11)

$$\bar{w}_{ij} = \frac{1}{k} \left[ \bar{w}_{ij}^1 + \bar{w}_{ij}^2 + \cdots + \bar{w}_{ij}^k \right]$$  \hspace{2cm} (12)

4. THE PROPOSED METHOD FOR RANKING CONTRACTORS

Contractors ranking steps of a manufacturing unit are as follows:

Step 1: determining ranking criteria and contractors' selection.

By literature review six important criteria considered by experts are introduced as follows:

<table>
<thead>
<tr>
<th>Administrative capacity</th>
<th>Financial stability</th>
<th>Reputation</th>
<th>Offered price and cost</th>
<th>Experience</th>
<th>Technical capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>$C_2$</td>
<td>$C_3$</td>
<td>$C_4$</td>
<td>$C_5$</td>
<td>$C_6$</td>
</tr>
</tbody>
</table>

**Table 1. Contractors selection's criteria**

Step 2: determine the weights of contractor selection criteria

Experts were asked to give each criterion a score according to table (2), the mean of experts' scores are shown as criteria's weights in table (3) using equation (10):

<table>
<thead>
<tr>
<th>interval-valued triangular fuzzy numbers</th>
<th>Linguistic variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[(0,0);0;(1,1.5)]$</td>
<td>Very low</td>
</tr>
<tr>
<td>$(0,0.5);1;(2.5,3.5)]$</td>
<td>Low</td>
</tr>
<tr>
<td>$[(0,1.5);3;(4.5,4.5)]$</td>
<td>Relatively low</td>
</tr>
<tr>
<td>$(2.5,3.5);5;(6,7,5)]$</td>
<td>Average</td>
</tr>
<tr>
<td>$[(4.5,5.5);7;(8,9.5)]$</td>
<td>Relatively high</td>
</tr>
<tr>
<td>$(5.5,7.5);9;(9.5,10)]$</td>
<td>High</td>
</tr>
<tr>
<td>$[(8,5,9.5);10;(10,10)]$</td>
<td>Very high</td>
</tr>
</tbody>
</table>

**Table 2. Linguistic variables for ranking**
Table 3. The weight of criteria

<table>
<thead>
<tr>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>$C_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[(0.06,0.14);0.23;(0.4,0.48)]$</td>
<td>$[(0.11,0.21);0.33;(0.5,0.59)]$</td>
<td>$[(0.09);0.18;(0.34,0.39)]$</td>
<td>$[(0.18,0.29);0.44;(0.61,0.69)]$</td>
<td>$[(0.21,0.33);0.49;(0.68,0.77)]$</td>
<td>$[(0.2,0.29);0.41;(0.59,0.62)]$</td>
</tr>
</tbody>
</table>

Step 3: Decision matrix formed using above weights was weighted and then first to fourth steps were conducted to obtain the interval and the relative closeness of each alternative (contractors) to the positive and negative ideals which its results are shown in table (4).

Table 4. The final result of TOPSIS

<table>
<thead>
<tr>
<th></th>
<th>$D_{1+}$</th>
<th>$D_{2+}$</th>
<th>$D_{1-}$</th>
<th>$D_{2-}$</th>
<th>$RC_1$</th>
<th>$RC_2$</th>
<th>$RC^*$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>3.37</td>
<td>2.47</td>
<td>1.03</td>
<td>1.29</td>
<td>0.34</td>
<td>0.23</td>
<td>0.29</td>
<td>2</td>
</tr>
<tr>
<td>A2</td>
<td>2.67</td>
<td>2.47</td>
<td>1.02</td>
<td>1.29</td>
<td>0.34</td>
<td>0.28</td>
<td>0.31</td>
<td>1</td>
</tr>
<tr>
<td>A3</td>
<td>2.91</td>
<td>2.75</td>
<td>0.71</td>
<td>0.94</td>
<td>0.25</td>
<td>0.20</td>
<td>0.22</td>
<td>4</td>
</tr>
<tr>
<td>A4</td>
<td>2.79</td>
<td>2.61</td>
<td>0.88</td>
<td>1.12</td>
<td>0.30</td>
<td>0.24</td>
<td>0.27</td>
<td>3</td>
</tr>
<tr>
<td>A5</td>
<td>3.06</td>
<td>2.93</td>
<td>0.55</td>
<td>0.72</td>
<td>0.20</td>
<td>0.15</td>
<td>0.17</td>
<td>5</td>
</tr>
</tbody>
</table>

In which $[D_{1+},D_{2+}]$ indicates the interval of each alternative to the positive ideal and $[D_{1-},D_{2-}]$ is the interval to the negative ideal and they are calculated with equations (7) and (8). In addition, $[RC_{11},RC_{12}]$ indicates the relative closeness for each alternative which is calculated through equation (9). And finally, it is $RC^*$ which is the midpoint of $[RC_{11},RC_{12}]$ and the final ranking is obtained based on it. An alternative that has more $RC^*$ will be placed in a higher ranking. Accordingly, A2 is selected as the best contractor.

5. RESULTS

In recent years, the rapid process of transferring most activities to the contracting companies has been started. Outsourcing is a strategy that many organizations use to gain a competitive advantage. One of the important issues that will increase the success likelihood of these projects is selecting the right contractor. This study was also carried out in this regard and it is found a holistic view about different criteria which may affect on selecting the best contractor and also a method to evaluate different contractors using these criteria. The overall conducted works are:
a. Identifying criteria affecting contractors' selection in the first stage and then achieving the most effective criterion of these criteria and also determining the weights of these criteria through a questionnaire which was sent to the experts.

b. Ranking contractors and selecting a contractor who gained the maximum score. Extended fuzzy TOPSIS method with interval-valued triangular fuzzy numbers was used to implement the project. Using interval-valued triangular fuzzy numbers helps the more transparency of experts' views. Using TOPSIS method a contractor can be selected who has the minimum interval to the positive ideal and the maximum interval to the negative ideal based on the benefit and cost criteria

REFERENCES


