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Identification and prioritization of effective factors in assessment and ranking of contractors using fuzzy multi-criteria techniques

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A B S T R A C T

In the recent years, issues like high competitive pressure, globalization, business difficulties, resources limits, technological complications and activities specialization, fast changes in environment, etc. have caused organizations to reconsider their management methods. As a result, they are looking forward to branding new strategies in order to achieve competitive advantages. Focusing on main competences and outsourcing most of the activities are some of these strategies. Assessment management and selecting the appropriate contractor who holds adequate efficiency is of critical importance for having a project accomplished in time and with foreseen resources. Various qualitative and quantitative factors of different importance are involved in contractors' assessment and should be taken into account before decision making. In this paper, once the factors are identified using fuzzy screening method, they are prioritized according to their importance by means of fuzzy hierarchical analysis.

1. Introduction

Over past two decades, privatization has been concerned as the most important element in structural reform of developed and developing countries. Indeed, today most countries have some programs to hand over all or parts of public companies to private sector. Supplying a required legal basis for contribution in private sector, conducting, supervising and managing life cycle are the most significant factors that directly affect the risk of investment and then the corporation of this sector in economic activities (Plebankiewicz, 2009; Rao & Davim, 2008). Since the beginning of 70s, electricity industry in Iran has been initiating manufacturing and equipment, services, consulting, auditing, computer and issuing bills, network and electricity installations maintenance, due to changing organizational structure, establishing independent and private companies of power distribution and management as well as companies working in executive and contractual sectors. One of the requirements of privatization and downsizing is handing over some parts of organization performance to contractors in

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the form of projects. As of 2015, 1162 contractors have been working in Power Distribution Company of Fars Province, located in south west of Iran, and they implement network operation, power outage and connection of indebt subscribers, inspect measuring instruments installations, supervise the operation of converting network made of copper wire to self-supporting cable, install single-phase and three-phase counters, reform single-phase and three-phase equipment, etc. Obviously, because of the number of contractors and their important activities, they play a key role in power transmission. Paying no attention to this issue results in implementing the project over a longer period of time with low quality and higher cost. Also in some cases, it leads to no business justification of the project (Cheng et al., 2009; Diani & Shiruiyezad, 2012). An accurate and efficient planning is required to avoid resources loss and perform handed over activities so that productivity would be enhanced by using available funds as well as spending company funds optimally. There are different techniques and methods applied in evaluation, determinant preference, and contractor. Analytical hierarchy process (AHP) (Saaty, 1980), data envelopment analysis (DEA) (Charnes et al., 1084), genetics algorithm, neural networks are considered to handle different criteria for project assessment (Hsu et al., 2010). Many problems in decision-makings are pertaining to incomplete and inaccurate information. In addition, experts make decisions based on their individual qualification and they are dramatically intellectual. Thus, calculations should be performed in fuzzy space when experts' expressions are considered in research (Zadeh, 1975). In this study, filtration and AHP will be conducted in fuzzy space to reach a better conclusion. Then, theoretical framework, review of literature, methodology, research model, data analysis, findings and eventually conclusion will be brought forth for discussion.

2. Theoretical framework and review of the literature

One of the important acts in planning and making decision to properly implement projects is to select the right contractor. Indeed, contractors are considered as indispensible and significant in the process of projects, i.e. they mainly provide services and equipment. In any field of different projects, some contractors are potentially qualified. But selecting a right contractor is a problem. To evaluate contractors it should be noticed that in making each decision, decision makers would take into account some criteria or standards. If these criteria are quantitative and they can be defined numerically, there are various mathematical methods to solve them. However, when they are qualitative we cannot apply mathematical and quantitative methods so that specific method should be used (Mehrjerdi et al., 2010). Because of significant and increasing role of consultants and contractors in designing, various methods for selecting contractors are administered by governments and great employers in the world to implement different projects. The following methods are applying by world-bank and Asia development bank (Naseri & Afsar, 2011; Jaferi & Shiruiyezad, 2012):

1- Selection regarding quality and price
2- Selection regarding minimum price
3- Selection regarding quality
4- Selection regarding consultant's qualification
5- Selection regarding fixed price
6- Selection regarding authorized consultant

Weber et al. (1991) classified quantitative approaches into three categories for supporters and contractors selections:

A) Linear regression models

In these models, a weight determined intellectually will be assigned to each criterion and the maximum weight indicates the greatest importance. Rank of each criterion will be multiplied by its weight and then products will be added with one another to achieve a united form for each determinant. Finally, the determinant will be selected with the highest total rank. These models include AHP, ANP and multi-criteria design.

B) Mathematical programming models

Mathematical programming models may regulate decision-making based on mathematical objective function for decision makers. According to the number of objective functions, decision making process

can be divided into two groups: 1) mono-objective mathematical programming models, 2) multi-objective mathematical programming models

Many scholars apply mono-objective techniques like integer linear programming models in which a criterion, usually a price, is considered as an objective function and other criteria are taken into account as constrains. Often mono-objective models are used for minimizing purchase total costs, inventory costs, and order costs, however, in multi-objective models experts are going to achieve some criteria simultaneously, i.e. some objective functions will be presented maximally or minimally.

C) Statistical models

These models will randomly be used in selection under uncertain criteria. Most statistical models always consider the certainty of a criterion and the most effective model will be selected

In Iran, many researches have been conducted in selecting contractors. Asgharizadeh and Nasrolahi (2008) defined the importance and preference of cited indicators in group decision-making by AHP model as well as recognizing effective indicators on contractor selection. Specified indicators include technical skill, economic, financial and management power, specialized personnel, equipment, credit and well career record. Zare Mehrjerdi et al. (2010) examined criteria identified in ranking petrochemical projects contractors by multicriteria decision-making attributes. Also, they recognized the most effective criteria through designing a questionnaire and collected experts' opinion through another questionnaire. Then they assessed and introduced the best contractors as tender winners via Borda and TOPSIS methods. Naseri and Afsar (2011) defined selection, selection method, applied criteria and the importance of each one in selecting contractors. In this regard, they used information technology through the balanced scorecard and Delphi method to determine evaluation criteria and they identified more than 25 criteria. In addition, they specified the importance of each criterion by questionnaire and entropy method. Bakhshi et al. (2013) presented a new classification of the main criteria to select efficient contractors and also related sub-criteria affecting contractors abilities in projects that quality was considered as the most important factor. They evaluated and weighted criteria through fuzzy analytical hierarchy process. Tavakoli and Kamrani (2013) identified and ranked contractors selection criteria in power plants with the purpose of optimizing project management system. They improved the current status of power plants in Iran by required suggestions and strategies. Singh and Tiong (2005) presented a model that takes into account different kinds of criteria and specified sub-criteria. They used verbal variables based on fuzzy numbers theory that helps decision makers evaluate contractors' specialties. Also, decision makers may benefit from verbal variables in criteria and contractors' satisfaction.

Chen and Li (2007) presented a fuzzy framework to solve the problem of construction contractors' selection that takes into consideration knowledge, features of contractors, and allows decision makers to judge contractors' qualifications easily. This framework involves decision-making criteria analysis, evaluating and weighting criteria, and ranking handed over orders to contractors. They used fuzzy approaches such as fuzzy numbers, fuzzy TOPSIS, fuzzy filtering for contractors ranking. Plebankiewics (2009) proposed a fuzzy model that simultaneously consider different criteria of contractors' evaluation and what construction owners tend to achieve in the project. Construction owners evaluated based on verbal variables and in terms of criteria weights, purposes, and their satisfaction with criteria, which were achieved by contractors. Then they converted those variables to fuzzy numbers using fuzzy set and assessed contractors' evaluation and owners' satisfactions. Morote and Vila (2012) presented a systematic model for contractors' evaluation according to fuzzy logic because of ambiguous and uncertain conditions of construction projects. They concerned with technical equipment and facilities, experience, management ability, financial power, function and communications in the past, professional credit and health to evaluate contractors. Meanwhile, they precisely make the contractors' functions evaluation possible due to qualitative and quantitative criteria. In addition, a comprehensive set of contractors' evaluation criteria was achieved via studying the review of the literature and they are demonstrated in Table 1.

Table 1

Contractors' evaluation criteria

Main criteria	sub-criteria	References
Price	Proposed price	Zare Mehrjerdi et al. (2010), Sadeghi et al. (2009), Khakbaz Abyaneh et al. (2012), Mirhadifard (2005), Khodaei (2005), Heidari et al. (2008), Mohaghar et al. (2012)
	How to estimate and breakdown low prices and getting familiar to price list	Zare Mehrjerdi et al. (2010)
Experience and record	Experience in similar plans or performing similar actions	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Dashti et al. (2011), Sadeghi et al. (2009), Tavakoli& Kamrani (2011), Barzinpour & Namazifard (2011), Khakbaz Abyaneh et al. (2012), Eshtehardian (2003), Mirhadifard (2005), Kazemi Asiabar (2011), Rajaee et al. (2008), Mohaghar et al. (2012), Plebankiewics (2009), Arsalan et al. (2008), El-Sawalhi et al. (2007).
	Having experience in related industry	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Tavakoli & Kamrani (2011), Khakbaz Abyaneh et al. (2012), Eshtehardian (2003), Mirhadifard (2005), Khodaei (2005), Kazemi Asiabar (2011), Rajaee et al. (2008), Mohaghar et al. (2012).
	Having experience in project site	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Mohaghar et al. (2012).
	Company establishment year and its precedence of service	Zare Mehrjerdi et al. (2010)
Equipment	Having machinery and equipment and their numbers	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Dashti et al. (2011), Ravanshadnia et al. (2006), Zakeri afshar et al. (2014), Dayani & Shirouyezad (2012), Khakbaz Abyaneh et al. (2012), Mirhadifard (2005), Kazemi Asiabar (2011), Khavari Nejad. (2012), Heidari et al. (2008), Mohaghar et al. (2012).
	Maintenance system	Ravanshadnia et al. (2006), Dayani & Shirouyezad (2012)
	Appropriate technology	Sadeghi et al. (2009), Barzinpour & Namazifard (2011), Eshtehardian (2003), Mirhadifard (2005), Rajaee et al. (2008).
Technical ability of human resource	The qualification of the number of human force, technicians and key elements	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Tavakoli & Kamrani (2011), Ravanshadnia et al. (2006), Dayani & Shirouyezad (2012), Mohaghar et al. (2012). Arsalan et al. (2008),
	Technicians experience and knowledge and key elements	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Tavakoli & Kamrani (2011), Ravanshadnia et al. (2006), Dayani & Shirouyezad (2012), Mohaghar et al. (2012). Arsalan et al. (2008),
	Staff creativity power	Heidari et al. (2008), Khakbaz Abyaneh et al. (2012), Sadeghi et al. (2009), Dashti et al. (2011).
Financial, credit and logistic power	Contractor financial power	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Dashti et al. (2011). Ravanshadnia et al. (2006), Dayani & Shirouyezad (2012), Khakbaz Abyaneh et al. (2012), Eshtehardian. (2003), Khodaei (2005), Kazemi Asiabar (2011), Khavari Nejad. (2012), Shakiba Zahed,(2012), Rajaee et al. (2008). Arsalan et al. (2008), El-Sawalhi et al. (2007), Nassar and Hosny (2013).
	Bank credit of the last fiscal year	Tavakoli & Kamrani (2011)
	Paying tax over 5 years a go	Tavakoli & Kamrani (2011)
	Gross income over the last five years	Tavakoli & Kamrani (2011)
	Documented fixed assets	Tavakoli & Kamrani (2011)
Scheduling and project control	Supplying scheduling to complete the project	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Kazemi Asiabar (2011), Nassar and Hosny (2013).
	Taking action based on planning and having no unauthorized delay in previous projects	Tavakoli& Kamrani (2011), Razmi et al. (2006), Mohaghar et al. (2012). Arsalan et al. (2008),
	Comprehensive system of planning and project control	Razmi et al. (2006), Mohaghar et al. (2012). Kazemi Asiabar (2011)
	Duration of proposed job	Ravanshadnia et al. (2006), Dayani & Shirouyezad (2012)
Quality	Labor quality system	Zare Mehrjerdi et al. (2010), Sadeghi et al. (2009), Barzinpour & Namazifard (2011), Eshtehardian (2003), Mirhadifard (2005), Tavakoli& Kamrani (2011), Shakiba Zahed,(2012), Dayani & Shirouyezad (2012), Khodaei (2005), Arsalan et.Al (2008), El-Sawalhi et al. (2007), Nassar and Hosny (2013).
	Executive bid for improving quality	Razmi et al. (2006)
	Having documentaries in quality management system	Razmi et al. (2006), Bakhshi et al. (2013), Dayani & Shirouyezad (2012), Khodaei (2005)
	Technical ability and equipment in quality control unit	Bakhshi et al. (2013)
	Creativity of quality control unit	Bakhshi et al. (2013), Dayani & Shirouyezad (2012), Mohaghar et al. (2012).
Organizational factors	Organizational structure	Golbaharzadeh et al. (2013), Eshtehardian (2003), Ravanshadnia et al. (2006), Plebankiewics (2009)
	Sustainability and organizational maturity	Dayani & Shirouyezad (2012)
Policies pertaining to human resources	Cultural fit	Sadeghi et al. (2009), Barzinpour & Namazifard (2011)
	Motivating personnel	Tavakoli & Kamrani (2011)
	Supervising a proper act	Tavakoli & Kamrani (2011)
	Duely payment of salary and benefits	Tavakoli & Kamrani (2011), Razmi et al. (2006)
	Making no mistakes by human resource	Tavakoli & Kamrani (2011)
	Specialized training of staff	Tavakoli & Kamrani (2011), Mohaghar et al. (2012). Arsalan et al. (2008)
	Executing professions ranking plan	Tavakoli & Kamrani (2011)
Certifications	Contractual qualification certification	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Tavakoli & Kamrani (2011), Dayani & Shirouyezad (2012)
	Membership in specialized association	Tavakoli& Kamrani (2011)
	Company rank (competitive status in industry)	Zare Mehrjerdi et al. (2010), Dayani & Shirouyezad (2012)
Security and standard	Professional security	Ravanshadnia et al. (2006), Mirhadifard (2005)
	Security management	Ravanshadnia et al. (2006), Mirhadifard (2005), Daiani & Shirouyezad(2012), Bakhshi et al. (2013), Razmi et al. (2006), Shakiba Zahed,(2012), Mohaghar et al. (2012), Nassar and Hosny (2013). Arsalan et al. (2008)
	Observing environmental standards	Ravanshadnia et al. (2006), Mirhadifard (2005)
Factors pertaining to customer	Responding and flexibility	Golbaharzadeh et al. (2013)
	The potentiality of supplying necessary requirements of employer	Sadeghi et al. (2009)
	Flexibility and responding to unexpected problems	Mirhadifard (2005)
	Customer management, services and after – sale services	Sadeghi et al. (2009), Khakbaz Abyaneh et al. (2012)
	The possibly of having strategic long-term relationships	Khodaei (2005)
Factors pertaining to contractor	Education and records of company manager	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Tavakoli& Kamrani (2011), Dashti et al. (2011), Razmi et al. (2006), Mohaghar et.al(2012), Dayani & Shirouyezad(2012), Mirhadifard (2005), Kazemi Asiabar (2011), Rajaee et al. (2008), Heidari et al. (2008), Morote and Vila (2012)
	Executive record of managing director	Tavakoli & Kamrani (2011), Shakiba Zahed,(2012)
	Effective management and proper management system for taking action	Razmi et al. (2006), Kazemi Asiabar (2011), Khavari Nejad (2012), El-Sawalhi et al. (2007).
	The benefit of continuing contractor activity	Razmi et al. (2006)
	Steady positions of members of board of directors and technicians	Razmi et al. (2006), Bakhshi et al. (2013)
	Work limit	Zare Mehrjerdi et al. (2010), Golbaharzadeh et al. (2013), Dayani & Shirouyezad (2012), Heidari et al. (2008), Sadeghi et al. (2009)
	Customization of contractor	Zare Mehrjerdi et al. (2010), Shakiba Zahed (2012)
Past function	Public credit	Shakiba Zahed (2012), Sadeghi et al. (2009)
	Previous long-term relationships and relationships closeness	Razmi et al. (2006)
	Failures and accidents in previous projects	Sadeghi et al. (2009), Shakiba Zahed (2012), Bakhshi et al. (2013), Dayani & Shirouyezad (2012)
	Scale of previous projects	Razmi et al. (2006), Mohaghar et al. (2012)
	Well record in previous actions and satisfaction of previous employers (contractor popularity)	Ravanshadnia et al. (2006), Mirhadifard (2005), Zare Mehrjerdi et.Al(2010), Razmi et.Al(2006), Tavakoli& Kamrani (2011), Kazemi Asiabar (2011), Barzinpour& Namazifard (2011), Khavari Nejad. (2012), Heidari et al. (2008), Rajaee et al. (2008), Morote and Vila (2012), El-Sawalhi et al. (2007).
Specialized interview	Specialized interview	

3. Methodology and research model

This research is applied one regarding its goals. In the review of the literature, library method was applied to collect subject matters and field survey and questionnaire were administered to ask experts' opinions to determine criteria and their weights. Fig. 1 shows research parts.

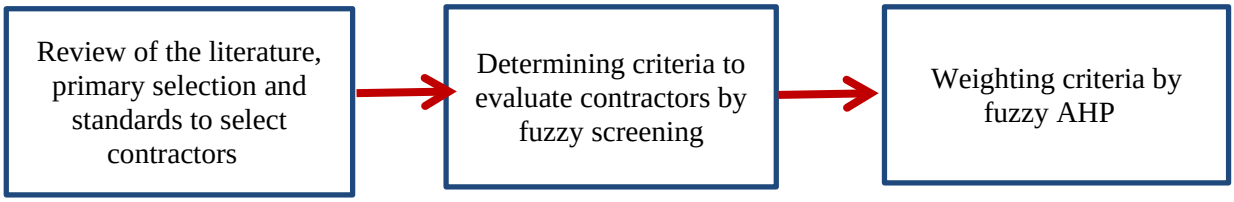

Fig. 1. Research parts

As it is mentioned in this study, fuzzy screening was used to finalize indicators and fuzzy AHP was applied to weigh criteria.

3.1 Fuzzy Screening

Fuzziness is a type of imprecision characterizing classes with insufficient sharply defined boundaries. Fuzzy logic is a superset of conventional (Boolean) logic extended to handle the concept of partial truth. As its name suggests, it is the logic underlying modes of reasoning which are approximate rather than precise. The importance of fuzzy logic is derived from the fact that most modes of human reasoning and especially common sense reasoning are approximate in nature. The fuzzy modeling approaches, including the fuzzy screening methods, are based on the concept of linguistic variable. Linguistic variable is a word or sentence in a natural or artificial language (Kickert, 1978). The significance of linguistic variable is that it facilitates graduate transitions between its states and, consequently, it possesses a natural capability to express and to deal with imprecise and ambiguous statements (e.g. the decision-makers' preferences with respect to the importance of evaluation criteria are typically expressed in linguistic terms such as very important , important , unimportant , etc. also, the preferences with respect to attribute values and cut-offs points are often expressed by means of linguistic terms). The idea of linguistic variable is for operationalizing evaluation criterion and preferences. It is also for the aggregation procedures in the fuzzy screening techniques. There are two main techniques for executing the aggregation of linguistic information. First, the approximation or indirect approach implements the membership functions related to the linguistic terms. Next, the trapezoidal/triangular membership functions are normally applied to capture the vagueness of the linguistic terms (Eastman, 1997; Munda, 1995). Finally, the direct or symbolic approach makes direct implementation of labels for computing, which is based on the premise that the set of linguistic terms is an ordered structure uniformly distributed on a scale. Both the approximation and symbolic approaches are associated with two basic fuzzy operations:

3.2. Minimization and/or maximization operations for aggregation qualitative information

The MIN or intersection operator is associate with the logical AND, which produces for any given fuzzy sets the largest set from among those produced by all possible fuzzy intersections. This interpretation implies no positive compensation (trade-off) between degrees of membership of the fuzzy sets and it is a non-compensation operator. This means that an alternative is rejected on the basis of poor performance with respect to, at least, one attribute, even if it performs well above the average based on other attributes. Moreover, the fuzzy MAX operation corresponds to the logical OR operation and it creates the smallest fuzzy set among the fuzzy sets produced by all possible fuzzy unions (Kickert, 1978; Ross, 1995). In aggregation, various evaluation criteria the *MAX* operator creates the maximum degree of membership computed by any of the fuzzy sets representing evaluation factors.

Therefore, it is a fully compensation operator, which means that an alternative is recognized as an acceptable one based on an exceptionally high value of one attribute irrespective of poor performance in terms of other attributes. Formally, for two sets, *A* and *B*, on the universe X

$$A \cap B \rightarrow \mu_{A\cap B}(x) = MIN[\mu_A(x), \mu_B(x)], \quad (1)$$

and

$$A \cup B \rightarrow \mu_{A\cup B}(x) = MIN[\mu_A(x), \mu_B(x)], \quad (2)$$

are the intersection and union operators, respectively; $\mu_A(x)$ and $\mu_B(x)$represent membership in sets *A* and *B* for the element *x* in the universe *X*.

One of the difficulties with the approximation approach to fuzzy screening is that it is often a chllening task to build meaningful membership functions with the linguistic values. The symbolic technique prevents this problem by executing aggregation operations on labels (linguistic values) directly. The method needs the decision-maker to provide his/her estimates with respect to the performance of alternatives. More specifically, for each alternative, the decision-maker is requested to make an assessment on a qualitative scale to determine how alternative satisfies each of the evaluation criteria. There is empirical evidence to show that a seven-point scale is appropriate for multicriteria evaluation (Saaty, 1980). Specifically, the evaluation is given in labels, S_l (1,2,.....,q) from the following scale *S* (Yager, 1993; Nieto-Morote & Ruz-Vila, 2012):

S_7 Outstanding (OU)	S_6 Very High (VH)	S_5 High (H)	S_4 Medium (M)
S_3 Low (L)	S_2 Very Low (VL)	S_1 None or Negligible (N)	

The use of such a scale provides a natural ordering, $S_k > S_l$ (S_k is preferred to S_l) if K > l and consequently the minimum and maximum of any two labels can be defined by

$$\min (S_K, S_l) = S_k \text{ if } S_k \leq S_l \quad (3)$$

and

$$\max (S_k, S_l) = S_k \text{ if } S_k \geq S_l \quad (4)$$

Thus, the *i*th location can be assigned a collection of *n* qualitative attribute values, x_{ij} . Each attribute value is an element of the set of allowable label *S*. Moreover, the decision-maker is requested to assign a measure (weight) of importance, α_j, to each of the attributes under consideration based on the same scale, *S*. Finally, a crucial aspect of the symbolic approach is consensus function. The consensus function is defined as follows,

$$Q_A(k) = S_{b(k)}$$

$$b(k) = INT\left[1 + (k\frac{q-1}{r})\right] \qquad k = 0,1,2,\ldots.r \quad (5)$$

Given the set of attribute values and the set of measures of importance, the screening procedure needs to determine the overall value (label) for each alternative; that is, aggregate the attributes and weights for each location. The overall value, *ui* , for the *i*th alternative is computed as follows,

$$u_i = \max_j\{Q(j) \cap B_{ij}\} \geq S^*, \qquad i = 1,2,\ldots,m \quad (6)$$

where *Q*(*j*) is the consensus function for the measure of importance of the *j*th attribute, *Bij* is the level of the *j*th attribute for the *i*th alternative, ∪ is the union of the two sets, and S* is the minimum

acceptable overall value (threshold). The screening rule given in Eq. (6) can be interpreted as a measure of the degree to which an alternative satisfies the following proposition: all important factors are satisfied. In better words, if a factor is considered to be important then an alternative should perform well with respect to that factor. This is reached by incorporating the preferences (the measures of importance), $Q(j)$, into the screening rule (6) (Ross,1995; Yager, 1993).

3.3 Fuzzy AHP

The aim of any fuzzy AHP (FAHP) method is to prioritize ranking of alternatives. FAHP method, as the decision support system, helps decision makers make better choices both in relation to tangible criteria and intangible criteria (Tang & Lin, 2011).

The process of applied FAHP is listed as follows:

Step 1. Building the Hierarchical Structure

First we build the hierarchical structure. The hierarchical structure is described as follows. The goal is placed at the top of hierarchy, and the general criteria are placed at second level. The secondary sub-criteria with respect to each dimension are placed at third level.

Step 2. Building the Pair-wise Comparison Matrix

By the second questionnaires gathered from selected experts, we obtain the relative importance of paired criteria factors at level n+1 under the evaluation of criteria at level *n* by individual experts' opinions, and the pair-wise comparison matrix is accordingly conducted.

Step 3. Calculating Triangular Fuzzy Numbers

Concerning the relative importance of each individual evaluation construct in pair-wise comparison matrix, triangular fuzzy number is calculated to integrate all experts' opinions. It can be used to present the fuzziness of all experts' opinions with respect to the relative importance of paired factors.

$$\tilde{a}_{ij} = (\alpha_{ij}, \beta_{ij}, \delta_{ij}), \tag{7}$$

where

$\tilde{a}_{ij}$: Triangular fuzzy number

α_{ij}: The minimum of the j-th subcriterion subordinated to the i-th general criterion

β_{ij}: The geometric mean of the j-th subcriterion

δ_{ij} : The maximum of the j-th subcriterion subordinated to the i-th general criterion

Step 4. Building the Fuzzy Positive Reciprocal Matrix

After triangular fuzzy numbers are solved to represent the fuzziness of experts' opinions, the fuzzy positive reciprocal matrix A can be further built.

$$A = [\tilde{a}_{ij}] \qquad \tilde{a}_{ij} = [\alpha_{ij}, \beta_{ij}, \delta_{ij}] \tag{8}$$

Step 5. Calculating the Fuzzy Weights of Fuzzy Positive Reciprocal Matrix

In our study, the method developed by Buckley (1985) and improved by Hsu (1998) has been employed to calculate the fuzzy weights. This method is based on the experts' precise value and synthesized the experts' opinions with the geometric mean instead of the fuzzy numbers input directly by experts. Thus, not only the consistency but also the concept of normalization are easily achieved. Through the following formulas, the positive reciprocal geometric mean *Zi* of triangular fuzzy numbers and the fuzzy weight $\overline{W}_i$ can be obtained.

$$Z_i = [\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \times \tilde{a}_{in}]^{1/n}, \forall_i \quad (9)$$

$$\bar{W}_i = Z_i \otimes (Z_1 \oplus Z_2 \oplus \ldots + Z_n)^{-1} \quad (10)$$

$$\tilde{a}_1 \otimes \tilde{a}_2 \cong (\alpha_1 \times \alpha_2, \beta_1 \times \beta_2, \delta_1 \times \delta_2) \quad (11)$$

$$\tilde{a}_1 \oplus \tilde{a}_2 \cong (\alpha_1 + \alpha_2, \beta_1 + \beta_2, \delta_1 + \delta_2) \quad (12)$$

$$Z_1^{-1} = (\delta_1^{-1}, \beta_1^{-1}, \alpha_1^{-1}) \quad (13)$$

$$\tilde{a}_1{}^{1/n} = \{\alpha_1^{1/n}, \beta_1^{1/n}, \delta_1^{1/n}\} \quad (14)$$

Step 6. Defuzzification

Since the weights of all evaluation criteria are fuzzy values, it is necessary to compute a non-fuzzy value by the process of defuzzification. The defuzzified weight *Wi* can be obtained as follows,

$$W_i = \frac{W_{\alpha i} + W_{\beta i} + W_{\delta i}}{3} \quad (15)$$

$W_{\alpha i}$: The right-end value of the fuzzy weight

$W_{\beta i}$: The value of the fuzzy weight with the degree of membership as 1

$W_{\delta i}$: The left-end value of the fuzzy weight

Step 7. Normalization

In order to effectively compare the relative importance among evaluation criteria, we normalize the obtained weights using the following formula.

$$NW_i = \frac{W_i}{\sum_{i=1}^{n} W_i} \quad (16)$$

Step 8. Synthesis of Hierarchy

The weight of each individual evaluation criterion at bottom level can be obtained by the implementation of step 1 through step 7. In addition, the weights of criteria or sub-criteria at upper level are the synthesis of the weights of their subordinations applying the following formula. Hence, the weights of all criteria at every level of hierarchy can be obtained.

$$Nw_k = Nw_i \times Nw_{ip} \quad (17)$$

4. Findings

4.1. Finalizing indicators by fuzzy screening

When experts filled in 20 fuzzy screening questionnaires and results are analyzed, consensus function of each expert was obtained in Table 2.

Table 2
Consensus function of each expert

expert	consensus function	expert	consensus function	expert	consensus function	expert	consensus function
Expert 1	N	Expert 6	VL	Expert 11	M	Expert 16	H
Expert 2	N	Expert 7	L	Expert 12	M	Expert 17	VH
Expert 3	N	Expert 8	L	Expert 13	M	Expert 18	VH
Expert 4	VL	Expert 9	L	Expert 14	H	Expert 19	VH
Expert 5	VL	Expert 10	M	Expert 15	H	Expert 20	OU

The maximum share of each expert opinion with his consensus function regarding each sub-criterion is concerned and total score and result will be obtained based on Table 3 in order to accept or reject each of them. Since this study has been accomplished with the purpose of determining contractors' evaluation and preference worked in the company, criteria such as price, experience, organizational factors, prior function and specialized interview, considered important in determining contractors' prequalification, have been removed. On the other hand, criteria like equipment, technical ability of human force, scheduling and project control, work quality system, proper policies of human resources, certifications, security and standard have been selected to evaluate and prefer the present contractors.

Table 3
Total score and the result of each indicator

Main criteria	sub-criteria	total score	Result	Main criteria	sub-criteria	total score	Result
Price	Proposed price	VH	×	policies pertaining to human resources	cultural fit	VH	×
	how to estimate and breakdown low prices and getting familiar to price list	VH	×		motivating personnel	VH	×
		VH	×		supervising a proper act	OU	✓
Experience and record	experience in similar plans or performing similar actions	VH	×		duely payment of salary and benefits	OU	✓
	having experience in related industry	VH	×		making no mistakes by human resource	VH	×
	having experience in project site	VH	×		specialized training of staff	OU	✓
	company establishment year and its precedence of service	OU	✓		executing professions ranking plan	OU	✓
Equipment	having machinery and equipment and their numbers	OU	✓	Certifications	contractual qualification certification	OU	✓
	maintenance system	OU	✓		membership in specialized association	OU	✓
	Appropriate technology	OU	✓		company rank (competitive status in industry)	OU	✓
technical ability of human resource	the qualification of the number of human force, technicians and key elements	OU	✓	Security and standard	professional security	VH	×
	technicians experience and knowledge and key elements	OU	✓		security management	OU	✓
	staff creativity power	VH	×		observing environmental standards	OU	✓
financial, credit and logistic power	contractor financial power	VH	×	Factors pertaining to customer	responding and flexibility	OU	✓
	bank credit of the last fiscal year	VH	×		the potentiality of supplying necessary requirements of employer	OU	✓
	paying tax over 5 years a go	VH	×		flexibility and responding to unexpected problems	OU	✓
	gross income over the last five years	VH	×		customer management, services and after –sale services	OU	✓
	documented fixed assets	VH	×		the possibly of having strategic long-term relationships	VH	×
	supplying scheduling to complete the project	OU	✓	factors pertaining to contractor	education and records of company manager	VH	×
Scheduling and project control	taking action based on planning and having no unauthorized delay in previous projects	OU	✓		executive record of managing director	VH	×
	comprehensive system of planning and project control	OU	✓		effective management and proper management system for taking action	VH	×
	duration of proposed job	OU	×		the benefit of continuing contractor activity	VH	×
	supplying scheduling to complete the project	OU	✓		steady positions of members of board of directors and technicians	VH	×
quality	executive bid for improving quality	OU	✓		work limit	VH	×
	having documentaries in quality management system	OU	✓		customization of contractor	VH	×
	technical ability and equipment in quality control unit	VH	×		public credit	VH	×
	creativity of quality control unit	VH	×	past function	previous long-term relationships and relationships closeness	VH	×
Organizational factors	Organizational structure	VH	×		failures and accidents in previous projects	VH	×
	Sustainability and organizational maturity	VH	×		scale of previous projects	VH	×
					Well record in previous actions and satisfaction of previous employers (contractor popularity)	VH	×
				specialized interview	specialized interview	VH	×

4.2. Weighting and ranking the main criteria by fuzzy analytical hierarchy process(Fuzzy AHP)

Dimensions of the main criteria confirmed in fuzzy screening are demonstrated in Table 4.

Table 4
Name and symbol of the main criteria

C1	C2	C3	C4	C5	C6	C7	C8
Equipment	technical ability of human resource	Scheduling and project control	quality	policies pertaining to human resources	Certifications	Security and standard	Factors pertaining to customer

After 15 experts filled up questionnaires, data has been collected, a questionnaire was definitely designed and completed for ease of use, absolute numbers were converted to triangular fuzzy numbers and based on Table 5 all opinions were combined obtained results were analyzed by means of comparison matrix of the main criteria.

Table 5
Integration of experts' opinions

	C1			C2			C3			C4		
C1	1	1	1	0.14	0.56	5	0.14	1.66	6	0.17	1.01	8
C2	0.2	1.80	7	1	1	1	0.25	2.34	6	0.25	1.74	6
C3	0.17	0.54	7	0.17	0.42	4	1	1	1	0.14	0.61	5
C4	0.125	0.99	6	0.17	0.57	4	0.2	1.88	7	1	1	1
C5	0.11	0.67	4	0.11	0.52	6	0.11	0.69	6	0.13	0.72	8
C6	0.11	0.24	2	0.11	0.2	2	0.11	0.32	3	0.11	0.33	5
C7	0.17	1.7	9	0.14	0.95	9	0.25	2.59	9	0.25	2.24	9
C8	0.17	0.85	5	0.13	0.5	3	0.13	1.03	5	0.14	0.88	5
	C5			C6			C7			C8		
C1	0.25	1.49	9	0.5	4.13	9	0.11	0.64	6	0.20	1.2	6
C2	0.17	1.93	9	0.5	4.96	9	0.11	0.97	7	0.33	2.0	8
C3	0.17	1.57	9	0.33	3.27	9	0.11	0.44	4	0.20	1.0	8
C4	0.13	1.39	8	0.20	3.36	9	0.11	0.48	4	0.20	1.1	8
C5	1	1	1	1	2.95	9	0.11	0.38	6	0.14	0.8	6
C6	0.11	0.34	1	1	1	1	0.11	0.22	0.50	0.13	0.3	4
C7	0.17	2.83	9	2	4.7	9	1	1	1	0.25	2.9	9
C8	0.17	1.27	7	0.25	3.55	8	0.11	0.37	4	1	1	1

Weighting and ranking main criteria were accomplished by fuzzy analytical hierarchy process based on data in Table 5 and their results are mentioned in Table 6. According to quantities presented in Table 6, the most important criteria of contractors' evaluation and preference determined through fuzzy analytical hierarchy process are security (0.0179), technical ability of human force (0.015) and equipment (0.0138).

Table 6
Weighting and ranking main criteria using FAHP

Main criteria	Fuzzy weight	Ranking
Equipment	0.138	3
Technical ability of human resource	0.150	2
Scheduling and project control	0.126	6
Quality	0.128	4
Policies pertaining to human resources	0.1263	5
Certifications	0.046	7
Security and standard	0.179	1
Factors pertaining to customer	0.106	8

4.3. Weighting an ranking sub-criteria by fuzzy analytical hierarchy process

According to the above-mentioned descriptions of main criteria, sub-criteria were weighted and ranked after converting absolute numbers to triangular fuzzy numbers in terms of integrating opinions and achieving a united idea.

5. Conclusion

As it is cited in this study, evaluation criteria and contractors preferences have been accomplished based on experts' opinions then mention criteria have been weighted and preferred. Therefore, the findings are observable in Table 7.

Table 7
Fussy weight of the main criteria and sub-criteria by FAHP

Main criteria	Fuzzy weight	sub-criteria	Fuzzy weight
Equipment	0.138	Having machinery and equipment and their numbers	0.38
		Maintenance system	0.29
		Appropriate technology	0.32
Technical ability of human resource	0.15	The qualification of the number of human force, technicians and key elements	0.36
		Technicians experience and knowledge and key elements	0.42
		Staff creativity power	0.22
Scheduling and project control	0.1262	Supplying scheduling to complete the project	0.30
		Taking action based on planning	0.37
		Comprehensive system of planning and project control	0.33
Quality	0.128	Executive bid for improving quality	0.34
		Having documentaries in quality management system	0.26
		Technical ability and equipment in quality control unit	0.39
Policies pertaining to human resources	0.1263	Supervising a proper act	0.31
		Duely payment of salary and benefits	0.34
		Specialized training of staff	0.35
Certifications	0.046	Contractual qualification certification	0.45
		Company rank	0.55
Security and standard	0.179	Professional security	0.45
		Security management	0.41
		Observing environmental standards	0.14
Factors pertaining to customer	0.106	Responding and flexibility	0.24
		The potentiality of supplying necessary requirements of employer	0.27
		Flexibility and responding to unexpected problems	0.26
		Customer management, services and after –sale services	0.22

Today decisions are being made in situations that are increasingly complicated. In many cases, driving a benefit of experts of different fields is required since criteria will be selected and weighted due to experts' intellectual judgment in fuzzy space. In previous studies contractors' prequalification for participation in tenders were discussed and criteria like proposed price, financial power, career records and experiences of contractors were recognized as the most important criteria. This study aimed at evaluating, ranking authorized contractors who won tender, and now they are working in the company through contracts. In evaluating those contractors' criteria such as equipment, technical power of human force, quality system, scheduling, project control, security and standards, factors related to employer, certifications were selected according to experts' opinions and the preference of each criterion and the sub-criterion have been specified in Table 9 using fuzzy analytical hierarchy process. As we can see from the results of Table 7, the most important sub-criteria of the main ones consist of company rank (score 0.055), contractor qualification certificate (0.045), among sub-criteria certifications (0.46), number of accidents in previous projects (0.045), among security and standard criteria (0.179), technicians knowledge and experiences and key elements (0.042) and technical power of human forces (0.015).

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