Fifth International Conference on Construction in the 21st Century (CITC-V)
"Collaboration and Integration in Engineering, Management and Technology"
May 20-22, 2009, Istanbul, Turkey

A Fuzzy Logic Approach for Contractor Selection

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Abstract
Contractor selection is the process of selecting the most appropriate contractor to deliver the project with specified quality, time, and cost. Construction clients had realized through the last decades that the lowest price bid is not always the best. Evaluation of contractors based on multi-criteria basis is, therefore, becoming more important to the construction industry. In most countries, contractor selection is done upon regulating laws that take into consideration different circumstances involved in the industry. In Egypt, for example, tender law is evaluating contractors according to both technical and financial basis, but no specific technical criteria were determined in each type of construction industry. This paper presents a fuzzy logic framework to help decision-makers to evaluate the capability of the contractors in residential building projects. An in-depth literature review of the criteria that may affect prequalifying and selecting the appropriate contractor in different countries are presented. Semi-structured interviews were conducted with construction experts to select the appropriate criteria that suit Egyptian industry. An illustrative example is then presented to demonstrate the data requirements and the application of the method in selecting the most appropriate contractor for residential building projects.

Keywords
Contractor selection, Multi-criteria, Fuzzy logic, Tender law

1. Introduction

Contractor selection is one of the most important processes of construction industry, as this process leads to either good or bad level of owner's achieving goals regarding cost, time and quality of a project. In Egypt, the selection of the contractor is mainly associated with the lowest price, but lowest bid price is not always the best (Egyptian Law of Contracting, 1998). The lowest bid price method may lead to poor quality, construction delays, and many more consequences which results in more expenses. In private sector, it is not absolutely essential to select the lowest bid price. But in most cases the price is the governing factor (El Agroudy, 2008).

Many researchers have identified the criteria for contractor selection. For example, Hatush and Skitmore (1997) identified universal criteria for prequalification and bid evaluation, and the means by which different emphasis can be accommodated to suit the requirements of clients and projects. In another work, the Department of Treasury and Finance, Australia (1999) introduced guidelines for tender evaluation using weighted criteria for building works and services. Rather than automatically accepting the lowest price, the tender assessment process applies weighting for skills, quality, experience and previous performance in a manner to ensure value for money. The analytical hierarchy process (AHP) was used to assist in the contractor selection process. It identifies contractors with the best potential to deliver satisfactory outcomes in a final contractor selection process which is not based simply on the lowest bid **(**Fong and Choi, 2000**)**. Mahdi and Fereig (2001) introduced an approach to structuring a Decision Support System (DSS) to select the optimum contractor. The objective of that DSS was to match the contractor's characteristics with the project's individuality. A knowledge-based expert system was developed to assist the decision-makers in selecting the optimum contractor. Sonmez *et al*., (2001) used a multiple criteria decision-making method in order to deal with uncertain, incomplete, or imprecise assessments due to lack of information, time pressure and/or shortcomings in expertise as well as for the meaningful and robust aggregation. This paper addressed these issues by applying an evidential reasoning approach to a contractor prequalification problem. Shen *et al*., (2003) presented a computer-aided decision support system for assessing a contractor's competitiveness. Measures of competitiveness were employed to describe a contractor's strengths and weaknesses, thus to assist project clients in identifying proper contractors at the pre-qualification stage. In another work, Shen *et al*., (2004) investigated the characteristics of construction business environment in China and identifies the key parameters used in assessing contractors' competitiveness for awarding construction contracts. A multi-criteria decision-making (MCDM) system is used for contractor selection Cheng and Li (2004). The AHP had been used as a tool for MCDM. However, AHP can only be employed in hierarchical decision models. Wong (2004) outlined the use of clients' tender evaluation preferences for predicting a contractor performance via a logistic regression (LR) approach. A total of 31 clients' tender evaluation criteria were selected to develop a LR model for predicting contractor performance. Nossair *et al*., (2005) discussed different methods for contractor selection. The criteria affecting the evaluation of tenders in competitive bidding are determined. From the results of a questionnaire survey, the weights for the different parameters are determined. Shen *et al*., (2006) identified the key Competitiveness Indicators (KCIs) for assessing contractor competitiveness in the Chinese construction market. An index value is used to indicate the relative significance of various indicators based on which KCIs are identified.

Waara and Bröchner (2006) explained how public owners use multiple criteria for the award of construction contracts. It is likely that non price criteria support the alignment of owner and contractor interests, and that bidder behavior should be affected by the likelihood of repeated contracts, and by the transparency of owners' evaluation procedures. The work done by (Lam *et al*., 2001) aimed to improve the objective of contractor prequalification. Using fuzzy neural network (FNN) model, eighty-five cases with detailed decision criteria and rules for prequalifying Hong Kong civil engineering contractors were collected. These cases were used for training and testing the FNN model. The research made by Singh and Tiong (2004) aimed to develop a fuzzy decision model for construction contractor selection involving investigating multiple criteria selection tendencies of construction clients, relationship among decision criteria, and construction client's preferences of criteria in the contractor selection process. They presented a systematic procedure based on fuzzy set theory to evaluate the capability of a contractor to deliver the project as per the owner's requirements. Li *et al*., (2007) proposed a fuzzy framework to solve construction contractor prequalification which is a crucial decision making process to select capable potential bidders and ensure the success of construction projects. That framework included decision criteria analysis, weights assessment, and decision model development.

This study aims to define the main criteria for prequalifying and evaluating construction contractors in competitive bidding of building construction in Egypt for both public and private sectors. Then, the relative weight of each criterion is determined through a questionnaire survey distributed among different construction parties: clients, consultants, and contractors. A fuzzy logic model is then developed to build a framework for contractor selection to investigate contractor's capabilities against inexact, vague, and qualitative criteria. Accordingly, an illustrative example is used to demonstrate the applicability of the developed model.

2. Identifying the Most Effective Criteria for Contractor Selection

By reviewing the literature, it was found that there are many factors that could affect the prequalification and selection process of the appropriate contractor. Those factors vary in their importance and strength of affect in the selection procedure. Some factors may have high effect in the selection at certain place and at the same time the effect is low in the Egyptian market. Also, some factors may be considered not effective at all. So, in order to choose and identify the most factors that have high effect in selecting the appropriate contractor, the factors had to be revised by expertise in Egypt. Accordingly, after the collection of these criteria, semi-structured interviews were conducted with twelve construction experts whose experiences are more than 20 years to select the most important criteria from the collected ones. In these interviews, criteria were listed and then combined, and finally selected to suit the construction industry in Egypt. The final 35-criteria list that is believed to affect the contractor selection is determined. These criteria are classified into seven major groups as shown in Figure 1.

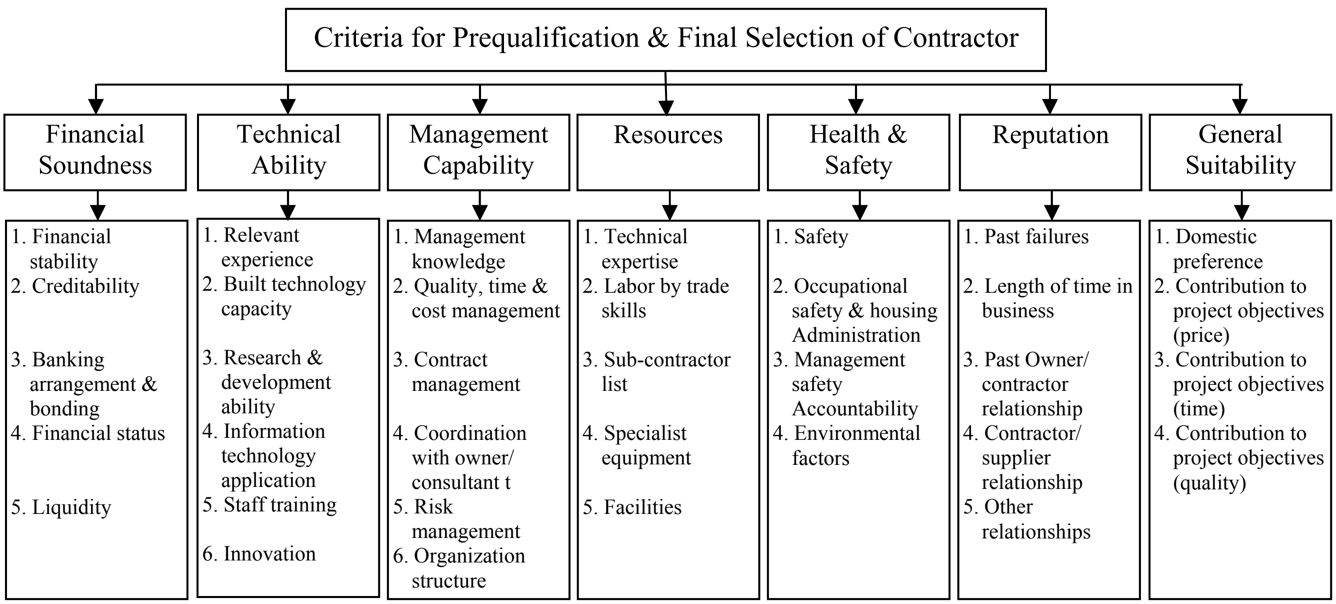

Figure 1: Criteria for Prequalification and Final Selection of Contractor

After this initial screening, an attempt is made to shorten the 35-criteria list to determine the highly effective criteria. In order to determine the weight and relative importance of each criterion, a questionnaire survey is designed and distributed among the different construction parties, namely: owners, consultants, and contractors. The questionnaire was designed on a numerical scale; an expert was asked to give a degree between 0 and 10 to reflect his/her opinion in the degree of importance for each of the 35 criteria. In this study, 100 questionnaires were distributed among different construction parties and 73 were collected out of them. The data are gathered and then analyzed to assign the resultant degree for each criteria based on the summed opinion of all experts. The importance index of each factor was calculated based on the statistical analysis and finally, the factors were ranked according to their degree of importance. Factors with importance index greater than average were considered as the highly important factors in prequalifying and selecting the appropriate contractor. The analysis of the data shows that only eleven criteria out of the 35 criteria represent the most effective criteria in selecting the most appropriate contractor in building construction in Egypt. Table 1 presents these eleven criteria under their six main groups.

Table 1: The Most Effective Criteria for Contractor Selection

Main Criteria	Sub-Criteria
Financial Soundness	- Financial stability - Financial status - Liquidity
Technical Ability	- Relevant Experience
Management Capability	- Quality, Time & cost management - Coordination with owner/consultant
Resources	- Labor by trade skills
Reputation	- Past failures
General Suitability	- Contribution to project obj.(Price) - Contribution to project obj.(Time) - Contribution to project obj.(Quality)

3. Fuzzy Logic Framework for Contractor Selection

Since Zadeh (1965) introduced the concept of a fuzzy set, it has been employed in numerous areas. The concept is founded on the fact that some notions, though meaningful, may not be clearly defined. A fuzzy linguistic variable is defined as a variable, the values of which are words, phrases, or sentences in a given language. Since words are usually less precise than numbers, linguistic variables provide a method to characterize complex systems that are ill defined to be described in traditional quantitative terms. Fuzzy set theory is a tool that transforms linguistic control strategy into a mathematical control method. In this paper, six fuzzy input variables are identified as the most influential factors for contractor selection. Also, one output variables represent the contractor suitability.

3.1 Fuzzy Input Variables

As discussed earlier, eleven criteria were identified as the main factors affecting contractor selection. For simplification, the eleven criteria are grouped to six main criteria. For example, the three criteria: financial stability, financial status and liquidity which are related to the financial situation of the contractor are grouped into one main criterion named financial soundness. Similarly, the other criteria are grouped in the same way. Finally, the six main criteria are: Financial Soundness (FS), Technical Ability (TA), Management Capability (MC), Resources (RS), Reputation (RP), and General Suitability (GS). A family of fuzzy sets has been suggested for the five fuzzy variables and, for simplicity, was limited to three membership functions “Low” (L), “Medium” (M), and “High” (H) (Figure 2). The shape and range of values of the three membership functions (L, M, and H) were determined through experimentation. Accordingly, triangular and trapezoidal shapes were adopted (Fig. 3). These two shapes are the most frequently used in the literature (Elbeltagi and Hegazy, 2001).

3.2 Fuzzy Output Variable

In selection of the best contractor, the suitability of the contractor to the specified project is represented by a fuzzy linguistic variable. Such linguistic fuzzy variable is represented by a family of linguistic terms (fuzzy sets): “Poor”, “Good” and “Very Good” as shown in Fig 3. These three fuzzy sets cover the space of suitability of the contractor to the specified project ranging from “Poor suitability” for “Poor” to “Very Good suitability” for “Very Good”. The fuzzy sets “Poor” and Very Good” have trapezoidal membership functions covering the whole range of suitability of contractor. While, the fuzzy set "Good" overlaps with the other two membership functions for both sides. The range of each fuzzy set is based on the experts' opinion obtained from the questionnaire results.

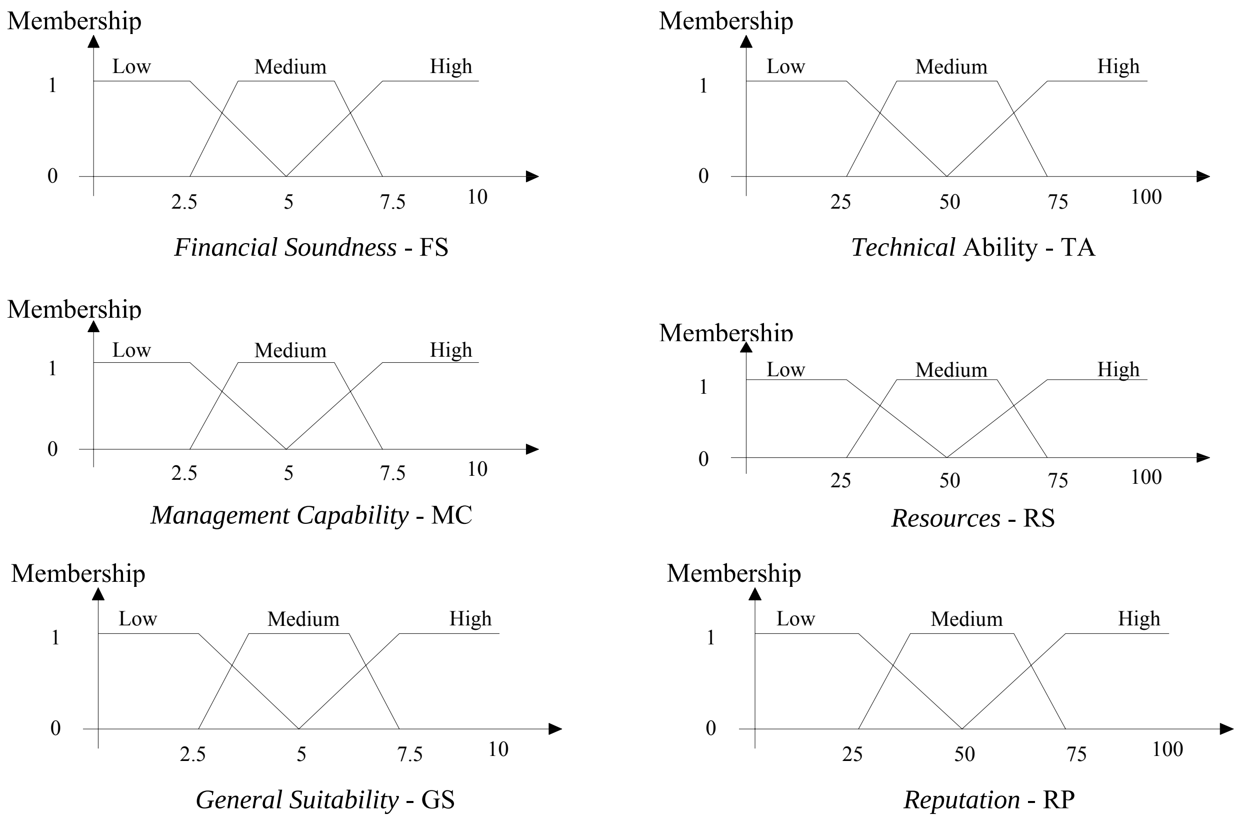

Figure 2: Fuzzy Input Variables

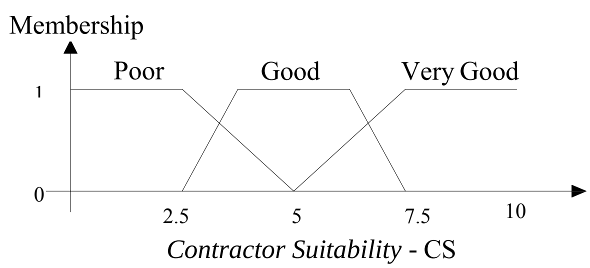

Figure 3: Fuzzy Output Variable

3.3 Fuzzy Decision Rules

Fuzzy rules define the value or levels of a decision-maker in controlling a system using fuzzy control. Since each of the fuzzy input variables has three membership functions, there could be a total of 3^6 (729) different combinations of preconditions that affect the selection of the contractor. As discussed before, each criterion is represented in three forms: "low", "medium" and "high". Therefore, it is essential to present those three forms for each criterion and figure out in each case the corresponding output suitability. In this study, in order to compose the fuzzy rules; a score of 1, 2 and 3 is given to the inputs "Low", "Medium" and "High" respectively. When a rule is composed, the sum of the scores of the preconditions will range from 6 (when all the preconditions are "Low") to 18 (when all the preconditions are "High"). Therefore, to specify the consequence for each rule's composition, the range from 6 to 18 is divided into three sets. If the rule's composition is between 6 and 10 the consequence is considered "Poor". If the rule's composition is between 11 and 14 the consequence is considered "Good". Finally, if the rule's composition is between 15 and 18 the consequence is considered "Very Good". For example, one rule may read: "If FS is medium (score equals 2) and TA is low (score equals 1) and MC is high (score equals 3) and RS is high (score equals 3) and RP is low (score equals 1) and GS is high (score equals 3) then contractor suitability is Good". The summation of preconditions scores equals 13 which lead to the good suitability of the contractor for this case.

3.4 Contractor Selection Using Fuzzy Rule-Based System

With the membership functions and fuzzy rules formulated, it is possible to use them with specific values of the input variables (numeric not linguistic) to compute a numeric value of the output variable. This process is known as the fuzzy rule-based inference. In the inference process, the firing strength of each fuzzy rule is calculated. This is based on the degree to which the input elements meet the preconditions of a rule, which is measured by the fetched membership values from the fuzzy set concerned. The firing strength of a rule determines how much its consequence can be applied to the output value. The output membership function of a rule is clipped off at a height corresponding to the firing strength of that rule (Elbeltagi and Hegazi, 2001): $F_i = \min(\omega_1, \omega_2, \omega_3, \omega_4, \omega_5, \omega_6)$; Where: F_i = strength of rule number i; $0 \leq F_i \leq 1$; and ω_1, ω_2, ω_3, ω_4, ω_5, and ω_6 represent the memberships of the financial soundness, technical ability, management capability, resources, reputation, and general suitability, respectively, in the precondition fuzzy sets of rule *i*.

4. Implementation and Validation

To facilitate the implementation process and the use of the developed model, a user-friendly interface is designed to allow users to enter data easily using drop-down boxes (Figure 4). The Fuzzy Logic Tool Box of the MATLAB® program was used to process the fuzzy logic inference system. The interface consists of two main parts; one part for technical evaluation, and another part for financial evaluation.

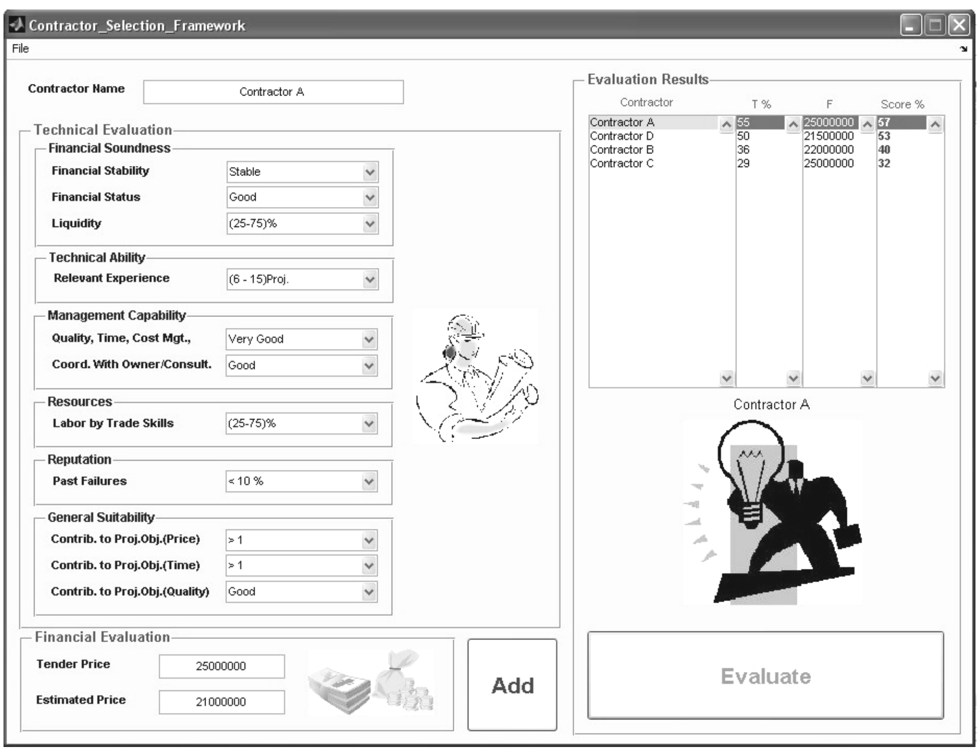

Figure 4: Contractor Selection Framework Interface

Having the eleven inputs are identified and entered, the developed system translate these criteria into six main criteria to be used by the fuzzy logic model. The user may push the “Evaluate” button to display the outputs, where the contractors are ranked in descending order as shown in Figure 4.

4.1 Example Application

To demonstrate the applicability of the developed fuzzy logic model and its system, an example application is presented. The case study represents a residential compound consisting of 20 villas was announced in a limited tendering. The project is owned by a national real estate private company. The project budget as per consultant studies equal to LE 21 million, the project duration as per the contract documents is three years. The minimum contractor classification that can apply for this project according to Egyptian Federation for Construction Contractor is grade three. The payment system includes quarterly based payments according to work volume, no advance payment is allowed. Four contractors applied to the open tendering with the following characteristics: contractor A: bid price of LE 25 million, three years and six months duration, contractor of grade one; contractor B: bid price of LE 22 million, three years duration, contractor of grade three; Contractor C: bid price of LE 20.5 million, four years duration, contractor of grade three; and Contractor D: bid price of LE 21.5 million, three years duration, contractor of grade two. Evaluation of the four contractor filled by the decision makers are presented in Table 2.

Table 2: Contractors' Data

Contractor	Financial Stability	Financial Soundness	Liquidity	Relevant Experience	Quality, time, cost	Coord. with owner/ consultant	Labor by trade skills	Past Failures	Price	Time	Quality
A	Stable	Good	75-100%	> 15	Good	Good	75-100%	< 10	> 1	> 1	V. Good
B	Medium stability	Good	0-25%	0-5	Good	Good	0-25%	10-30	> 1	= 1	Good
C	Medium stability	Good	25-75%	6-15	Good	Good	25-75%	10-30	< 1	= 1	Good
D	Stable	Good	25-75%	6-15	Good	Good	75-100%	< 10	> 1	= 1	V. Good

The process starting by input the criteria values for each contractor, then by clicking the “Add” button to save the entered data and move to the next contractor data. The “Evaluate” button is then pressed to rank the contractors. Results showed that the best contractor is contractor “A”, who has got a score of 57 %.

4.2 Model Validation

Having the model tested using a case study, it was necessary to check the decision makers' opinion about the model. To accomplish this, a simple questionnaire form was designed and distributed to twelve decision makers. Structured interviews were conducted with them to introduce the model, explain its main features and how it could be used. Then, each of them was given the opportunity to try the model by himself and evaluate different contractors in his previous projects and after that evaluate the model through the questionnaire form. The average of the given scores is 3.19 out of 4.0, giving 79.75 % which can be considered an acceptable level that shows the validity of the developed model.

5. Summary and Conclusions

In this study, the main criteria for prequalifying and selecting contractors in building construction in Egypt are identified. A questionnaire survey is used to rank these criteria and determine their relative importance. Based on the statistical analysis of the collected data, eleven criteria were identified as the most important criteria in contractor selection. These criteria are: financial stability, financial status, liquidity, relevant experience, quality-time-cost management, coordination with owner/consultant, labor by trade skills, past failures, contribution to objectives (price), contribution to objectives (time), and contribution to objectives (quality). These criteria are then grouped into six main criteria to simplify the fuzzy model development. These six main criteria are named as: financial soundness, technical ability, management capability, resources, reputation, and general suitability. Then, a fuzzy logic model is developed to help decision makers in prequalifying and selecting the appropriate contractor for a given job. To facilitate the use of the developed model, a friendly user interface was developed. In order to test the model and to verify its generalization use, an illustrative example was applied to the model successfully. Model validation was achieved using a questionnaire to the decision makers.

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