Contractor selection in MCDM context using fuzzy AHP

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Abstract

Contractor selection is one of the most important problem in supply chain and its strongly effect on firm’s performance. Because a significant amount of a university’s budget assigns to construction contracts, contractor selection is an important problem for the financial status of universities. Since Contractor selection is a multi-criteria decision making problem (MCDM), lots of methods proposed to face this problem. Selection is a broad comparison of contractors using a common set of criteria and measures. Analytic hierarchy process (AHP) and other traditional methods widely used for contractor and vendor selection by researches regarding to lots linguistic variables and both qualitative and quantitative criteria and to tackle ambiguous nature of contractor selection problem, although there is some Insufficiency about them. In this article we use FAHP that is a fuzzy extension of AHP to handle the fuzziness of the data involved in deciding the preferences of different decision variables. The linguistic level of comparisons produced by experts for each comparison is tapped in the form triangular fuzzy numbers to construct fuzzy pairwise comparison matrices. We priorities Tehran university’s construction contractor about each criteria and determine the best one about all of them.

Keywords:
analytic hierarchy process, contractor selection, fuzzy set theory, multi-criteria decision making problem.

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1. Introduction

In recent years supplier selection problem has received considerable attention in the supply chain management literature. There are many companies that tend to increase their financial performance through cutting their costs by choosing a suitable supplier. Since a significant part of the company's budget is assigned to contractor contracts, choosing the right supplier is very important. The contemporary supply management is to maintain long-term partnership with suppliers, and use fewer but reliable suppliers. Therefore, choosing the right suppliers involves much more than scanning a series of price lists, and choices will depend on a wide range of factors which involve both quantitative and qualitative. (Ho et al., 2010) Because of many criteria and different suppliers, how to choose a suitable and right supplier is important for many corporations. A suitable supplier may become and develop into a cooperative and long-term partnership in SCM, which can help the growth of a company and can be crucial to the success of the business (Chen & Chao, 2012).

In each industry such as construction, there are a lot of contractor companies which claim that they supply their services with the lower price, better quality and more suitable to the firm's needs than their competitors. Companies try to find a contractor that brings the most beneficiary in comparison with others and this beneficiary can be in each criteria such as cost, quality, flexibility and so on. Simultaneously taking all of these factors into account is difficult for decision makers and managers, so they prefer to focus on just one or two more important factors and ignore other factors even though they are significant in determine the most suitable contractor (Lee, 2009).

Most of supplier selection proposed models are according to simple decision making supposes. It doesn't seem most of this method pay attention to the unstructured and complicated nature of current
contract and venture decisions (Boer et al., 1998). The nature of supplier selection decision making problems is generally complicated and unstructured and there are many quantitative and qualitative criteria that must be considered to identify the appropriate supplier. Supplier selection and evaluation is especially an MCDM problem consists of multi-criteria factors and the factors can be both qualitative and quantitative. Since supplier selection problem process requires a formal, systematic and rational choosing model, there’re lots of proposed models about supplier selection and evaluation (Huang et al., 2006).

MCDM approaches extensively proposed for supplier selection such as the analytic network process (ANP), fuzzy set theory, analytic hierarchy process (AHP), data envelopment analysis (DEA), mathematical programming, case-based reasoning (CBR), genetic algorithm (GA) and simple multi-attribute rating technique (SMART) (Ho et al., 2010). Finding the best way to evaluate and select supplier is difficult and companies use different ways facing this problem. Then the most important issue in supplier selection is to develop a method to choose the right supplier and it’s essential to use a systematic and effective procedure or method to select the most appropriate supplier (Chen & Chao, 2012; Chen et al., 2006). Some innovative approaches, based on artificial intelligence techniques such as Fuzzy Logic match very well with decision-making situations where supplier’s evaluation is also perceptive, decision-makers express heterogeneous judgments, many decision rules are implied and unstructured, precise and accurate data are not available (Dulmin et al., 2003).

In this study we aim to prioritize contractor selection criteria and rank the construction contractors according to decision aims with take all of the essential criteria into account by utilizing the structure of criteria in the fuzzy analytic hierarchy process (FAHP). The main
questions of this study are as follows:
1. What is the rank of construction contractors in our decision model, according to all contractor criteria?
2. What is the rank of construction contractors in our decision model, according to each contractor criterion?

The rest of the paper is arranged as follows. Firstly, the recent rating methods in supplier selection will be briefly discussed. Secondly, the essential criteria for supplier selection will be reviewed and we will portray the decision hierarchy of this paper. The proposed method uses the FAHP to rank contractors. Therefore, thirdly, the fuzzy set theory and fuzzy AHP will be briefly described. Then, the proposed rating method using FAHP is presented. Finally, we will rank construction contractors using FAHP process and we will demonstrate the contractor rating according to both each criterion and decision model as a whole.

2. Background

There are lots of keywords associated with the supplier selection. The term “supplier selection” and “vendor selection” are interchangeably used in the literature. These two terms have a same meaning about the process of selection. The term “contractor selection” and “tender selection” refer to similar processes to supplier selection. The term “contractor selection” is mostly associated with the purchasing of services offered by a firm in urban and engineering and construction industry in particular. (Snomez, 2006). Research on supplier selection can be traced back to the early 1960s and different solution methodologies have been proposed to deal with it, ranging from linear programming to nonlinear programming. Treating supplier selection as an optimization problem requires the formulation of an objective function. (Huang et al., 2007).

Braglia and Petroni (2000) applied DEA to measure the efficiencies
al. (2006) constructed a multi-objective programming model to select the optimal suppliers and determine the optimal order quantity possible ways of generating the weightings. Wadhwa and Ravindran (2007) modeled the supplier selection problem as a multi-objective programming problem.

In recent decade there were some researches about a contractor or supplier evaluation and selection that use AHP, fuzzy set theory and integration of these two methods to deal with supplier selection problems. Akarte et al. (2001) developed a web-based AHP system to evaluate the casting suppliers with respect to 18 criteria. Muralidharan et al. (2002) proposed a five-step AHP-based model to aid decision makers in routing and selecting suppliers with respect to nine evaluating criteria. Chan (2003) developed an interactive selection model with AHP to facilitate decision makers in selecting suppliers. Chain and Chan (2004) applied AHP to evaluate and select suppliers. Liu and Hai (2005) applied AHP to evaluate and select suppliers. Chen et al. (2006) presented a hierarchy model based on fuzzy sets theory to deal with the supplier selection problem. Sarkar and Mohapatra (2006) suggested that performance and capability were two major measures in the supplier evaluation and selection problem. Florez-Lopez (2007) picked up 14 most important evaluating factors from 84 potential added-value attributes, which were based on the questionnaire response from US purchasing managers. Xia and Wu (2007) incorporated AHP into the multi-objective mixed integer programming model for supplier selection. Kahraman et al. (2003) applied a fuzzy AHP to select the best supplier in a Turkish white good manufacturing company. Chan and Kumar (2007) also used a
fuzzy AHP for supplier selection. Chain and Chan (2010) proposed an AHP based model to solve the supplier evaluation and selection problem taking the example of fashion industry. Kumar and Roy (2011) proposed a rule based model with the application of AHP to aid the decision makers in vendor evaluation and selection taking the power transmission industry. Chang et al. (2011) proposed fuzzy decision making trial and evaluation laboratory (DEMATEL) method to effectively find evaluation factors for supplier selection. Jiang and Chan (2011) proposed a methodology with the application of fuzzy set theory (FST), based on twenty criteria to deal with supplier evaluation and selection problem. This paper tried to go beyond the previous literature and considers all the significant criteria, which have been ignored in the supplier selection problem. There are a bit articles about contractor selection, so to deal with contractor selection problems (like construction contractor selection as it investigated in this paper) that we often deal with some companies which their supply is a combination of their products and services, the context of selection is different and supplier selection model must fit to such context properly.

3. Contractor selection criteria

**C1: Technical:** To provide a consistently high quality product or service, promote successful development efforts, and ensure future improvements, a firm needs competent technical support from its suppliers.

**C2: Capability and skill:** The potential capacity to produce a good or service. Some factors that should be considered are internal manufacturing capacity, constraining processes, direct labor availability and key components/materials availability.

**C3: Financial:** The firm should require its suppliers to have good financial position. Financial strength can be a good Indicator of the
supplier’s long-term stability. A solid financial position also helps ensure that performance standards can be maintained and that products and services will continue to be available.

**C4: Managerial:** Maintaining a good supplier relationship requires management stability. The firm should have confidence in its supplier’s management’s ability to run the company. It is also important that the supplier’s management be committed to managing its supply base. The supplier’s level of quality, service, and cost are directly affected by its supplier’s ability to meet its needs.

**C5: Facilities and support resource:** The supplier’s resources need to be adequate to support product or service development. Criteria need to consider the supplier’s facilities, information systems, and provisions for education and training.

**C6: Performance history:** The historical experiments of working with a special supplier and the amount of satisfaction or dissatisfaction.

![Figure 1. Hierarchy for Contractor selection](image)

Contractor selection decision making hierarchy tree is portrayed in figure 1. The contractors have been choosen among construction companies which sent their proposal price to technical office, Tehran.
university to participate in establishing Tehran university dormitory building trend that was held in 2010. The contractors are Bonyan Saze, Charbarg, Abad Tadbir, Tabanshahr and Omran Vaheb in order to contractor numbers.

4. Fuzzy set theory and fuzzy AHP

The analytic hierarchy process (AHP) is widely used for tackling multi-attribute decision-making problems in real situations but this method is often criticized for using of a discrete scale of one to nine and to its inability to adequately handle the inherent uncertainty and imprecision associated with decision maker’s perception. However, in many practical cases the human preference model is uncertain and decision makers might be reluctant or unable to assign exact numerical values to the comparison judgments (chan et al., 2007).

Since some of the evaluation criteria involve a high degree of subjective judgment and individual preferences, it is very difficult for the decision maker to express their preferences in exact numerical values and to provide exact pairwise comparison judgments so AHP, in spite of its popularity and simplicity in concept, is not sufficient to take into account the uncertainty associated with the mapping of one’s perception to a number. The linguistic assessment of human feelings and judgments are vague and it is not reasonable to represent it in terms of precise numbers. It feels more confident to give interval judgments than fixed value judgments. To improve the AHP method, triangular fuzzy numbers are used to decide the priority of one decision variable over another and this is fuzzy extended of AHP (FEAHP) approach to represent decision makers’ comparison judgments to decide the final priority of different decision criteria.

The fuzzy set theory has the advantage of mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic to many problems. Like other artificial
intelligence method it has some advantages within uncertain, imprecise and vague contexts than AHP and other MCDM method, in resembles human judgments. This method uses the triangular fuzzy numbers as a pairwise comparison scale for deriving the priorities of different selection criteria and attributes. The weight vectors with respect to each element under a certain criterion is developed using the principle of the comparison of fuzzy numbers. It’s efficiently handled the fuzziness of the data involved in the supplier selection decision and can take into account quantitative and qualitative data in the multi-attribute decision making problems. In this approach triangular fuzzy numbers are used in the preferences of one criterion over another. Triangular fuzzy numbers also used for determining each supplier capacity about each criterion then by using the extent analysis method, the synthetic extent value of the pairwise comparison is calculated, the weight vectors are decided and normalized, thus the normalized weight vectors will be determined. As a result, based on the different weights of criteria the final priority weights of the alternative global suppliers are decided. Finally the weight of each supplier about each criterion will be determined and the best contractor will be chosen according to its capacity of each criteria and the weight of that criteria on contractor selection. (Chan et al., 2007)

A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. Two triangular fuzzy number \( M_1 (m_1^-, m_1, m_1^+) \) and \( M_2 (m_2^-, m_2, m_2^+) \) shown in Fig. 2 are compared. When \( m_1 \geq m_2^- \), \( m_1 \geq m_2 \), \( m_1^+ \geq m_2^+ \), we define the degree of possibility \( V (M_1 \geq M_2) = 1 \). Otherwise, we can calculate the ordinate of the highest intersection point (Chang, 1996 mentioned by Lee, 2009):
Table 1. Importance (or preference) of one criterion over another

<table>
<thead>
<tr>
<th>Linguistic scale</th>
<th>Triangular fuzzy numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute</td>
<td>$(7/2, 4, 9/2)$</td>
</tr>
<tr>
<td>Very strong</td>
<td>$(5/2, 3, 7/2)$</td>
</tr>
<tr>
<td>Strong</td>
<td>$(3/2, 2, 5/2)$</td>
</tr>
<tr>
<td>Fairly strong</td>
<td>$(2/3, 1, 3/2)$</td>
</tr>
<tr>
<td>Equal</td>
<td>$(1, 1, 1)$</td>
</tr>
<tr>
<td>Fairly weak</td>
<td>$(2/3, 1, 3/2)$</td>
</tr>
<tr>
<td>Weak</td>
<td>$(2/5, 1/2, 2/3)$</td>
</tr>
<tr>
<td>Very weak</td>
<td>$(2/7, 1/3, 2/5)$</td>
</tr>
<tr>
<td>Zero</td>
<td>$(2/9, 1/4, 2/7)$</td>
</tr>
</tbody>
</table>

Figure 2. Two triangular fuzzy numbers $M_1$ and $M_2$

$$
\mu(d) / \mu(m_1) = \frac{m_1^- - d}{(m_1^- - m_1)} \quad \text{and} \quad (1)

\mu(d) / \mu(m_2) = \frac{m_2^- - d}{(m_2^- - m_2)} \quad \text{and} \quad (2)

\text{then } \mu(d) = \frac{(m_1^- - m_2^-) / ((m_1^- - m_1) - (m_2^- - m_2)) \leq 1} \quad (3)

\text{The value of fuzzy synthetic extent with respect to the criterion form goals is defined as:}

$$
F_t^* = \sum_{j=1}^{m} M_{jk}^j \times \left[ \sum_{k=1}^{n} \sum_{j=1}^{m} M_{jk}^j \right]^{-1} \quad (4)

\text{Where } M_{jk}^j = [M_{ijk}^j, M_{ijk}^j, M_{ijk}^j] \quad (5)
A convex fuzzy number can be defined by:

\[ V(F \geq F_1, F_2, \ldots, F_K) = \min V(F \geq F_i) \quad i = 1, 2, \ldots, K \]  

(8)

\[ D(F_i) = \min V(F_i \geq F_k) = w_i \quad K = 1, 2, \ldots, n, K \neq i \]  

(9)

Based on the above procedure, we can calculate the weights, \( w_i \), of criteria.

\[ W' = (w_1', w_2', \ldots, w_n')^T = (d(F_1), d(F_2), \ldots, d(F_n))^T \]  

(10)

After normalization, the priority weights are as follows:

\[ W = (w_1, w_2, \ldots, w_n)^T \]  

(11)

5. Methodology

Based on Lee (2009) and Chan & Kumar (2007), a systematic fuzzy AHP model for supplier selection is proposed in this section. The steps are summarized as follows:

Step1. Identify all important criteria in contractor selection that mentioned in supplier selection literature.

Step2. Ask experts to identify the most important criteria that involve in contractor selection.

Step3. Design a questionnaires base on criteria that exploited in step 2 to pairwise compare elements.

Step4. Ask experts to fill out the nine scale questionnaires by choosing the most appropriate linguistic comparison variable. In this step, the experts compare two criteria respect to their capability in supporting contractor selection goals.

Step5. Transform expert's responds into nine scale numbers and calculating the final comparative value of each comparison by geometric mean.
Step 6. Transform final numerical comparison into triangular fuzzy numbers according to Table 1.

Step 7. Calculate criteria relative important weights in supplier selection according to the 4th to 11th formulas that mentioned in Part 4.

Step 8. Ask experts to fill out the nine scale questionnaires by choosing the most appropriate linguistic comparison variable to compare two contractor respects to their capability in support each criterion.

Step 9. Repeat step 5 to 7 to calculate contractor relative important weight in support each criterion.

Step 10. Calculate the final contracted weight by synthesizing priorities of each contractor under each criterion and by multiplying the calculated weights of criteria attained in step 7 to the calculated weight of each contractor in supporting each criterion.

Table 2. The Fuzzy evaluation of criteria with respect to the overall objective

<table>
<thead>
<tr>
<th>Objects</th>
<th>Criterion 1</th>
<th>Criterion 2</th>
<th>Criterion 3</th>
<th>Criterion 4</th>
<th>Criterion 5</th>
<th>Criterion 6</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criterion 1</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(7/2, 4, 9/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>W1 = 0.301</td>
</tr>
<tr>
<td>Criterion 2</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>W2 = 0.237</td>
</tr>
<tr>
<td>Criterion 3</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>W3 = 0.137</td>
</tr>
<tr>
<td>Criterion 4</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(7/2, 4, 9/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>W4 = 0.301</td>
</tr>
<tr>
<td>Criterion 5</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>W5 = 0.019</td>
</tr>
<tr>
<td>Criterion 6</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>W6 = 0.003</td>
</tr>
</tbody>
</table>

Based on the collected opinions of the experts and the proposed model, the performance results of the suppliers can be generated as follows:

\[
\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij}^k = \left( \frac{1}{9}, \frac{1}{9}, \frac{1}{9} \right) + \ldots + \left( \frac{1}{9} \right) = (38.95, 45.17, 57.64)
\]

\[
\left[ \left( \frac{1}{38.95} \right)^{-1} \right]^{-1} = \left( \frac{1}{38.95} \cdot \frac{1}{45.17} \cdot \frac{1}{57.64} \right) = (0.018, 0.022, 0.023)
\]
The fuzzy synthetic degree values of criterion can be calculated as follows:

\[ F_1 = (8.83 \times 0.018, 11.00 \times 0.022, 13.50 \times 0.028) = (0.15, 0.24, 0.38) \]

Following a similar calculation, the fuzzy synthetic degree values of other four contractor selection criteria are obtained as shown below:

\[ F_2 = (0.12, 0.20, 0.32) \]
\[ F_3 = (0.09, 0.14, 0.24) \]
\[ F_4 = (0.16, 0.24, 0.38) \]
\[ F_5 = (0.05, 0.07, 0.12) \]
\[ F_6 = (0.06, 0.10, 0.16) \]

The fuzzy synthetic degree values of criterion can be calculated as follows:

\[ F_1 = \left( \frac{\sum_{j=1}^{6} M_{j1}^{l} \times \left[ \sum_{i=1}^{n} \sum_{j=1}^{6} M_{ij}^{l} \right]^{-1}}{1} \right) \]

\[ F_1 = (8.83 \times 0.018, 11.00 \times 0.022, 13.50 \times 0.028) = (0.15, 0.24, 0.38) \]

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\[ F_4 = (0.16, 0.24, 0.38) \]
\[ F_5 = (0.05, 0.07, 0.12) \]
\[ F_6 = (0.06, 0.10, 0.16) \]

V(F_1 \geq F_2) = 1, V(F_1 \geq F_3) = 1, V(F_1 \geq F_4) = 1, V(F_1 \geq F_5) = 1, V(F_1 \geq F_6) = 1

V(F_2 \geq F_1) = 0.79, V(F_2 \geq F_3) = 1, V(F_2 \geq F_4) = 0.79, V(F_2 \geq F_5) = 1, V(F_2 \geq F_6) = 1

V(F_3 \geq F_1) = 0.46, V(F_3 \geq F_2) = 0.68, V(F_3 \geq F_4) = 0.46, V(F_3 \geq F_5) = 1, V(F_3 \geq F_6) = 1

V(F_4 \geq F_1) = 1, V(F_4 \geq F_2) = 1, V(F_4 \geq F_3) = 1, V(F_4 \geq F_5) = 1, V(F_4 \geq F_6) = 1

V(F_5 \geq F_1) = 0.31, V(F_5 \geq F_2) = 0.06, V(F_5 \geq F_3) = 0.29, V(F_5 \geq F_4) = 0.34,
Contractor selection in MCDM context using fuzzy AHP

V(F₂ ≥ F₆) = 0.71
V(F₆ ≥ F₁) = 0.03, V(F₂ ≥ F₂) = 0.26, V(F₆ ≥ F₃) = 0.61, V(F₆ ≥ F₄) = 0.01, V(F₆ ≥ F₅) = 1

The weights are calculated as follows:

d(F₁) = \min \ V (F₁ ≥ F₂, F₃, F₄, F₅, F₆) = \min (1, 1, 1, 1, 1) = 1

d(F₂) = \min \ V (F₂ ≥ F₁, F₃, F₄, F₅, F₆) = \min (0.79, 1, 0.79, 1, 1) = 0.79

d(F₃) = \min \ V (F₃ ≥ F₁, F₂, F₄, F₅, F₆) = \min (0.46, 0.68, 0.46, 1, 1) = 0.46

d(F₄) = \min \ V (F₄ ≥ F₁, F₂, F₃, F₅, F₆) = \min (1, 1, 1, 1, 1) = 1

d(F₅) = \min \ V (F₅ ≥ F₁, F₂, F₃, F₄, F₆) = \min (0.31, 0.06, 0.29, 0.34, 0.71) = 0.06

d(F₆) = \min \ V (F₆ ≥ F₁, F₂, F₃, F₄, F₅) = \min (0.03, 0.26, 0.61, 0.01, 1) = 0.01

W' = (d(F₁), d(F₂), ..., d(F₆))ᵀ = (1, 0.79, 0.46, 1, 0.06, 0.01)ᵀ

After normalization, the normalized weight of contraction selection criteria is:

W = (0.301, 0.237, 0.137, 0.301, 0.019, 0.003)

Similar procedures are carried out to calculate relative importance weight of contractors with respect to each selection criterion. These weights are shown in the right columns of follow tables (table 3-8).

Table 3. The Fuzzy evaluation of criteria with respect to 1th criterion

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>(1, 1, 1)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(1, 1, 1)</td>
<td>0.031</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>(3/2, 2, 5/2)</td>
<td>(1, 1, 1)</td>
<td>(3/2, 2, 5/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>0.215</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(1, 1, 1)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.115</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>(7/2, 4, 9/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>(1, 1, 1)</td>
<td>(7/2, 4, 9/2)</td>
<td>0.608</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>(1, 1, 1)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(1, 1, 1)</td>
<td>0.031</td>
</tr>
</tbody>
</table>

Table 4. The Fuzzy evaluation of criteria with respect to 2th criterion

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(1, 1, 1)</td>
<td>0.081</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(1, 1, 1)</td>
<td>0.100</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.067</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>(7/2, 4, 9/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>(1, 1, 1)</td>
<td>(3/2, 2, 5/2)</td>
<td>0.652</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(1, 1, 1)</td>
<td>0.100</td>
</tr>
</tbody>
</table>
Table 5. The Fuzzy evaluation of criteria with respect to 3th criterion

<table>
<thead>
<tr>
<th>Criterion 3</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.130</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.175</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.175</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>(7/2, 4, 9/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.332</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(1, 1, 1)</td>
<td>0.189</td>
</tr>
</tbody>
</table>

Table 6. The Fuzzy evaluation of criteria with respect to 4th criterion

<table>
<thead>
<tr>
<th>Criterion 4</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>(1, 1, 1)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.091</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>(5/2, 3, 7/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>0.344</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>(3/2, 2, 5/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.249</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(1, 1, 1)</td>
<td>0.181</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(1, 1, 1)</td>
<td>0.135</td>
</tr>
</tbody>
</table>

Table 7. The Fuzzy evaluation of criteria with respect to 5th criterion

<table>
<thead>
<tr>
<th>Criterion 5</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>(1, 1, 1)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(1, 1, 1)</td>
<td>0.083</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>(3/2, 2, 5/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>0.285</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.276</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>(3/2, 3, 5/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(1, 1, 1)</td>
<td>(5/2, 3, 7/2)</td>
<td>0.473</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>(1, 1, 1)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(1, 1, 1)</td>
<td>0.083</td>
</tr>
</tbody>
</table>

Table 8. The Fuzzy evaluation of criteria with respect to 6th criterion

<table>
<thead>
<tr>
<th>Criterion 6</th>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
<th>Supplier 4</th>
<th>Supplier 5</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.030</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(2/5, 1/2, 2/3)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/3, 1, 3/2)</td>
<td>0.077</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>(2/3, 1, 3/2)</td>
<td>(3/2, 2, 5/2)</td>
<td>(1, 1, 1)</td>
<td>(2/3, 1, 3/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>0.316</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>(3/2, 2, 5/2)</td>
<td>(5/2, 3, 7/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(1, 1, 1)</td>
<td>(7/2, 4, 9/2)</td>
<td>0.499</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/3, 1, 3/2)</td>
<td>(2/7, 1/3, 2/5)</td>
<td>(2/9, 1/4, 2/7)</td>
<td>(1, 1, 1)</td>
<td>0.078</td>
</tr>
</tbody>
</table>

Table 9. shows a summarized of suppliers with respect to each criterion.

<table>
<thead>
<tr>
<th>Contractor selection goals</th>
<th>Criterion 1</th>
<th>Criterion 2</th>
<th>Criterion 3</th>
<th>Criterion 4</th>
<th>Criterion 5</th>
<th>Criterion 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier 1</td>
<td>0.031</td>
<td>0.081</td>
<td>0.130</td>
<td>0.091</td>
<td>0.083</td>
<td>0.030</td>
</tr>
<tr>
<td>Supplier 2</td>
<td>0.215</td>
<td>0.100</td>
<td>0.175</td>
<td>0.344</td>
<td>0.285</td>
<td>0.077</td>
</tr>
<tr>
<td>Supplier 3</td>
<td>0.115</td>
<td>0.067</td>
<td>0.175</td>
<td>0.249</td>
<td>0.076</td>
<td>0.316</td>
</tr>
<tr>
<td>Supplier 4</td>
<td>0.608</td>
<td>0.652</td>
<td>0.332</td>
<td>0.181</td>
<td>0.473</td>
<td>0.499</td>
</tr>
<tr>
<td>Supplier 5</td>
<td>0.031</td>
<td>0.100</td>
<td>0.189</td>
<td>0.135</td>
<td>0.083</td>
<td>0.078</td>
</tr>
</tbody>
</table>
And the final contractor weight by synthesizing priorities of each contractor under each criterion by defining \( W_i \) as criteria weights and \( W_{ij} \) as contractor weights about each criterion can be calculated as follow:

\[
W_k = \sum_{j=1}^{n} (W_i \times W_{ij})
\]

\( W_k = (0.031*0.301)+(0.081*0.237)+...+(0.030*0.003) = 0.076 \)

Respectively other contractor's weight calculated as follows:

\[
W_k = 0.222 \\
W_k = 0.152 \\
W_k = 0.449 \\
W_k = 0.102
\]

The final results portrayed in following charts:

![Figure 3. Line chart of contractors weight with respect to each criteria](image-url)
As mentioned before, the normalized weights of contraction selection criteria calculated as:

\[ W = (\text{technical}=0.301, \text{Capability}=0.237, \text{Financial}=0.137, \text{Managerial}=0.301, \text{Facilities}=0.019, \text{Performance history}=0.003) \]

So it can be received through article's finding, the priority of 5 construction contractor is as follows:

1- Tabanshahr, 2- Charbarg, 3- Abad Tadbir, and 4,5- Omran Vaheb, Bonyan Saze about technical criterion.
1- Tabanshahr, 2,3- Charbarg, Omran Vaheb, 4-, Bonyan Saze and 5- Abad Tadbir about skill capability criterion.
1- Tabanshahr, 2- Omran Vaheb, 3,4- Abad Tadbir, Charbarg and 5- Bonyan Saze about financial criterion.
1- Charbarg, 2- Abad Tadbir, 3- Tabanshahr, 4- Omran Vaheb and 5- Bonyan Saze about managerial criterion.
1- Tabanshahr, 2- Charbarg and 3,4,5- Abad Tadbir, Bonyan Saze, Omran Vaheb about facilities criterion.
1- Tabanshahr, 2- Abad Tadbir, 3,4- Charbarg, Omran Vaheb and 5- Bonyan Saze about performance history criterion.

And as the result of all FAHP system the priority of 5 construction contractor is as follows:
1- Tabanshahr, 2- Charbarg, 3- Abad Tadbir, and 4- Omran Vaheb and 5- Bonyan Saze.

6. Conclusion and future work

In this paper a fuzzy AHP approach has been presented to select the best construction contractor for Tehran university technical office. The main criteria have been chosen respect to construction context and experience of the experts in the respective fields. Each chosen factor affecting the performance of the contractor has been analyzed and discussed. Fuzzy set theory is incorporated into the model to overcome the uncertainty and ambiguity in human decision-making process.

As it can be found in paper results, managerial criterion that almost do not attract sufficient attention in the contractor selection decision making, in common with technical criterion has the first place in affecting contractor performance. Despite, there is wide attention to the financial criterion and even in some cases it is the only selection factor, it does not have a significant effect on supporting the goals of selection. Considering this paper results, pay attention to just one or two important factors in contractor selection and ignore other factors is not logically acceptable and so this research provides a comprehensive model that considers all affecting factors in contractor selection. The model can accept a wide range of factors and dynamic nature of model help decision makers to add or omit any factors according to decision making context.

This research work can be extended to many important industries that contractor and supplier selection are very important to them, and in some industries that choosing the right supplier can make competitive advantages for firms.
References


Talluri, S., Narasimhan, R., Nair, A., 2006. Vendor performance with supply