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A Fuzzy AHP Model for Selection of Consultant Contractor in Bidding Phase in Vietnam

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Abstract: Project Management Consultant (PMC) plays a vital role in the overall performance of any project. Selecting right PMC for right project is the most crucial challenge for any construction owner. Thus, PMC selection is one of the main decisions made by owners at the early phase of construction project. It is not easy for the project owner to select a competent PMC due to the fuzziness, imprecision, vagueness, incomplete and qualitative criteria of the decision. This paper presents a model for selecting PMC contractor using the Fuzzy Analytical Hierarchy Process (FAHP). And a fuzzy number based framework is proposed to be a viable method for PMC contractor selection. A case study to illustrate the application of the model is also presented in this paper.

Keywords: Project Management Consultant, Fuzzy Analytical Hierarchy Process, Decision Making, Vietnam

I. INTRODUCTION

Nowadays, construction projects are becoming much more complex, costly, and risky. The success of large construction projects, especially infrastructure projects, depends on many elements such as budget, quality, and rate of progress... To ensure success, all parties in project need to have a really close cooperation via co-ordination and mutual assistance. Nguyen et al. (2004) observed that the highest rated characteristic for effective project is related to project management consultant. With the same viewpoint, Ng et al. (2001) asserted "employing incompetent consultants may lead to problems in design, planning, cost control and supervision, which could in turn affect the time, cost, quality and risk levels of a project". Thus, PMC selection is one of the most crucial owner's decisions

The aims of PMC selection are both to minimize the possibility of contractor default, the time involved in bidding by restricting the number of eligible contractors involved, and to minimize or optimize all risks (Lam et al. 2001). In practice, a PMC selection process can be divided into two stages. First, a number of potential PMCs are invited and investigated based on a set of predetermined criteria; and then a short list of PMC is finalized by project owner, or prequalification stage. Second, an appropriate contractor is selected from the short list. A proper PMC's selection process, which takes into account other quality-based criteria, is therefore necessary to ensure the quality of the consultants appointed (Ng et al. 2001). Despite, there has been a trend that lowest-price is a commonly used key for PMC selection. However, the lowest bidder is not always the most economic choice in the long term as the client runs the risk of poor performance by that consultant during the project life (Nieto-Morote and Ruz-Vila, 2012). On the other hand, project owner should realize that the most qualified consultant firms may not necessarily offer the lowest price. Many recently published works acknowledge that, the selection of the consultants for construction projects should be on the basis of a set of multiple decision criteria that is both price and non-price related (San Cristobal, 2012; Singh and Tiong, 2005; Fong and Choi, 2000).

PMC selection can be regarded as a complicated nonlinear classification problem, in which decisions are made according to the qualification criteria, PMC's attributes and decision makers' judgment. Furthermore, PMC selection is a multi-criteria decision problem that is, in essence, largely dependent on the uncertainty and vagueness in the nature of construction projects and subjective judgments of the decision makers (Singh and Tiong 2005). Russell and Skibniewski (1988) also pointed out that contractor selection is a decision-making process that involves the development and consideration of a wide range of necessary and sufficient decision criteria as well as the participation of many decision-making parties. The research reported in this paper is a part of a study that aims at developing a state-of-the-art model using fuzzy analytical hierarchy process (FAHP) to improve the objectiveness of PMC selection.

II. LITERATURE REVIEW

The research field of contractor selection has attracted numerous researchers around the world. Many

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different methods have been proposed and applied such as cluster analysis(Holt, 1998), the analytical hierarchy process (Fong and Choi, 2000; Al-Harbi. 2001; Madhi et al.. 2002; Topcu. 2004), the analytic network process (Cheng and Li. 2004), logistic regression (Wong. 2004), multi-attribute utility theory (Hatush and Skitmore. 1998; Lambropoulos. 2007), decision support systems (El-Sayegh. 2009), elimination and choice expressing reality III (ELECTRE III) (Marzouk. 2010), the technique for order preference by similarity to ideal solution (TOPSIS) and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods (San Cristóbal, 2012). However, most of these models have their drawback which tend to ignore vagueness, fuzziness, and human behavior inherent in the nature of construction projects (Li and Nie 2007) such as: (1) it does not take into account the imprecise criteria; (2) the decision is made by a single person rather than multiple decision makers; and (3) it is used crisp value which is inadequate in the uncertain environments.

A PMC selection problem is complex and difficult since there exist: multi-criteria both qualitative and quantitative in nature; multiple decision makers; uncertainty and risk; and incomplete information, imprecise data, and vagueness surrounding the decision making. Thus, according to Hipel et al. (1993), PMC selection is a multiple participant multiple criteria decision making process. This process is a complex multi-criteria decision making (MCDM) problem in which involves much inexact, uncertain, incomplete, or qualitative information that is very difficult to measure, especially, the judgments and preference of decision makers. Therefore, the decision makers should express their assessment of PMC performance on decision criteria based on using linguistic terms instead of numerical values.

Many attempts have been made to find a satisfactory solution for the optimal selection based on using fuzzy logic. Nguyen (1985) presented a model which allows taking into consideration 3 criteria: cost, presentation of bid information and past experience, as well as different scenarios of a construction owner's preferences. Singh and Tiong (2005) proposed a procedure of choosing a bidder using a fuzzy decision framework where the notion of the Shapely value is used to determine relative importance of each criteria, and linguistic variables based on fuzzy numbers theory is constructed for decision makers to evaluate the contractor's attributes. Lam et.al (2001) developed a fuzzy neural network (FNN) model, amalgamating both the fuzzy set and artificial neural network theories aiming to improve the objectiveness of contractor prequalification. Through FNN theory, the fuzzy rules as used by prequalifiers can be identified and the corresponding membership functions can be transformed. Li and Nie (2007) proposed a fuzzy framework-based fuzzy number theory to solve construction contractor prequalification issues, which include decision criteria analysis, weights assessment, and decision model development. Relative importance of criteria and evaluation of criteria assigned by decision makers were expressed in linguistic variables and then a fuzzy arithmetical operation was employed to aggregate the fuzzy numbers into the final decisions, it can aid decision makers in the prequalification process. Following this instruction, decision criteria structure was given. Next, a fuzzy framework, based on fuzzy number, was established to deal with bidder issues

The above-mentioned methods had both advantages and drawbacks though they focused on improving various aspects of bidder selection. This study presents a proposal of a fuzzy AHP approach. This approach has overcome some limitations of traditional AHP method. The conventional AHP approach may not fully reflect a style of human thinking because the decision makers (DM) usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values (crisp value) (Trivedi et al., 2011). First, the Fuzzy AHP method is used to determine weights of criteria and sub-criteria in the pair-wise comparison hierarchical structure. After that, the evaluation of criteria of each PMC by DMs is expressed in linguistic statement based on fuzzy number theory rather than numerical (crisp) values.

III. FUZZY NUMBER

Uncertain and vague data in decision-making problems can be handed using the Fuzzy Set Theory introduced by Zadeh (1965). In a universal set of discourse X, a fuzzy subset A of X is defined by a membership function $\mu_A(x)$, which maps each element x in X to a real number in the interval [0,1]. The function value of $\mu_A(x)$ signifies the grade of membership of x in A (Figure I). When $\mu_A(x)$ is large, its grade of membership of x in A is strong (Nieto-Morote and Ruz-Vila, 2012). Fuzzy numbers are among the various types of fuzzy sets. In a real life system, trapezoidal and triangular fuzzy numbers are commonly used. In this paper, triangular fuzzy number is used. A triangular fuzzy number A is denoted by three real number and is considered as A=[a,b,c] which membership for triangular fuzzy number is defined as:

$$\mu_A(X) = \begin{cases} \frac{(x-a)}{(b-a)} & a \le x \le b \\ \frac{(c-x)}{(c-a)} & b \le x \le c \\ 0 & Otherwise \end{cases}$$

Where $a<b<c$, and scale of preference texture to be used by DMs

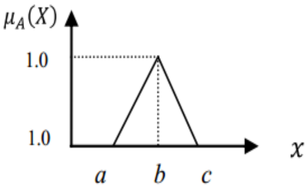

FIGURE I
GRAPHICAL REPRESENTATION OF TRIANGULAR MEMBERSHIP FUNCTION

According to fuzzy arithmetic, operation on the fuzzy numbers can be expressed of any two positive fuzzy numbers $A=[a_1,a_2,a_3]$ and $B=[b_1,b_2,b_3]$ as (Kaufmann and Gupta, 1991):

TABLE I
OPERATION ON FUZZY NUMBER

Operator	Formulae	Product
Additition	A⊕B	$(a_1+b_1, a_2+b_2, a_3+b_3)$
Subtraction	AΘB	$(a_1-b_1, a_2-b_2, a_3-b_3)$
Multiplication	A⊗B	$(a_1xb_1, a_2xb_2, a_3xb_3)$
Division	AØ B	$(a_1/b_1, a_2/b_2, a_3/b_3)$

IV. CRITERIA FOR PMC's SELECTION

Ng and Skitmore (1999) affirmed that "A crucial task in bidder selection process is to establish a set of decision criteria through which the capabilities of contractors are measured and judged". Criteria for PMC's selection may vary between projects since the characteristics of them are distinct although there are some common characteristics of process (Nieto-Morote and Ruz-Vila, 2012). The starting point of this research is to indentify criteria for PMC selection. At first, a list of criteria is established thanks to reviewing previous works. To test the appropriateness and popularity of the criteria in the list with Vietnamese context, then a semi-structured interview is organized with the participation of eighteen experienced experts. They all have at least ten years of experience in project management and bidding field. During the interview, the experts give many suggestions to add, delete, or adjust criteria. The five main criteria (and sixteen sub-criteria) are finally screened and selected as followings:

- Past experience: The consultant should have similar and sufficient past experience with the current project.
- Financial stability: The consultant must prove the overall stable financial status and capability to accomplish the work in the required time.
- Management resource: The consultant must have project manager and key team members qualified to perform the work categories on the project.
- Technical solution and methodology: The contractor must demonstrate their understanding of key elements of the current project and capability of planning, organizing and controlling a project.
- Tender price.

V. RESEARCH METHODOLOGY

The current study revises the fuzzy decision-making framework model of Singh and Tiong 2005 by calculating the weight of each criterion using FAHP model, integrating the fuzzy set and analytical hierarchy process theories The fuzzy framework of PMC's selection are shown in the model presented in Fig.II. A methodology is employed and briefly presented as follow:

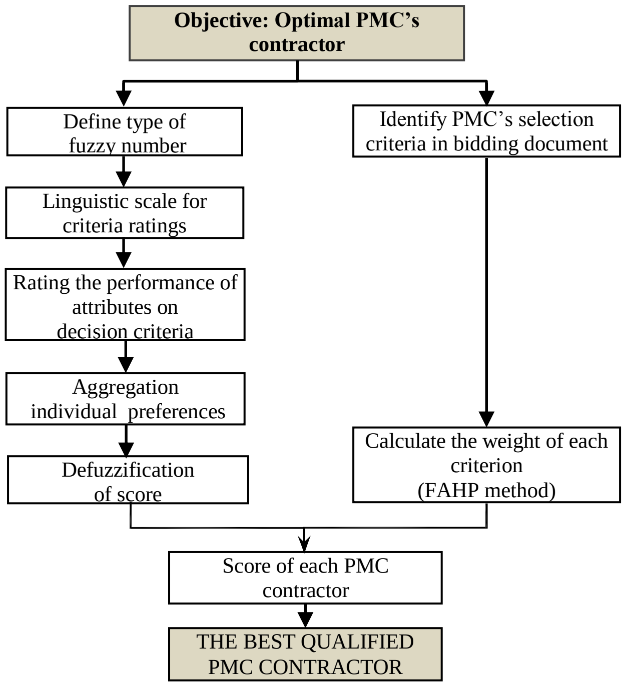

FIGURE II
PROPOSED FUZZY AHP FOR PMC's SELECTION
(modified after Singh and Tiong 2005)

- Identifying criteria (and sub-criteria) for PMC's selection in Vietnam. Those criteria are examined by experienced experts in project management and bidding sector in Vietnam. The most important criteria are selected using mean score and ranking method. After that, constructing the hierarchical decision making model includes the main criteria and sub-criteria of different hierarchical levels.
- Using the Fuzzy AHP method to develop the weight of sub-criteria. An expert group is invited to take part a survey with AHP questionnaire. The validation process in this stage uses the inconsistency index.
- After obtaining the global weight of all criteria, DMs is asked to assess their rating on each criterion of each bidder in linguistic terms; and then scores of bidders are calculated based on fuzzy model.
- Calculate the weight of each criterion (FAHP method)
- Develop the hierarchical structure

The first step in the fuzzy AHP method is to decompose the decision problem into a hierarchy that consists of the most important element of the decision problem (Boroushaki and Malczewski, 2008). The hierarchical model includes the main criteria (Level 2) and sub-criteria (Level 3). The final hierarchical structure of the model is shown in Figure III as below:

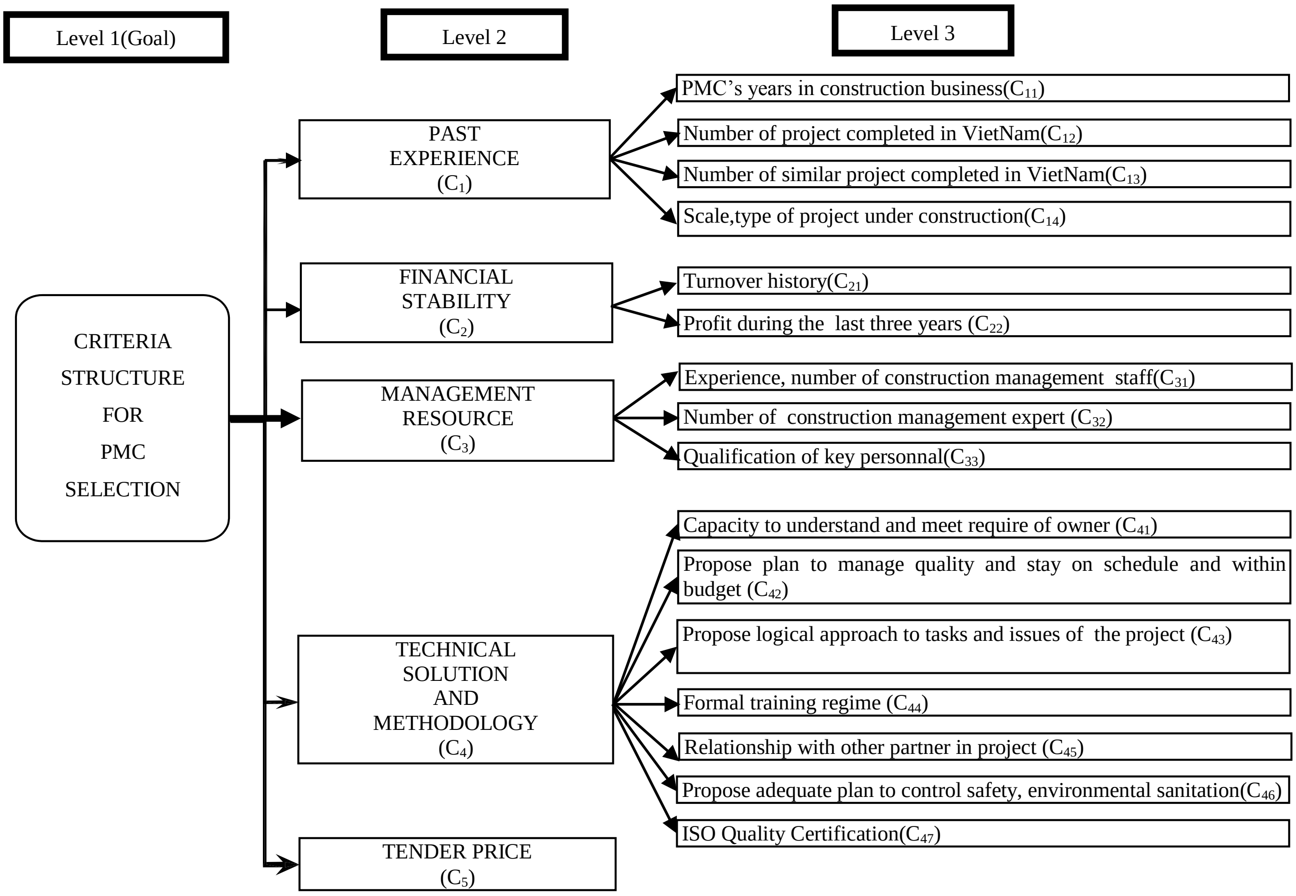

FIGURE III
THE HIERARCHICAL STRUCTURE

A.2 Collecting experts' judgment

Based on the established hierarchical structure in the previous section, an AHP format questionnaire is designed for data collection. The expert group is asked to rate on a fuzzy 9-point scale as shown in Table II. This fuzzy scale, using triangular fuzzy numbers proposed in Tesfamariam and Sadiq (2006), is an extension of original 9-point scale of Saaty (1980).

TABLE II
FUZZY SCALES OF PAIR-WISE COMPARISION

Original AHP Scale	**Fuzzy AHP Scale**	**Definition**
1	(1, 1 ,1)	Equal importance
3	(3-Δ, 3, 3+Δ)	A little more importance
5	(5-Δ, 5, 5+Δ)	More importance
7	(7-Δ, 7, 7+Δ)	Much more importance
9	(9-Δ, 9, 9+Δ)	Strictly more importance
2, 4, 6, 8	(x-Δ, x, x+Δ)	Intermediate values between two adjacent judgments

Adapted from Tesfamariam and Sadiq (2006)
Δ is a fuzzification factor, the value Δ used in this study equals to 1.

The interview was conducted with the participation of eighteen experienced experts as aforementioned. The respondents were required to provide their judgment by comparing all criteria, sub-criteria with respect to upper level decision elements by using the fuzzy relative scale as shown in Table II. To increase the respondents' receptiveness, they were explicated clearly about the content of this study and how to perform the pair-wise comparisons. Data were gathered through personal interview. For various difficulties, face-to-face interviews were not possible for few interviewees. In such cases, the instruction and interview was conducted via phone or email.

A.3 Checking the Consistency Ratio (CR)

CR is designed to inform the decision makers to recognize the consistency in the pair-wise comparisons of each expert. It is also an advantage of the AHP method which maintains in the Fuzzy AHP. Saaty (1980) proposed a method of calculating the CR as follows:

$$CR = CR/RI \quad (1)$$

where RI is the random index which is obtained basing on the size of pairwise comparison matrices. The values of RI are tabulated in Table III. CR should not be, broadly assumed, more than 10%. According to Saaty and Kearns (1985), it can be acceptable when CR is approximately 20% or less. In this study, the "acceptable"' CR is approximately 10% or less. A few respondents had CR above 10% and they were asked to review their ratings. But caution was also taken not to purely reach the CR target but to ensure the conformity of their ratings. Few made adjustment while the others did not. According to Saaty, "an accurate judgment is more important than consistently inaccurate judgment". Lastly, 18 responses were used in the analysis.

TABLE III
THE RANDOME INDEX(SAATY,1980)

N	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

A.4 Combining the experts' judgments

An important issue in group decision making is how to combine individual judgments into a single judgment representing the opinion of the entire group. For triangular fuzzy numbers (lij, mij, uij), Meixner (2009) proposed to use geometric mean for lij, mij and uijk as in Eq.(2).

$$l_{ij} = \left(\prod_{k=1}^{k} l_{ijk}\right)^{\frac{1}{k}}; m_{ij} = \left(\prod_{k=1}^{k} m_{ijk}\right)^{\frac{1}{k}}; u_{ij} = \left(\prod_{k=1}^{k} u_{ijk}\right)^{\frac{1}{k}} \quad (2)$$

Where, (l_{ijk}, m_{ijk}, u_{ijk}) are the triangular fuzzy numbers evaluated by the k_{th} expert. k = [1, 18]

A.5 Performing defuzzification

This step aims at converting fuzzy data into crisp data. This paper adopted the defuzzifaction method proposed by Deng (1999). This method has two remarkable advantages (Deng, 1999):

- Taking into account α-cut representing the decision maker*'s degree of confidence* regarding critical weights and alternative ratings. A greater α-cut value shows a more confident decision maker (i.e.,the higher value of α represents a more confident decision maker whereas the lower value of α denotes lack of confidence over the fuzzy judgment). Respect to an α-cut value, left value and right value of membership function need to be determined as shown in Eq.(3)
- Incorporating the decision maker's *attitude towards risk* through an optimism index λ. Following that, the greater the λ is, the more optimistic the decision maker's view is (see Eq.(4) below).

$$Z_\alpha = \begin{pmatrix} [z^\alpha_{11l}, z^\alpha_{11l}] & [z^\alpha_{12l}, z^\alpha_{12r}] & \cdots & [z^\alpha_{1ml}, z^\alpha_{1mr}] \\ [z^\alpha_{21l}, z^\alpha_{21r}] & [z^\alpha_{21l}, z^\alpha_{21r}] & \cdots & [z^\alpha_{2ml}, z^\alpha_{2mr}] \\ \cdots & \cdots & \cdots & \cdots \\ [z^\alpha_{n1l}, z^\alpha_{n1r}] & [z^\alpha_{n2l}, z^\alpha_{n2r}] & \cdots & [z^\alpha_{nml}, z^\alpha_{nmr}] \end{pmatrix} \quad (3)$$

$$z^\lambda_{ij\alpha} = \lambda.z^\alpha_{ijr} + (1-\lambda).z^\alpha_{ijl}, \lambda \in [0,1]. \quad (4)$$

$$z^\alpha_{ijl} = (m_{ij} - l_{ij})\alpha + l_{ij} \quad (5)$$

$$z^\alpha_{ijr} = u_{ij} - (u_{ij} - r_{ij})\alpha \quad (6)$$

The z^α_{ijr} & z^α_{ijl} in Eq.(4) can be calculated by Eq.(5) and Eq.(6) which are proposed by Liou and Wang (1992). An example of the level 2 defuzzification results is shown in Table IV with of α=0.5 and λ=0.5.

TABLE IV
THE RESULTS OF DEFUZZIFICATION

	C_1	C_2	C_3	C_4
C_1	1.00	2.37	0.28	0.37
C_2	0.42	1.00	0.17	0.35
C_3	3.53	5.78	1.00	1.63
C_4	2.68	2.87	0.61	1.00

Sensitivity analysis was also performed on the criteria against confidence degree. It is applied for three cases: pessimistic DMs (λ=0), moderate DMs (λ=0.5), optimistic DMs (λ=1). Because the minor changes in criteria weights may lead to major changes in global weights of sub-criteria, the α-cut values with increment of 0.1 were used in sensitivity analysis. The results depicted a little sensitivity of weights in both respondents' attitudes and degree of confidence. An example of the sensitivity analysis is shown in Figure IV with λ=0.5.

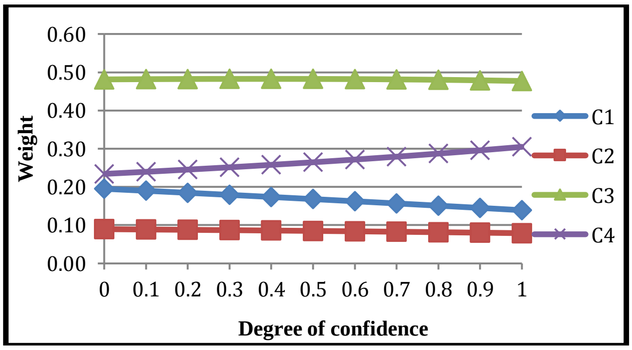

FIGURE IV
SENSITIVITY ANALYSIS OF FACTOR WEIGHTS FOR A MODERATE DMs(λ=0.5)

A.6 Calculating the weights of criteria and sub-criteria

Due to low sensitivity of the weights, the further analysis was carried out for the case of moderate attitudes (α = 0.5 and λ = 0.5). Table V tabulates the weights of criteria and sub-criteria.

TABLE V
THE WEIGHTS OF CRITERIA AND SUB-CRITERIA

Factors	Weights of criteria(W_i)	Sub-criteria (W_j)	Local weights of sub-criteria	Global weights of sub-criteria ($W_{ij}=W_i \times W_j$)
C_1	0.144	C_{11}	0.140	0.020
		C_{12}	0.275	0.040
		C_{13}	0.493	0.071
		C_{14}	0.093	0.013
C_2	0.081	C_{21}	0.487	0.040
		C_{22}	0.513	0.042
C_3	0.478	C_{31}	0.249	0.119
		C_{32}	0.598	0.286
		C_{33}	0.153	0.073
C_4	0.296	C_{41}	0.211	0.062
		C_{42}	0.242	0.072
		C_{43}	0.262	0.078
		C_{44}	0.122	0.036
		C_{45}	0.080	0.024
		C_{46}	0.049	0.014
		C_{47}	0.034	0.010

The result of pair-wise comparisons demonstrates that the main criterion of "Management Resource" (C_3) has highest priorities. It is, therefore, obvious that management resources for project plays a crucial role to the success of the project. It also reflects that "Management Resource" criterion should be a prerequisite for the selection of PMC.

It is further observed that the priority of the sub-criterion "Number of construction management expert" (C_{32}) is highest and remarkable. Key manager is widely recognized as crucial factor in project management since his/her critical role in leading and integrating staff, making decisions to achieve owner's desired goals.

A. BUILDING LINGUISTIC VARIABLES

A linguistic variable is a variable whose values are words or sentences in a natural language (Lam et.al 2001). Regarding the criteria assessment, the decision maker will rate each characteristic (subcriteria) of each bidder in the fuzzy term of "poor", "good", "very good", etc,. It is comfortable for DMs to describe their assessment in fuzzy term instead of an exact numerical assessment due to fuzziness, uncertainty, vagueness encompassed. To help the decision makers to assess the criteria of each bidder and to simplify the implementation, the fuzzy terms are expressed in triangular fuzzy numbers. This fuzzy number type is more intuitive and more natural interpretation than the other fuzzy number types with irregular shapes. The calculations are also less complicated (Nieto-Morote and Ruz-Vila, 2012). Seven linguistic variables with their corresponding fuzzy numbers were chosen and presented in Table VI.

TABLE VI
LINGUISTIC SCALE FOR CRITERIA ASSESSMENT
(source: Yawei Li,Nie et al (2007))

Linguistic variables	**Fuzzy Number**
Very poor (VP)	[0;0;0.1]
Poor (P)	[0;0.15;0.3]
Below average (BA)	[0.1;0.3;0.5]
Average (A)	[0.3;0.5;0.7]
Above average (AA)	[0.5;0.7;0.9]
Good (G)	[0.7;0.85;1]
Very good (VG)	[0.9;1;1]

A. Aggregate Individual Preference

Assuming that a set of n PMC contractors were invited to participate in the selection process, this set of PMCs is expressed as:

$$A=(A_1,A_2,A_3,\ldots,A_n)$$

where $A_i = i_{th}$ contractor, and i = 1,2,...,n.

Each bidder can be rated by m criteria, and then criteria set is:

$$C=(C_1,C_2,C_3,\ldots,C_m)$$

where $C_k = k_{th}$ criterion, k = 1,2,3,...,m.

Let a_{ij}^k be the fuzzy number assigned to an alternative (PMC) A_i by DM_j for the decision criterion C_k, then the average of fuzzy numbers across all the p DMs can be expressed as in Eq.(7) (Singh and Tiong 2005):

$$A_{ij}^k = (1/p) \otimes (a_{i1}^k \oplus a_{i2}^k \oplus \ldots \oplus a_{ip}^k) \text{ where } j = 1,2,...p \quad (7)$$

where p = numbers of DMs involved in the evaluation process

B. Defuzzification

Defuzzification is an operation that produces a nonfuzzy or crisp value that adequately represents the degree of achievement of the PMCs on the criteria. Once a fuzzy number of each alternative (PMC) is defuzzified, the crisp numbers are compared and ranked accordingly. Thereby, ranking of PMC contractors can be obtained. The defuzzified value e of a triangular fuzzy number can be expressed as following Eq.(8) (Kaufmann and Gupta 1991):

$$e=(a_1+2a_2+a_3)/4 \quad (8)$$

Where $[a_1;a_2;a_3]$ is triangular fuzzy number

VI. CASE STUDY

A commercial, office and residential complex project located in downtown Ho Chi Minh city is taken as an example to illustrate the fuzzy PMC's selection proposed approach. Its total investment is expected to over $200 million. In the project, after conducting a prequalification by examination of their files and records only three PMCs named (anonymously) O, P and Q were eligible. These three PMCs and the project are intended to use as sample for validating the proposed model. The performance of the PMC's attributes regarding aforesaid criteria set (16 sub-criteria) are assessed by the DMs group consist of three decision makers DM_1, DM_2, DM_3. For simplicity, only the sub-criterion named "PMC's years in construction business" (C_{11}) is presented detail hereafter as an example.

First of all, the three DMs rated the sub-criterion "PMC's years in construction business" using the linguistic scale. Table VII shows the assessment.

TABLE VII
FUZZY RATINGS OF THE PMC's PERFORMANCES REGARDING SUB-CRITERION(C_{11})

Bidder	PMC's years in construction business (C_{11})											
	Linguistic variables			Fuzzy Number								
	DM_1	DM_2	DM_3	DM_1			DM_2			DM_3		
O	AA	G	AA	0.5	0.7	0.90	0.7	0.85	1.00	0.5	0.7	0.90
P	AA	AA	AA	0.5	0.7	0.90	0.5	0.7	0.90	0.5	0.7	0.90
Q	BA	AA	AA	0.1	0.3	0.5	0.5	0.7	0.90	0.5	0.7	0.90

DM=Decision Maker; BA= Below average; AA= Above average; G= Good

Using Eq.(7) for aggregating individual preference, the average fuzzy score for the PMCs regarding sub-criterion (C_{11}) is obtained as in Table VIII.

TABLE VIII
AVERAGAGE FUZZY SCORE OF THE
PMC' PERFORMANCES REGARDING SUB-CRITERION(C_{11})

Bidder	Average fuzzy scores			Defuzzified values
O	0.57	0.75	0.93	0.750
P	0.50	0.70	0.90	0.700
Q	0.37	0.57	0.77	0.567

Using Eq. (8) for defuzzification, the crisp scores on sub-criterion (C_{11}) for the contractors are obtained as follows:

Bidder O : e_O=(0.57+2x0.75+0.93)/4=0.750
Bidder P : e_P=(0.50+2x0.70+0.90)/4=0.700
Bidder Q : e_Q=(0.37+2x0.57+0.77)/4=0.567

Similarly, the crisp scores of the all criteria can be obtained and listed in Table IX. In the last step, the total score (SC) for each PMC can be calculated by using the simple additive weighting method (Hwang and Yoon, 1981) as follows:

$$SC_{ij} = \sum e_i \times W_{ij} \tag{9}$$

Where: e_i : crisp scores on the sub-criterion i, and W_{ij} is global weight of sub-factor C_{ij}, as shown in Table IX

TABLE IX
TOTAL SCORE FOR THE PMC CONTRATOR REGARDING SUB-CRITERIA

Sub-criteria	Crisp scores on sub-criterion(e_i)			Global weights of sub-criteria (W_{ij})	Scores on sub-criterion		
	PMC Contractor				PMC Contractor		
	O	P	Q		O	P	Q
C_{11}	0.750	0.700	0.567	0.020	0.015	0.014	0.011
C_{12}	0.800	0.850	0.850	0.040	0.032	0.034	0.034
C_{13}	0.550	0.850	0.850	0.071	0.039	0.060	0.060
C_{14}	0.842	0.567	0.633	0.013	0.011	0.007	0.008
C_{21}	0.892	0.933	0.892	0.040	0.036	0.037	0.036
C_{22}	0.775	0.800	0.800	0.042	0.033	0.034	0.034
C_{31}	0.892	0.850	0.850	0.119	0.106	0.101	0.101
C_{32}	0.842	0.892	0.933	0.286	0.241	0.255	0.267
C_{33}	0.883	0.792	0.883	0.073	0.064	0.058	0.064
C_{41}	0.800	0.683	0.842	0.062	0.050	0.042	0.052
C_{42}	0.683	0.617	0.733	0.072	0.049	0.044	0.053
C_{43}	0.933	0.892	0.933	0.078	0.073	0.070	0.073
C_{44}	0.700	0.750	0.750	0.036	0.025	0.027	0.027
C_{45}	0.775	0.933	0.892	0.024	0.019	0.022	0.021
C_{46}	0.617	0.550	0.617	0.014	0.009	0.008	0.009
C_{47}	0.658	0.883	0.883	0.010	0.007	0.009	0.009
Total Scores for each PMC Contractor($SC_{ij}=\Sigma e_i x W_{ij}$)					**0.807**	**0.823**	**0.859**

Finally, the total score of the technical proposal (TPS) for the services of all PMC Contractors can be obtained as shown in Table X

TABLE X
TOTAL SCORE OF THE TECHNICAL PROPOSAL
FOR ALL PMCs

PMC Contractor	SC_{ij}	Total score of the technical proposal ($TP=\sum SC_{ij}$)
O	0.807	
P	0.823	2.461
Q	0.831	

Assuming that the PMCs offered the fees for the services in their tender proposals, the fees are shown in Table XI. Base tender price is the amount which, in the opinion of DMs is economically low enough to deliver the project without compromising the quality standards and health and safety aspects of the facility or end product (Singh and Tiong 2005). For this example, assuming that base tender price for the project is $3.235 million. Using the same way as TPS, the total score of the tender price (TCS) is calculated.

TABLE XI
TOTAL SCORE OF THE TENDER PRICE
FOR ALL PMCs

PMC Contractor	Price (million.$)	Score of the tender price	Total score of the tender price (TCS)
Base tender price	3.235	1.000	
PMC O Price	3.080	1.050	
PMC P Price	3.230	1.002	3.089
PMC Q Price	3.120	1.037	

The importance index of the value TPS and TCS can be calculated using Equation as follows:

$$W_{TP}=TP/(TP+TC)=2.461/(2.461+3.089)=0.443$$
$$W_{TC}=TC/(TP+TC)=3.089/(2.461+3.089)=0.557$$

The overall score for each PMC contractor can be calculated as shown in Table XII. For example, the overall score for PMC O is calculated by $(0.807\times0.443+1.050\times0.557) = 0.942$. The overall scores are used to rank the PMCs.

TABLE XII
FINAL RANKING OF CONTRACTORS

PMC Contractor	SC_{ij}	Score of the tender price	Overall sore	Ranking
O	0.807	1.050	0.942	2
P	0.823	1.002	0.922	3
Q	0.831	1.037	0.946	1

According to the outcome of the proposed approach, the ranking order of three PMC is Q > O >P. It shows that the PMC Q is the best for carrying out project. It is obvious from the result that the PMC P and O, who offered the highest and lowest prices respectively, ranked last and second in ranking order because of low scores on the other criteria. It again affirmed that the lowest price proposal is not necessarily the most economic choice in the long term.

VII. CONCLUSION

The success of large construction project has always been a craving of client as well as all project participants. However, various factors affect the success level of construction project. Among of these factors, PMC is one of the most important factors. Hence, the selection of an appropriate PMC is a crucial process which must cautiously be executed by every owner. PMC selection is a multi-criteria decision making process. This study proposed a FAHP-based process for PMC selection.

The findings of this study provide some practical guidelines useful not only to Vietnamese practitioners but also to others who are concerned about PMC selection. Hence, this model is not only a theoretical model, but also a feasible and efficient framework to apply in practice for a practitioner. A case study of skyscraper construction project in Viet Nam is presented to illustrate the approaches, which demonstrates the viability and practicability of the fuzzy methodology to the PMC selection problem.

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