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Contractors' Self-Qualification Using Fuzzy Approach

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***Abstract*—** *After selection of contractor in a bid, the first question for unselected contractors is the reason of their loss. This helps them to improve their qualification and increase their chance for satisfaction in future. Criteria that are important in contractor qualification are contractor organization, financial consideration, management resources, past experiences, and past performance, among others. As contractor qualification is a multi-objective procedure, including inexact, vague and qualitative criteria, fuzzy approach seems to be appropriate for judgement. In this paper, utilizing fuzzy set theory, criteria that are important for bidders are ranked. According to the results, Management resources is the most and Contractors' organization is the least important criterion for bidders. This ranking, helps contractors to find the easiest way to improve their qualifications.*

***Keywords*—** *Qualification, contractor, bidding, fuzzy set theory, ranking.*

I. INTRODUCTION

To ensuring the success of construction projects, contractor selection is a crucial decision making process. At first, a large number of potential contractors are invited and investigated via a set of criteria and then a short list is established for prequalification stage. Second, in bid evaluation stage the appropriate contractor is selected from the short list. In bid evaluation stage, named prequalification stage, incompetent and inexperienced contractors are eliminated from consideration. Contractor selection is a multi-criteria problem. Holt *et al.*, 1994-a, established decision criteria framework. These criteria includes contractor's organization, financial consideration, management resources, past experiences, past performance, among others. Each of these criteria are divided to various sub criteria. Several models for prequalification are discussed in the literatures. Most of the papers are based on subjective judgement or qualitative analysis (Russell and skibniewski 1988, 1990). Evidential reasoning theory and the degree of belief was used to elicit decision makers' preferences by Sonmez*et al.*, (2002). Elazouni 2006, used neural network for contractor selection. Rashvand *et al.*, 2015, reports on the results of a study to develop a comprehensive contractor evaluation model that directly addresses the contractor management capabilities and practices as a critical additional element at the prequalification stage. Korytárová*et al.*, 2015, have been studied information about qualification criteria on the sample of 345 tenders for public works contracts, in particular for road structures, schools and water and sewage facilities and equipment in Czech Republic and Poland. Analytical part focuses on the extent of qualification criteria use and discusses their application in the context of ensuring fairness of the competition with regard to non-discriminatory nature of the qualification. Support vector machines (SVM) has been used by Attar, *et al.*, 2013, to forecast a contractor's deviation from a client's objectives.

Traditional models ignored vagueness, uncertainty and human behavior inherent in construction project. Traditional models ignored vagueness, uncertainty and human behavior inherent in construction project. The multi-criteria process of selection, involves inexact, uncertain, incomplete and qualitative information that is difficult to measure. Fuzzy set theory proposed by Zadeh 1965, enables qualifying imprecise information to make decisions based on incomplete data. Lin and Chen 2004, proposed a fuzzy approach that assessments are described in linguistic terms, whereas screening criteria are weighted by their relative importance. Singh and Tiong 2005, proposed a fuzzy framework where linguistic variables are constructed based on fuzzy number theory and shapely value is used to determine relative importance of each attribute.

For contractors, prequalification can be taken as external auditing of their capabilities. One of the questions for contractors after losing a bid is the reason of failure. Some of the criteria are somehow out of the control of the contractor. For example, financial standing and past experience problems are those parameters that cannot be modified in short time, but some of their sub criteria may be adjustable. It is desirable for contractor to know that which sub criteria have more attention is qualification.

In this paper, fuzzy set theory is used to determine that which sections in criteria structure is more important for prequalification. The results of this research, helps contractors to amend their abilities and to increase their chance in bid winnings. In this regard, first, the parameters that are involved for contractor selection is discussed. Then, after mentioning the fuzzy logic principles, an approach to ranking criteria and sub criteria is presented.

II. PREQUALIFICATION VARIABLES

In this paper, the decision criteria set presented by Holt *et al.*, 1994-a, is applied. Their developed method, evaluate contractor prequalification criteria and introduced guidelines for identified criteria and their weights. The Holt *et al.*, 1994-a, variables are according to Fig. 1.

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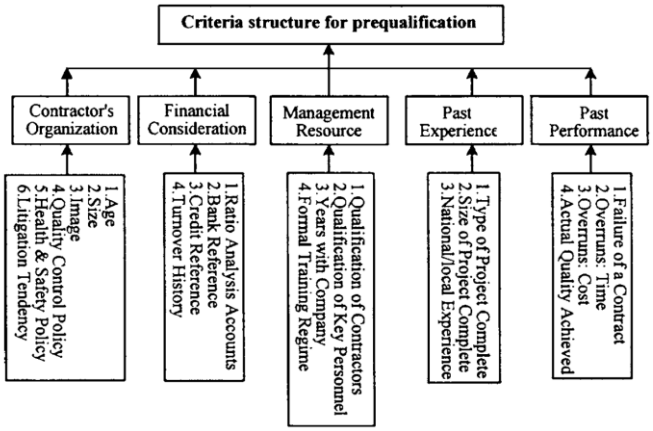

Fig. 1. Prequalification variables (Based on Holt *et al.*, 1994-a)

The definition of each sub criterion is as follows:

Size investigates the adequacy of contractors' resources to undertake the project. For this, the maximum required financial commitment by contractor should compared with contractor capacity.

Age shows stability, reliability and accrued experience. Trading company under the same company name within the construction sector for a specified period (at least three years) is important.

Image is recognized by contractors' membership in trade or specialist associations.

Quality control policies are the procedures adopted by a member or an accounting firm to provide reasonable assurance that the firm and its personnel comply with professional and engagement standards and regulatory and legal requirements and that reports issued by the firm or engagement partners are appropriate. British Standard 5750 is useful in this case.

Health and Safety Policy is promoted and enforced by ACT 1974.

Litigation tendency answers the question that if the contractor is defendant or plaintiff. There is an intrinsic link between litigation tendency and claim consciousness which can be determined by observing cost overruns.

Ratio analysis accounts offers statements that are valuable against norms or critical limits and information for the purpose of trend observation.

Bank reference demonstrates if the contractor have been with its bankers for a minimum period of three years.

Credit reference should be from suppliers of enough trading history. Otherwise, the supplier may be one who is being promptly paid because the service being supplied are crucial to the contractor's business.

Turnover history mirrors a contractor's trading for a given period with an increase in turnover representing growth. Turnover should increase by more than the rate of inflation if the business is progressing. A steady increase in turnover is a positive sign.

Qualification of company owners is important dependent upon the nature and size of the organization. For example, a director of a small private company whilst being an owner, is also a manager and hence is deeply involved in daily works. Conversely, public company owners are the shareholders for whom the majority have little to do with daily management activities.

Qualification of key personnel is crucial to successful project outcome. The quality of supervisory personnel assigned to a contract reflects on the total efficiency of a contractor's efforts, the key man in the process being the site manager. Academic qualification, membership of a professional institute, age range (optimum 30-40 years) and experience overseas are four key evaluation areas that can be considered.

Key personnel years with company reflects how manager is familiar with company organizational structure.

Formal training regime shows how managers coordinate resources to achieve their company's and client's objectives. Formal training should be complemented by exercising an internal system of departmental work experience.

Type of projects completed provides if the contractor has the requisite experience, i.e., similar project nature, scope and size.

Size of projects completed gives insight to the contractor's potential ability to commit adequate resources to a large project and to scale down operations from major works to small contract. The project should not be so small relative to a contractor's normal size of project.

National or local experience determined geographic areas of operation. Company size is a prime determinant of whether it may be classified as national or local. A national company will have greater geographic experience perhaps achieved through a network of regional offices. A national company has wider catchment and therefore greater ability to tackle certain type of contracts. Establishing trading links with local suppliers and labor is more difficult in new areas.

Failure to have completed a contract is against contractor obligations under a contract. If a contractor has failed to complete a contract then the reason must be established. A maximum score is awarded to a contractor who has never failed to complete a contract or where the fault for non-completion does not lie with the contractor.

Time overruns occur when projects or tasks within a project is not completed by the time the project plan specifies. This can occur when materials to complete a project are back ordered and work cannot be completed until the materials arrive. Sometimes, labor shortages can cause work to be completed slower than anticipated.

Cost overruns may occur because of unfavorable price fluctuations, variations in the work or monetary claims by the contractor.

Actual quality achieved investigates past clients' levels of satisfaction with the quality of previous works by the contractor.

III. Fuzzy Set Concept

Traditional set theory is predicted on fundamental binary relationship between an object and a set. The object is either a member of the set, or it is not a member of the set. The traditional approach would be to map a given performance as either pass or fail. By contrast, fuzzy set theory allows the mapping of objects as partially in a set (Zadeh 1983, 1999). Rather than using an in or out approach, an object can be part

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in and part out. FST allows to include the universe between 0 and 1. This is why FST seems to be appropriate to assess or judge in an interrelated with a high degree of complexity areas. In fuzzy set approach, the uncertainty is handled through membership functions. Zadeh 1965, demonstrated that membership is a matter of degree. As explained by Klir and Yuan 1995, the proposition is not necessarily either true or false, as required by two value logic, but it may be true only to some degree. In fuzzy set theory, the world is gray, not black and white. In other words, facts are rarely completely true or false, but the truth is found in a little of both. In many cases, a partial membership in both areas of true and false is the appropriate position. The key is to determine if this gray are is acceptable in cases where any mistake and human error is not tolerable.

IV. Fuzzy Approach to Self-Qualification

4.1. Fuzzy Numbers and Linguistic Variables

A triangular fuzzy number is a particular fuzzy set F, and its membership function $\mu F(x)$ is a continuous linear function as Eqs. (1)-(3), Cakir and Canbolat, 2008:

$$F \subseteq \Re \tag{1}$$

$$\mu F(x): \Re \to [0,1] \tag{2}$$

$$\mu F(x) = 0 \text{ for all } x \in (-\infty, l] \cup [u, +\infty) \text{ and } \mu F(x) = 1 \text{ for } x = m \tag{3}$$

Where $l, m, u \in \Re$; l and u are lower and upper bounds, respectively and m is the most likely value of F. $\mu F(x)$ is monotonically increasing when $x \in [l, m]$ and monotonically decreasing when $x \in [m, u]$. Fig. 2, illustrates a triangular fuzzy number. Therefore, a triangular fuzzy number can be defined as a triplet (l, m, u). Its membership function is as follows:

$$\mu F(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \tag{4}$$

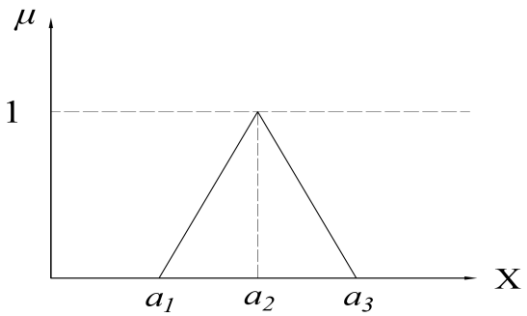

Fig. 2. Illustration of a triangular fuzzy number.

If $A(a_1, a_2, a_3)$ and $B(b_1, b_2, b_3)$, be two fuzzy number, the distance between them, through Euclidean distance measurement, can be calculated as:

$$dist(A, B) = \left(\frac{1}{3} \sum_{i=1}^{3} (a_i - b_i)^2 \right)^{1/2} \tag{5}$$

A fuzzy linguistic variable is an expression that describes a collection of values. Linguistic variables refer to the evaluation of the importance degree in evaluation of a given criterion, whereas linguistic variable values refer to the evaluation of the degree of materials satisfying the criterion. In this paper, seven linguistic variables to express the importance degree of criteria (very low, low, moderate low, moderate, moderate high, high, and very high) are used, according to Fig. 3 and Table I.

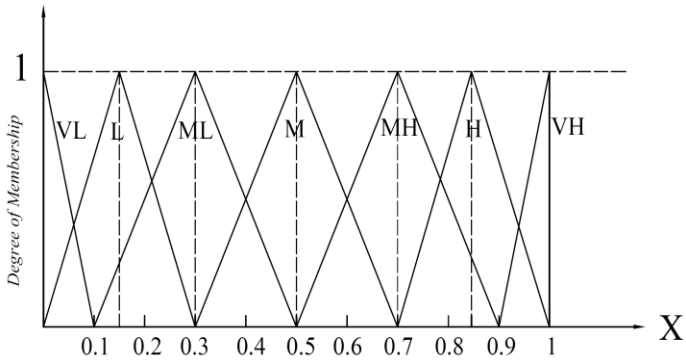

Fig 3. Membership function of linguistic variables

TABLE I. Linguistic variablesand related fuzzy numbers.

Linguistic variables	Fuzzy numbers
Very low (VL)	(0,0,0.1)
Low (L)	(0,0.15,0.3)
Moderate low (ML)	(0.1,0.3,0.5)
Moderate (M)	(0.3,0.5,0.7)
Moderate high (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.85,1.0)
Very high (VH)	(0.9,1.0,1.0)

4.2. Model Development

Assuming that a set of criteria that is important for self-qualification are

$$C = (c_1, c_2, c_3, \ldots, c_n) \tag{6}$$

Where $c_j = j$th criteria, $j = 1, 2, \ldots, n$. Each criteria can be valued by m sub-criteria, and then factor set is

$$SC = (sc_1, sc_2, sc_3, \ldots, sc_m) \tag{7}$$

Where $sc_i = i$th criteria, $i = 1, 2, \ldots, m$.

According to Table I, the importance of each criteria, wc_j, and rating of each sub-criteria, rsc_i are assessed by decision makers. Therefore, the fuzzy evaluation value of each criteria can be calculated (Chen 2001) as:

$$FEV_j^* = \sum_{i=1}^{m} (wc_j \otimes rsc_i) \tag{8}$$

The obtained $FEV_j^* = (f_1^j, f_2^j, f_3^j)$ should be normalized to obtain the final fuzzy evaluation value of each criteria:

$$FEV_j = \frac{FEV_j^*}{f_3^*} \tag{9}$$

Where

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$$f_3^* = \max_j f_3^j \quad (10)$$

4.3. Ranking Criteria

According to Eq. 9, the fuzzy rating of each criterion has been obtained. It is denoted as a fuzzy number, so ranking of these fuzzy numbers should be done to achieve the ranking order of each criterion. Sengupta 1998; Gonzalez 1990; Yager 1981, have been proposed several methods for ranking fuzzy numbers. In this paper, three approaches, i.e., weight center, fuzzy TOPSIS, and simple defuzzification methods are provided.

4.3.1. Weight center method (WCM)

For a fuzzy number, $A(a_1, a_2, a_3)$, the weight center can be defined as:

$$W_A = \frac{\int_X \mu_A(x)\, x dx}{\int_X \mu_A(x)\, dx} \quad (11)$$

Regarding the fuzzy triangular number, the weight center can be calculated as:

$$W_A = \frac{a_1 + a_2 + a_3}{3} \quad (12)$$

In our analysis, the fuzzy number, A, is the calculated FLD_j for each criterion.

4.3.2. Fuzzy TOPSIS method (FTM)

TOPSIS is a crisp multi-criteria decision making method, assuming that the best selection should be as close as possible to the ideal solution and the farthest from the negative ideal solution (Triantaphyllou and Lin 1996). Tsao 2003, combined TOPSIS and fuzzy number theory to propose FT method. According to this method, the final ranking of each criterion is obtained by:

$$FR_j = \frac{D_j^+}{D_j^+ + D_j^-} \quad (13)$$

Where D_j^+ and D_j^- are the Euclidean distance between FLD_j and the ideal solution G_A and negative ideal solution B_A, respectively.

For simplification, in this study, the ideal solution and negative ideal solution are defined as:

$$G_A = (1,1,1), \qquad B_A = (0,0,0) \quad (14)$$

4.3.3. Simple defuzzification method (SDM)

Defuzzification is an inverse transformation that maps the output from the fuzzy domain into the crisp domain. After fuzzy calculation, there is a linguistic output variable that should be translated to crisp value. According to Kaufmann and Gupta 1991; Cheng and Liu 2002; Sing and Tiong 2005, the defuzzification formula of a triangular fuzzy number is as follows:

$$e = (a_1 + 2a_2 + a_3)/4 \quad (15)$$

Based on Eq. 15, the ranking order of each criterion is obtained.

V. Problem Analysis

Three approaches, WCM, FTM, and SDM, are used to determine five criteria ranking order.

At first, the relative importance of the criteria should be determined. For the analysis method, the results obtained from Holt *et al.*, 1994-a, are used. Holt *et al.*, 1994-b, presented the results of a survey of 53 U.K. construction organizations, which revealed their perceived importance of factors influencing their choice of contractors. Weighting index was determined by using the relative index ranking technique and considering each factors' frequency.

TABLE II. Ranking order of variables refers to Holts, et al. 1994-a.

Criteria	Sub-Criteria	Factor Rank (Holts, et al. 1994-a)	Sub-Criteria Linguistic /Fuzzy Numbers	Overall Rank (Holts, et al. 1994-b)	Criteria Linguistic /Fuzzy Numbers
1- Contractors' organization	Size	4	M (0.3,0.5,0.7)	18	ML (0.1,0.3,0.5)
	Age	5	ML (0.1,0.3,0.5)	19	
	Image	6	L (0,0.15,0.3)	20	
	Quality Control Policy	3	MH (0.5,0.7,0.9)	17	
	Health & Safety Policy	1	VH (0.9,1,1)	13	
	Litigation Tendency	2	H (0.7,0.85,1)	15	
2- Financial consideration	Ratio Analysis Acount	4	M (0.3,0.5,0.7)	12	MH (0.5,0.7,0.9)
	Bank Reference	1	VH (0.9,1,1)	8	
	Credit Reference	3	MH (0.5,0.7,0.9)	11	
	Turnover History	2	H (0.7,0.85,1)	9	
3- Management resource	Qualification of owners	3	MH (0.5,0.7,0.9)	7	H (0.7,0.85,1)
	Q. of Key Persons	4	M (0.3,0.5,0.7)	10	
	Years with CO	2	H (0.7,0.85,1)	5	
	Formal Training Regime	1	VH (0.9,1,1)	2	
4- Past experience	T. of Projects Completed	3	MH (0.5,0.7,0.9)	4	VH (0.9,1,1)
	S. of Projects Completed	1	VH (0.9,1,1)	1	
	National or Local	2	H (0.7,0.85,1)	3	
5- Past performance	Failure to Have Completed Contract	1	VH (0.9,1,1)	6	H (0.3,0.5,0.7)
	Overruns: Time	4	M (0.3,0.5,0.7)	16	
	Overruns: Cost	3	MH (0.5,0.7,0.9)	14	
	Actual Quality Achieved	2	H (0.7,0.85,1)	9	

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The results of the survey is as Table II, column 3 and column 5. In this paper, these results are transferred to linguistic variables, according to Fig. 3 and Table I. In each criterion, to define the importance factor of each sub-criterion, VH is assigned to the factor rank 1, H is assigned to the factor rank 2, and so on (see Table II. Column 4). To find the importance factor of each criterion among criteria, the average of sub-criteria corresponding to that criterion is calculated. VH is assigned to the criterion that have the highest average of sub-criteria, H is assigned to the criterion that have the second average of sub-criteria, and so on (see Table II. Column 6).

VI. Results

Based on Eqs. 8-10, fuzzy evaluation value of each criteria is calculated:

$$FEV_1^* = \begin{pmatrix} 0.1+0.3+0+0.5+ \\ 0.9+0.7, 0.3+0.15+0.5+ \\ 0.7+1+0.85, 0.5+0.7+0.3+0.9+ \\ 1+1 \end{pmatrix} \otimes$$

$$(0.1, 0.3, 0.5) = (0.25, 1.05, 2.2)$$

$$FEV_2^* = \begin{pmatrix} 0.3+0.9+0.5+ \\ 0.7, 0.5+1+0.7+0.85, \\ 0.7+1+0.9+1 \end{pmatrix} \otimes (0.5, 0.7, 0.9)$$

$$= (1.2, 2.135, 3.24)$$

$$FEV_3^* = \begin{pmatrix} 0.5+0.3+0.7+0.9, \\ 0.5+0.85+0.7+1, \\ 0.9+0.7+1+1 \end{pmatrix} \otimes (0.7, 0.85, 1)$$

$$= (1.68, 2.59, 3.6)$$

$$FEV_4^* = \begin{pmatrix} 0.5+0.9+0.7, \\ 0.7+1+0.85, \\ 1+1+0.9 \end{pmatrix} \otimes (0.9, 1, 1)$$

$$= (1.89, 2.55, 2.9)$$

$$FEV_5^* = \begin{pmatrix} 0.9+0.3+0.5+0.7, \\ 0.5+0.7+0.85+1, \\ 0.7+0.9+1+1 \end{pmatrix} \otimes (0.3, 0.5, 0.7)$$

$$= (0.72, 1.53, 2.52)$$

$$f_3^* = \max f_3 = 3.6$$

$$FEV_1 = (0.25, 1.05, 2.2)/3.6 = (0.069, 0.292, 0.611)$$

$$FEV_2 = (1.2, 2.135, 3.24)/3.6 = (0.333, 0.593, 0.9)$$

$$FEV_3 = (1.68, 2.59, 3.6)/3.6 = (0.467, 0.719, 1)$$

$$FEV_4 = (1.89, 2.55, 2.9)/3.6 = (0.525, 0.708, 0.806)$$

$$FEV_5 = (0.72, 1.53, 2.52)/3.6 = (0.2, 0.425, 0.7)$$

Ranking order based on WCM:

$$W_1 = \frac{0.069+0.292+0.611}{3} = 0.324$$

$$W_2 = \frac{0.333+0.593+0.9}{3} = 0.609$$

$$W_3 = \frac{0.467+0.719+1}{3} = 0.729$$

$$W_4 = \frac{0.525+0.708+0.806}{3} = 0.680$$

$$W_5 = \frac{0.2+0.425+0.7}{3} = 0.442$$

$$W_3 > W_4 > W_2 > W_5 > W_1$$

So the overall rank order is: Management resource, Past experience, Financial consideration, Past performance, and Contractors' organization.

Ranking order based on SDM:

$$e_1 = \frac{0.069+2\times0.292+0.611}{4} = 0.316$$

$$e_2 = \frac{0.333+2\times0.593+0.9}{4} = 0.605$$

$$e_3 = \frac{0.467+2\times0.719+1}{4} = 0.726$$

$$e_4 = \frac{0.525+2\times0.708+0.806}{4} = 0.687$$

$$e_5 = \frac{0.2+2\times0.425+0.7}{4} = 0.438$$

$$e_3 > e_4 > e_2 > e_5 > e_1$$

Ranking order based on FTM:

$$dist(FEV_1, G_A) = \left(\frac{1}{3}\left((0.069-1)^2 + (0.292-1)^2 + (0.611-1)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.711$$

$$dist(FEV_1, B_A) = \left(\frac{1}{3}\left((0.069-0)^2 + (0.292-0)^2 + (0.611-0)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.393$$

$$FR_1 = \frac{0.711}{0.711+0.393} = 0.644$$

$$dist(FEV_2, G_A) = \left(\frac{1}{3}\left((0.333-1)^2 + (0.593-1)^2 + (0.9-1)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.455$$

$$dist(FEV_2, B_A) = \left(\frac{1}{3}\left((0.333-0)^2 + (0.593-0)^2 + (0.9-0)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.651$$

$$FR_2 = \frac{0.455}{0.455+0.651} = 0.411$$

$$dist(FEV_3, G_A) = \left(\frac{1}{3}\left((0.467-1)^2 + (0.719-1)^2 + (1-1)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.348$$

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$$dist\left(FEV_3, B_A\right) = \left(\frac{1}{3}\left(\left(0.467-0\right)^2 + \left(0.719-0\right)^2 + \left(1-0\right)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.760$$

$$FR_3 = \frac{0.348}{0.348+0.76} = 0.314$$

$$dist\left(FEV_4, G_A\right) = \left(\frac{1}{3}\left(\left(0.525-1\right)^2 + \left(0.708-1\right)^2 + \left(0.806-1\right)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.341$$

$$dist\left(FEV_4, B_A\right) = \left(\frac{1}{3}\left(\left(0.525-0\right)^2 + \left(0.708-0\right)^2 + \left(0.806-0\right)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.689$$

$$FR_4 = \frac{0.341}{0.341+0.689} = 0.331$$

$$dist\left(FEV_5, G_A\right) = \left(\frac{1}{3}\left(\left(0.2-1\right)^2 + \left(0.425-1\right)^2 + \left(0.7-1\right)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.595$$

$$dist\left(FEV_5, B_A\right) = \left(\frac{1}{3}\left(\left(0.2-0\right)^2 + \left(0.425-0\right)^2 + \left(0.7-0\right)^2\right)\right)^{\frac{1}{2}}$$

$$= 0.487$$

$$FR_5 = \frac{0.595}{0.595+0.487} = 0.55$$

$$3 > 4 > 2 > 5 > 1$$

VII. Conclusions

Self-qualification is very essential for contractors to win a bid. The procedure is inexact and uncertain because qualification is multi objective process with many qualitative and vague parameters. In this gray environment, fuzzy set theory is more appropriate than others.In this paper, a fuzzy approach is used to rank the criteria that are considered for qualification of contractors. According to the results, Management resource, Past experience, Financial consideration, Past performance, and Contractors' organization are relatively important to bidders for pre-qualification. Therefore, if a contractor wants to improve the chance to win, improving management resources is most effective and improving the organization is less effective.

VIII. Compliance with Ethical Standards

Arash Naji, declares that he has no conflict of interest. Samaneh Sadat Mousavi Nik, declares that she has no conflict of interest.

This article does not contain any studies with human participants or animals performed by any of the authors.

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