A Selection Method In Construction Project Management Using Analytic Network Process (ANP) As A Tool In Decision

Michael Almeida
Graduate School De La Salle University
michael_almeida@dlsu.edu.ph
Contact No. 0949-6769445

Abstract: The role of Construction Project Management in selecting the best contractor is necessary to eliminate the risks of project failure due to poor contractor's performance. Therefore, the evaluation of the prospective contractor's capability in a pre-qualification process is one of the important decisions to be made before executing the project. Instead of the existing industry practice in contractor selection which is based on expert judgement, reputation and lowest offer, a range of decision making tools that rely on multi-attribute ranking are available for solving the problem. In this paper the use of multi-criteria decision-making (MCDM) is suggested in determining criteria weights and contractor's selection during prequalification process. The analytic network process (ANP) is proposed to allow interdependent influences specified in the decision model. An example is illustrated to show how this tool is used, including the development of supermatrix and limit matrix. The result is compared to analytic hierarchy process (AHP) widely used tool for MCDM in ranking the score of each criterion and contractor. The results show that there is chance to make possible the objectives and rationalize complex decisions problems in construction project management. The significance of this paper will introduce ANP as a decision-making tool in determining the order of each criteria used to select the best alternative. ANP allows options for owner and construction managers in the selection of the best contractor for construction project and other selection activities.

Key Words: construction project management; contractor selection; multi-criteria decision-making; analytic network process; analytical hierarchy process

1. INTRODUCTION

Management of construction project is carrying out in control: have a hold over quality, schedule and costs. The significance of contractor's pre-qualification process in construction project management cannot be set aside. From the initial step of the building process to turn over ceremony, construction contractors plays a vital role. Failure to properly select a competent contractor can lead to problems for the entire project. The proper selection of contractors increases chances of project delivery within cost, time and quality.

The pre-qualification of contractors are very often conducted during pre-construction stage in the form of bidding or tendering. During tendering the potential contractors are selected based on their reputation or a set of pre-qualification criteria and with lowest proposals as shown in appendix 2 and table 1, respectively. In years, most owners and construction project managers made use of such method. As a result the lowest bidders often have problems in completing the project within cost, time and quality.

Table 1. Example Prequalification Evaluation Result

Description	%wt	Contractor Rating (%)			
		A	B	C	D
Methodology	13	7.65	3.85	9.46	8.69
Schedule	10	7.78	1.11	6.67	6.67
Quality	10	10.00	5.00	10.00	10.00
Safety	10	8.57	8.57	10.00	10.00
Manpower	4	3.33	0.00	4.00	2.67
Equipment	5	2.00	0.00	3.75	3.75
Organization	8	6.67	5.33	7.33	7.33
Personnel	10	4.17	0.00	5.00	6.67
Financial	30	20.93	10.80	24.09	23.70
Total Points	100	71.10	34.66	80.30	79.48

Several researchers (Holt *et al*, 1994; Russell *et al*, 1992; Ng, 1992) have identified different criteria in use for contractor selection. In a recent study, Hatush and Skitmore (1996a) found that all clients use what are implicitly the same type of criteria, but vary in the way they quantify the criteria, with most having to resort to a very subjective assessment based on information provided by the contractors. These common set of pre-qualification criteria (financial capability, past performance, past experience, resources, current workload and safety performance). Also many techniques are proposed and applied as a solution such as multi-criteria decision-making (MCDM), multi-attribute utility theory (MAUT), multi regression (MR), cluster analysis (CA), bespoke approaches (BA), fuzzy set theory (FST) and multivariate discriminant analysis (MDA) (Hatush and Skitmore, 1997; Holt, 1998; Mahdi et al., 2002). Among the techniques, MCDM is the well-known technique used in contractor selection. Analytical Hierarchy Process (AHP) is a multi-criteria decision-making method using a set of criteria for a decision problem and assign weights to the criteria (Saaty, 1990; Kamal et al., 2001; Chun-Chang Lin et al., 2008; Jaskowski et al., 2010). In the existing studies of contractor selection, AHP is used to develop a hierarchical framework wherein multi-attribute decision problems will be ordered(Fong and Choi, 200; Madhi et al., 2002). Theoretically, AHP only employ uni-directional relation between decision levels and not appropriate for multi-directional relationship (Saaty, 1988; Meade and Sarkis, 1998). To enhance AHP, analytic network process (ANP) is developed. ANP is a generic form of AHP and allows for more complex interdependent relationships among elements (Saaty, 1996). It is also known as the systems with feedback approach (Meade and Sarkis, 1998).

The objective of this research paper is to introduce the application of Analytical Network Process (ANP) on the contractor pre-qualification process. The paper will briefly review the concepts and application of ANP's implementation steps, and demonstrate ANP application on the contractor selection problem. It is hoped that this will encourage its application in construction project management.

2. METHODOLOGY

This research paper improves the AHP model by adding interdependence among criteria and feedback dependence from alternatives. Figure 1 shows the strict hierarchical structure being objective is on the highest level, with criteria and alternatives on lower levels, respectively, (Petronijevic et al., 2015). Figure 2 shows the new ANP decision network model. The difference from AHP model is a feedback network with components which indicates inner and outer dependence among elements and a loop indicating each element depends only on itself (Promentilla et al., 2005). The new model assumed the six criteria (C1, C2, C3, C4, C5, and C6) are interdependent and there is a feedback loop from elements in alternatives (A, B, C and D) to criteria elements. Data gathered from interviews and survey questionnaires in the previous study of Almeida (2016) were used in this research paper. Appendix 3 presents the sample data survey questionnaire. Table 2 shows the questions used for data collection. The pair-wise comparison matrices were formulated based from Saaty's 9-point priority scale measurement as shown in Table 3 and Judgment consistency ratio (CR) of $CI = (\lambda_{max} - n)/(n - 1)$, n is the matrix size with the appropriate value in Table 4. If CR is more than 0.10, the judgment matrix is inconsistent (Saaty, 1990). This paper adopts the original pair-wise comparison results in Almeida (2016) who compared six criteria for the four alternative contractors as shown in Tables 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 13, 14, 15, 16, 17.

The local priority vectors from the original pair-wise comparisons on the elements of the cluster and sub-cluster levels of Almeida (2016) was adopted to achieved a supermatix, which in turn obtains global priorities. Table 18 shows the supermatrix which contains the priorities for the judgement matrices. After entering the sub-matrices into the supermatix and adjusting its values to achieve column stochastic as shown in Table 19. The supermatrix is raised to limiting powers until weights have converged and remain stable (Saaty, 1996; Meade and Sarkis, 1998; Promentilla et al., 2005) as presented in Table 20.

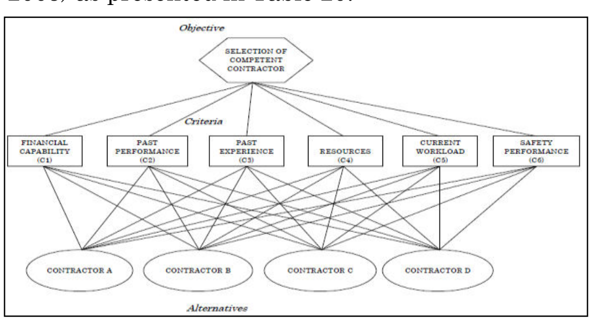

Fig.1, Hierarchical structure for AHP model

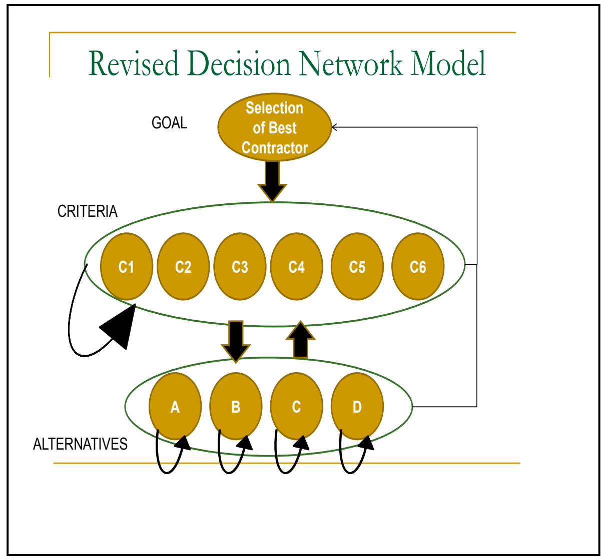

Fig.2, Analytic Network model

Table 2. Types of questions used for data collection

No.	Question	Answer
1	Which criteria between Financial Capability and Past Performance do you think is best in contractor selection?	Rating (1 to 9)
2	Which Contractor do you think is best in Financial Capability?	
3	Which criteria do you think is satisfied best by Contractor "A"?	

Table 3. Pair-wise comparison scale for AHP

Numerical rating	Verbal judgments of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

Table 4. Random consistency index (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3. RESULTS AND DISCUSSION

The AHP method was used in decision making process in selecting the best contractor during pre-qualification process. The ANP model consist of four alternatives as describe in appendix 1 and six criteria as follows:

C1 (Financial Capability) – involves contractor's sound financial position and profitability, here is considered minimum average annual construction turnover within the last five years;

C2 (Past Performance) – past client's levels of satisfaction with the quality of previous works and maintenance services during defects liability period by the contractors in the past five years;

C3 (Past Experience) – minimum value of contracts which are similar to the proposed works and which were successfully completed within the last five years;

C4 (Resources) – availability of competent personnel, owned major plants and equipments for construction

C5 (Current Workload) – construction activities which are underway, on-going and nearing completion;

C6 (Safety Performance) – safety performance/ accident rate in the past five years;

The results obtained from ANP and AHP are compared to ascertain the value of the overall priority vector or weights of the criteria and alternatives. Table 17 shows the overall priority weights of the four alternatives based from ANP, as well as in AHP. In AHP where strict independency governs , contractor C has the largest priority weight which is the best alternative. While in ANP specify dependence and feedback, still contractor C with the highest priority weights is the best alternative.

Table 17 shows the comparison of priority weights of the six criteria based from ANP and AHP. In AHP, because of its limited application in simple hierarchical structures, Past Experience has the lowest priority weights among each criteria. Since ANP specify interdependent influences of each criteria, Safety Performance together with Current Workload has almost equal priority weights which explain the equal importance of the criteria during contractor selection process.

Table 5. Pair-wise comparision matrix scores for six criteria

	C1	C2	C3	C4	C5	C6
C1	1	6	7	4	5	5
C2	1/6	1	6	3	4	1
C3	1/7	1/6	1	1	1	1
C4	1/4	1/3	1	1	1	2
C5	1/5	1/4	1	1	1	1
C6	1/5	1	1	1/2	1	1

Table 6. Normalized matrix for six criteria

	C1	C2	C3	C4	C5	C6	ω
C1	0.510	0.686	0.412	0.381	0.384	0.455	0.497
C2	0.085	0.114	0.353	0.286	0.308	0.091	0.200
C3	0.073	0.019	0.059	0.095	0.077	0.091	0.063
C4	0.128	0.038	0.059	0.095	0.077	0.182	0.089
C5	0.102	0.029	0.059	0.095	0.077	0.091	0.070
C6	0.102	0.114	0.059	0.048	0.077	0.091	0.085
						Σ =	1.00

λ_{max}= 6.540, CI= 0.11, RI=1.24, CR= 0.086 < 0.10 OK.

Table 7. Pair-wise comparision matrix "alternatives"

C1		A	B	C	D
	A	1	3	1/2	1/2
	B	1/3	1	1/4	1/4
	C	2	4	1	1
	D	2	4	1	1
C2		A	B	C	D
	A	1	5	1/2	1
	B	1/5	1	1/5	1/4
	C	2	5	1	2
	D	1	4	1/2	1
C3		A	B	C	D
	A	1	4	1/2	1/3
	B	1/4	1	1/5	1/6
	C	2	5	1	1/2

D	3	6	2	1
C4	**A**	**B**	**C**	**D**
A	1	6	1/3	1/2
B	1/6	1	1/8	1/7
C	3	8	1	1
D	2	7	1	1
C5	**A**	**B**	**C**	**D**
A	1	2	1/2	1/2
B	1/2	1	1/2	1/3
C	2	2	1	1
D	2	3	1	1
C6	**A**	**B**	**C**	**D**
A	1	1	1/2	1/2
B	1	1	1/3	1/2
C	2	3	1	1
D	2	2	1	1

Table 8. Normalized matrix " alternatives"

C1	A	B	C	D	ω
A	0.188	0.25	0.182	0.182	0.200
B	0.063	0.083	0.091	0.091	0.082
C	0.375	0.333	0.364	0.364	0.359
D	0.375	0.333	0.364	0.364	0.359
				Σ =	1.00

λ_{max}= 4.021, CI= 0.007, RI=0.9, CR= 0.008 < 0.10 OK.

C2	A	B	C	D	ω
A	0.238	0.333	0.227	0.235	0.258
B	0.048	0.067	0.091	0.059	0.066
C	0.476	0.333	0.455	0.471	0.434
D	0.238	0.267	0.227	0.235	0.242
				Σ =	1.00

λ_{max}= 4.047, CI= 0.016, RI=0.9, CR= 0.018 < 0.10 OK.

C3	A	B	C	D	ω
A	0.160	0.250	0.135	0.167	0.178
B	0.040	0.063	0.054	0.083	0.060
C	0.320	0.313	0.270	0.250	0.288
D	0.480	0.375	0.541	0.500	0.476
				Σ =	1.00

λ_{max}= 4.067, CI= 0.022, RI=0.9, CR= 0.025 < 0.10 OK.

C4	A	B	C	D	ω
A	0.162	0.272	0.170	0.137	0.188
B	0.027	0.045	0.064	0.039	0.044
C	0.486	0.364	0.511	0.549	0.413
D	0.324	0.318	0.255	0.275	0.356
				Σ =	1.00

λ_{max}= 4.071, CI= 0.024, RI=0.9, CR= 0.027 < 0.10 OK.

C5	A	B	C	D	ω
A	0.182	0.250	0.167	0.176	0.194
B	0.091	0.125	0.167	0.118	0.125
C	0.364	0.250	0.333	0.353	0.326
D	0.364	0.375	0.333	0.353	0.356
				Σ =	1.00

λ_{max}= 4.046, CI= 0.015, RI=0.9, CR= 0.017 < 0.10 OK.

C6	A	B	C	D	ω
A	0.167	0.143	0.176	0.167	0.163
B	0.167	0.143	0.118	0.167	0.148
C	0.333	0.429	0.353	0.333	0.363
D	0.333	0.286	0.353	0.333	0.326
				Σ =	1.00

λ_{max}= 4.021, CI= 0.007, RI=0.9, CR= 0.008 < 0.10 OK.

Table 9. Priority matrix

	A	B	C	D
C1(0.471)	0.200	0.082	0.359	0.359
C2(0.206)	0.258	0.066	0.434	0.242
C3(0.069)	0.178	0.060	0.288	0.476
C4(0.096)	0.188	0.044	0.413	0.356
C5(0.075)	0.194	0.125	0.326	0.356
C6(0.082)	0.163	0.148	0.363	0.326
Overall priority vector	0.206	0.083	0.374	0.341

Table 10. Pair-wise comparision matrix scores for six criteria Interdependency

C1	C2	C3	C4	C5	C6
C2	1	6	3	4	1
C3	1/6	1	1	1	1
C4	1/3	1	1	1	2
C5	1/4	1	1	1	1
C6	1	1	1/2	1	1
C2	**C1**	**C3**	**C4**	**C5**	**C6**
C1	1	7	4	5	5
C3	1/7	1	1	1	1
C4	1/4	1	1	1	2
C5	1/5	1	1	1	1

C6	1/5	1	1/2	1	1
C3	**C1**	**C2**	**C4**	**C5**	**C6**
C1	1	6	4	5	5
C2	1/6	1	3	4	1
C4	1/4	1/3	1	1	2
C5	1/5	1/4	1	1	1
C6	1/5	1	1/2	1	1
C4	**C1**	**C2**	**C3**	**C5**	**C6**
C1	1	6	7	5	5
C2	1/6	1	6	4	1
C3	1/7	1/6	1	1	1
C5	1/5	1/4	1	1	1
C6	1/5	1	1	1	1
C5	**C1**	**C2**	**C3**	**C4**	**C6**
C1	1	6	7	4	5
C2	1/6	1	6	3	1
C3	1/7	1/6	1	1	1
C4	1/4	1/3	1	1	2
C6	1/5	1	1	1/2	1
C6	**C1**	**C2**	**C3**	**C4**	**C5**
C1	1	6	7	4	5
C2	1/6	1	6	3	4
C3	1/7	1/6	1	1	1
C4	1/4	1/3	1	1	1
C5	1/5	1/4	1	1	1

Table 11. Normalized matrix for six criteria Interdependency

C1	C2	C3	C4	C5	C6	ω
C2	0.364	0.600	0.462	0.500	0.167	0.423
C3	0.061	0.100	0.154	0.125	0.167	0.119
C4	0.121	0.100	0.154	0.125	0.333	0.163
C5	0.091	0.100	0.154	0.125	0.167	0.126
C6	0.364	0.100	0.077	0.125	0.167	0.169
					Σ =	1.00

λ_{max}= 5.435, CI= 0.11, RI=1.11, CR= 0.098 < 0.10 OK.

C2	C1	C3	C4	C5	C6	ω
C1	0.510	0.412	0.381	0.384	0.455	0.559
C3	0.073	0.059	0.095	0.077	0.091	0.103
C4	0.128	0.059	0.095	0.077	0.182	0.133
C5	0.102	0.059	0.095	0.077	0.091	0.109
C6	0.102	0.059	0.048	0.077	0.091	0.096
					Σ =	1.00

λ_{max}= 5.072, CI= 0.18, RI=1.11, CR= 0.016 < 0.10 OK.

C3	C1	C2	C4	C5	C6	ω
C1	0.510	0.686	0.381	0.384	0.455	0.534
C2	0.085	0.114	0.286	0.308	0.091	0.183
C4	0.128	0.038	0.095	0.077	0.182	0.105
C5	0.102	0.029	0.095	0.077	0.091	0.079
C6	0.102	0.114	0.048	0.077	0.091	0.095
					Σ =	1.00

λ_{max}= 5.447, CI= 0.11, RI=1.11, CR= 0.10 = 0.10 OK.

C4	C1	C2	C3	C5	C6	ω
C1	0.510	0.686	0.412	0.384	0.455	0.564
C2	0.085	0.114	0.353	0.308	0.091	0.197
C3	0.073	0.019	0.059	0.077	0.091	0.065
C5	0.102	0.029	0.059	0.077	0.091	0.074
C6	0.102	0.114	0.059	0.077	0.091	0.101
					Σ =	1.00

λ_{max}= 5.449, CI= 0.11, RI=1.11, CR= 0.10 = 0.10 OK.

C5	C1	C2	C3	C4	C6	ω
C1	0.510	0.686	0.412	0.381	0.455	0.556
C2	0.085	0.114	0.353	0.286	0.091	0.191
C3	0.073	0.019	0.059	0.095	0.091	0.067
C4	0.128	0.038	0.059	0.095	0.182	0.084
C6	0.102	0.114	0.059	0.048	0.091	0.102
					Σ =	1.00

λ_{max}= 5.435, CI= 0.11, RI=1.11, CR= 0.098 < 0.10 OK.

C6	C1	C2	C3	C4	C5	ω
C1	0.510	0.686	0.412	0.381	0.384	0.562
C2	0.085	0.114	0.353	0.286	0.308	0.226
C3	0.073	0.019	0.059	0.095	0.077	0.062
C4	0.128	0.038	0.059	0.095	0.077	0.080
C5	0.102	0.029	0.059	0.095	0.077	0.071
					Σ =	1.00

λ_{max}= 5.369, CI= 0.11, RI=1.11, CR= 0.083 < 0.10 OK.

Table 12. Pair-wise comparision matrix scores for criteria and alternative feedback

A	C1	C2	C3	C4	C5	C6
C1	1	1	4	3	3	3
C2	1	1	3	3	3	3
C3	.25	.33	1	.33	2	2
C4	.33	.33	3	1	.33	4
C5	.33	.33	5	3	1	5
C6	.33	.33	.50	.25	.20	1
B	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**

C1	1	3	3	3	3	3
C2	.33	1	2	2	2	2
C3	.33	.50	1	.33	.33	.33
C4	.33	.50	3	1	.25	.25
C5	.33	.50	3	4	1	1
C6	.33	.50	3	4	1	1

C	C1	C2	C3	C4	C5	C6
C1	1	.33	3	.20	1	1
C2	3	1	5	1	5	5
C3	.33	.20	1	.20	.25	25
C4	5	1	5	1	5	2
C5	1	.20	4	.20	1	1
C6	1	.20	4	.50	1	1

D	C1	C2	C3	C4	C5	C6
C1	1	3	.33	3	1	1
C2	.33	1	.20	1	.33	.50
C3	3	5	1	4	3	3
C4	5	1	.25	1	.33	2
C5	1	3	.33	3	1	2
C6	1	2	.33	.5	.50	1

Table 13. Normalized matrix for criteria and alternative feedback dependence

A	C1	C2	C3	C4	C5	C6	ω
C1	0.395	0.300	0.194	0.283	0.388	0.167	0.291
C2	0.079	0.300	0.194	0.283	0.388	0.167	0.281
C3	0.132	0.100	0.065	0.031	0.025	0.111	0.062
C4	0.132	0.100	0.193	0.094	0.043	0.222	0.116
C5	0.132	0.100	0.322	0.283	0.129	0.278	0.198
C6	0.132	0.100	0.032	0.024	0.026	0.056	0.052
						Σ =	1.00

λ_{max}= 6.601, CI= 0.12, RI=1.24, CR= 0.096 < 0.10 OK.

B	C1	C2	C3	C4	C5	C6	ω
C1	0.387	0.500	0.200	0.209	0.396	0.396	0.349
C2	0.097	0.167	0.133	0.139	0.364	0.264	0.187
C3	0.129	0.083	0.067	0.023	0.044	0.044	0.061
C4	0.129	0.083	0.200	0.070	0.033	0.033	0.085
C5	0.129	0.083	0.200	0.279	0.132	0.132	0.159
C6	0.129	0.083	0.200	0.279	0.132	0.132	0.159
						Σ =	1.00

λ_{max}= 6.599, CI= 0.1, RI=1.24, CR= 0.096 < 0.10 OK.

C	C1	C2	C3	C4	C5	C6	ω
C1	0.088	0.114	0.136	0.064	0.075	0.098	0.094
C2	0.265	0.341	0.227	0.322	0.377	0.488	0.342
C3	0.029	0.068	0.045	0.064	0.019	0.024	0.040
C4	0.441	0.341	0.227	0.323	0.377	0.195	0.320
C5	0.088	0.068	0.182	0.064	0.075	0.098	0.094
C6	0.088	0.068	0.182	0.161	0.075	0.098	0.109
						Σ =	1.00

λ_{max}= 6.313, CI= 0.11, RI=1.24, CR= 0.050 < 0.10 OK.

D	C1	C2	C3	C4	C5	C6	ω
C1	0.150	0.200	0.136	0.024	0.162	0.105	0.167
C2	0.050	0.067	0.082	0.080	0.054	0.053	0.064
C3	0.450	0.333	0.408	0.320	0.486	0.315	0.387
C4	0.050	0.067	0.102	0.080	0.054	0.210	0.092
C5	0.150	0.200	0.136	0.024	0.162	0.210	0.184
C6	0.150	0.133	0.136	0.040	0.081	0.105	0.106
						Σ =	1.00

λ_{max}= 6.312, CI= 0.06, RI=1.24, CR= 0.050 < 0.10 OK.

Table 17. Overall priority weights (AHP and ANP)

	AHP	ANP
C1	.497	.391
C2	.200	.217
C3	.063	.088
C4	.089	.114
C5	.070	.092
C6	.085	.098
A	.206	.205
B	.083	.082
C	.374	.373
D	.341	.340

For prequalification purposes the decision makers can ensure the correctness of his judgement on the overall priorities of each criteria, sub-criteria and alternative using ANP.

4. CONCLUSIONS

The paper has presented ANP as an improved decision-making tool compared to AHP in determining not only hierarchic order of each criteria but also the interdependent relationship and feedback dependence used to select the best alternative. This enhanced selection method avoids many risks which may result to problems if the project was awarded to less capable contractor. Managing complex projects involves complex decision making abilities. Project failures not only result to poor selection of contractors but who made the selection process. The method can also be used in selecting who will be the best capable construction project manager.

Table 18. The supermatrix

SUPERMATRIX		GOAL	SELECTION CRITERIA						CONTRACTOR ALTERNATIVES			
			C1	C2	C3	C4	C5	C6	A	B	C	D
GOAL		1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
SELECTION CRITERIA	C1	**0.497**	0.000	0.559	0.538	0.564	0.556	0.562	0.291	0.349	0.094	0.167
	C2	**0.197**	0.423	0.000	0.183	0.197	0.191	0.226	0.281	0.187	0.342	0.064
	C3	**0.063**	0.119	0.103	0.000	0.065	0.067	0.061	0.062	0.061	0.040	0.387
	C4	**0.089**	0.163	0.133	0.105	0.000	0.084	0.080	0.116	0.085	0.320	0.092
	C5	**0.070**	0.126	0.109	0.079	0.074	0.000	0.071	0.198	0.159	0.094	0.184
	C6	**0.085**	0.169	0.096	0.095	0.101	0.102	0.000	0.052	0.159	0.109	0.106
CONTRACTOR ALTERNATIVES	A	0.000	0.200	0.258	0.176	0.188	0.194	0.163	1.000	0.000	0.000	0.000
	B	0.000	0.082	0.065	0.059	0.044	0.124	0.148	0.000	1.000	1.000	0.000
	C	0.000	0.359	0.435	0.289	0.413	0.326	0.363	0.000	0.000	1.000	0.000
	D	0.000	0.359	0.242	0.476	0.356	0.356	0.326	0.000	0.000	0.000	1.000

Table 19. The normalized Supermatrix

NORMALIZED SUPERMATRIX		INPUT MATRIX										
		GOAL	SELECTION CRITERIA						CONTRACTOR ALTERNATIVES			
			C1	C2	C3	C4	C5	C6	A	B	C	D
GOAL		0.5000	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333	0.3333
SELECTION CRITERIA	C1	0.2483	0.0000	0.1864	0.1792	0.1879	0.1852	0.1874	0.0969	0.1163	0.0315	0.0556
	C2	0.0984	0.1410	0.0000	0.0611	0.0657	0.0638	0.0752	0.0937	0.0622	0.1141	0.0213
	C3	0.0314	0.0397	0.0342	0.0000	0.0216	0.0223	0.0205	0.0207	0.0205	0.0135	0.1291
	C4	0.0445	0.0544	0.0445	0.0349	0.0000	0.0280	0.0266	0.0387	0.0282	0.1068	0.0307
	C5	0.0348	0.0419	0.0363	0.0265	0.0245	0.0000	0.0237	0.0660	0.0531	0.0312	0.0614
	C6	0.0427	0.0563	0.0319	0.0317	0.0336	0.0341	0.0000	0.0173	0.0531	0.0363	0.0353
CONTRACTOR ALTERNATIVE	A	0.0000	0.0666	0.0860	0.0586	0.0626	0.0645	0.0543	0.3333	0.0000	0.0000	0.0000
	B	0.0000	0.0272	0.0218	0.0197	0.0145	0.0414	0.0493	0.0000	0.3333	0.0000	0.0000
	C	0.0000	0.1198	0.1450	0.0963	0.1376	0.1086	0.1210	0.0000	0.0000	0.3333	0.0000
	D	0.0000	0.1198	0.0806	0.1587	0.1186	0.1188	0.1087	0.0000	0.0000	0.0000	0.3333

Table 20. The limit matrix

LIMIT SUPERMATRIX		LIMIT SUPERMATRIX										
		GOAL	SELECTION CRITERIA						CONTRACTOR ALTERNATIVES			
			C1	C2	C3	C4	C5	C6	A	B	C	D
GOAL		0.4006	0.4006	0.4006	0.4006	0.4005	0.4006	0.4006	0.4005	0.4006	0.4006	0.4006
SELECTION CRITERIA	C1	0.1568	0.1568	0.1568	0.1568	0.1567	0.1568	0.1568	0.1567	0.1568	0.1568	0.1568
	C2	0.0868	0.0868	0.0868	0.0868	0.0868	0.0868	0.0868	0.0868	0.0868	0.0868	0.0868
	C3	0.0354	0.0354	0.0354	0.0354	0.0354	0.0354	0.0354	0.0354	0.0354	0.0354	0.0354
	C4	0.0457	0.0456	0.0456	0.0456	0.0456	0.0456	0.0456	0.0456	0.0456	0.0456	0.0456
	C5	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367	0.0367
	C6	0.0393	0.0393	0.0393	0.0393	0.0393	0.0393	0.0393	0.0393	0.0393	0.0393	0.0393
CONTRACTOR ALTERNATIVE	A	0.0410	0.0410	0.0410	0.0410	0.0410	0.0410	0.0410	0.0410	0.0410	0.0410	0.0410
	B	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165	0.0165
	C	0.0747	0.0747	0.0747	0.0747	0.0747	0.0747	0.0747	0.0747	0.0747	0.0747	0.0747
	D	0.0682	0.0682	0.0682	0.0682	0.0681	0.0682	0.0682	0.0681	0.0682	0.0682	0.0682

5. ACKNOWLEDGMENTS

The author would like to thank Design Coordinates, Inc., colleagues and staffs for providing the data and support to conduct this research paper. Also to Dr. Michael Angelo Promentilla our professor with his guidance.

6. REFERENCES

Abudayyeh, O., Zidan, S., Yehia, S., and Randolph, D. "Hybrid Prequalification-Based, Innovative Contracting Model Using AHP." Journal of Management in Engineering (2007); 23(2), 88-96.

Almeida, M.V. Pre-Qualification Of Contractors For High-Rise Building Projects In Philippines: A Selection Method In Construction Management Using Analytic Hierarchy Process (AHP) As A Tool In Decision Making. DLSU Research Congress 2016.

Al-Subhi Al-Harbi, K.M., Application of AHP in project Management. International Journal of Project Management 19 (2001) 19-27.

Balubaid, M., Alamoudi, R. (2015). Application of the Analytical Hierarchy Process (AHP) to Multi-Criteria Analysis for Contractor Selection. American Journal of Industrial and Business Management, 2015, 5, pp.581-589.

Cakmak, P. and Cakmak, E. (2013) An Analysis of Causes of Disputes in the Construction Industry Using Analytic Hierarchy Process (AHP). AEI 2013: pp. 94-102.

Cheng, W.L.E., Heng L., 2004, Contractor selection Using the analytic network process, Construction Management and Economics 22, p. 1021-1032.

Chun-Chang Lin, Wei-Chih Wang, Wen-Der Yu. Improving AHP for construction with an adaptive AHP approach (A3). Automation in Construction 17; (2008) 180-187.

Eddie, W.L., Cheng, Li, H. (2004, December). Contractor selection using the analytic network process. Construction Management and Economics 22: pp.1021-1032

Fong, S.P. and Choi, S.K. (2000) Final contractor selectionusing the analytical hierarchy process. Construction Management and Economics, 18, 547–57.

Hatush, Z., Skitmore, R.M., (1996a), Common criteria for contractor selection, Construction Management and Economics (in press).

Hatush, Zedan and Skitmore, Martin R. (1997) Assessment and evaluation of contractor data against client goals using pert approach. Construction Management and Economics 15(4):pp. 327-340.

Hatush, Z., Skitmore, M., 1998, Contractor selection using multicriteria utility theory: an additive model, Building and Environment 33, p. 105-115

Huang, X. (2011, March). An Analysis of the Selection of Project Contractor in the Construction Management Process. International Journal of Business and Management. Vol.6, No.3, pp. 184-189.

Holt, G.D., Olomolaiye, P.O., Harris, F.C., 1994, Factors influencing UK construction clients' choice of contractor, Building and Environment, 1994 29 (2) p. 241-248.

Jaskowski, P., Biruk S., Bucon R., 2010, Assessing contractor selection criteria weights with fuzzy AHP method application in group decision environment, Automation in Construction 19, p. 120-126.

Kamal, M., Subhi, A., Harbi, A. Application of the AHP in project management. International Journal of Project Management 19 (2001). pp.19-27.

Mahdi, I.M., Riley, M.J., Fereig, S.M. and Alex, A.P. (2002) A multi-criteria approach to contractor selection. Engineering, Construction and Architectural Management,

Promentilla, M.A.B., Furuichi, T., Ishii, K., Tanikawa, N. (2005). Evaluation of remedial countermeasures using the analytic network process. Waste Management 26 (2006) 1410-1421.

Russell, J.S. (1992). Decision models for analysis and evaluation of construction contractors. Construction management and economics, 10, 185-202.

Saaty, T.L. (2008). Decision making with the analytic hierarchy process. Int. J. Services, Vol.1, No.1, pp.83-98.

Shiau, Y.C., Tsai, T.P., Huang, M.L. Use questionnaire and AHP techniques to develop subcontractor selection system.pp.1-6.

Skibniewski, M. and Chao, L. " Evaluation of Advanced Construction Technology with AHP Method." Journal of Construction Engineering and Management 118(3); (1992), 557-593.

Shapira, A. and Goldenberg, M. "AHP-Based Equipment Selection Model for Construction Projects."Journal of Construction Engineering and Management (2005): 131(12), 1263-1273.

Ng, S.T.T., (1992), Decision support system for contractor prequalification, University of Salford, Department of Surveying, UK.

Meade, L. and Sarkis, J. (1998) Strategic analysis of logistics and supply chain management systems using the analytic network process. Transportation Research Part E: Logistics and Transportation Review, 34(3), 201–15.

Petronijevic, M., Nikolic, A., Mikic, M., Ivanisevic, N. (2015 September). AHP Based Contractor

Selection Procedure for Highway Infrastructure Projects in Serbia. Croatian Association for Construction Management. pp. 206-214. Retrieved November 03, 2015 from Miljan Mikic. http://www.researchgate.net/publication/282732904

Plebankiewicz, E., 2009, Contractor prequalification model using fuzzy sets, Journal of Civil Engineering and Management 15 (4), p. 377-385.

Satty, T.L., "The Analytic Hierarchy Process", McGrawHill, New York, 1980.

Thomas L. Saaty. How to make a decision: The Analytic Hierarchy Process. European Journal of Operational Research 48;(1990) 9-26.

APPENDICES

APPENDIX 1. Company Description

Contractor A	Contractor B	Contractor C	Contractor D
Is recognized as one of the leading construction companies in the Philippines, known for the quality of its work and the excellence of its workforce. It has the broadest range of construction and engineering services, with expertise in the construction of large-scale heavy and light industrial projects, infrastructure, and property development projects all over the world. Over the years, Contractor A has built several power plants, refineries, petrochemical plants, cement plants, mining facilities, industrial plants, buildings, schools, hospitals, roads, bridges, seaports, airports, railways, water distribution stations, flood control systems, steel structures and modular assemblies. As such, it is a preferred contractor of global Engineering, Procurement and Construction Companies.	Started as a modest sub-contractor and gradually worked their way to become an AAA Contractor. In a span of only twelve (12) years from its inception.As service oriented organization, contractor B give utmost importance to client satisfaction by continually improving the means of delivering projects, in the **safest way** possible, of **highest quality** attainable, shortest time achievable, at a **reasonable cost**.	Established in 1975, is a leading international construction company. Headquartered in Hong Kong, contractor C delivers a portfolio of high-profile infrastructure projects throughout Asia. As a proven leader in the delivery of complex tunnel, rail and road networks, contractor C also delivers turn-key renewable energy infrastructure including utility-scale wind, geothermal energy and waste-to-power installations. Its building projects range from schools, embassies and luxury high-rise residential towers, to large scale leisure complexes, a growing number of which are built to international green building and energy efficiency standards. Contractor C currently operates in Hong Kong, Indonesia, India, Macau, Malaysia, Philippines, Singapore, Thailand and Iraq.	Over the years has left its mark on a multitude building projects and structures in the Philippines and abroad. Built its legacy and solid reputation on enduring values of excellence, high standards of quality and completed projects on or ahead of schedule. Continues to undertake new construction techniques and using new products and processes. With more than 5 decades of solid track record, contractor D build world-class expertise and extensive portfolio in high-rise and commercial building construction.

APPENDIX 2. Sample Prequalification Evaluation

			CONTRACTOR C						
DESCRIPTION			PARAMETERS	CHECKLIST	REMARKS	ASSESSMENT	PS	CP	RS
1.00	Construction Methodology	10%	(1) With program for mobilization at site, including procedure for turn-over of Excavation Works	(1) Included in submittal.	(1) With submittals in proposal for:		1	1	
					a. Temporary MEPS Layout for Temfacil	a. Proposal is acceptable.			
					b. Procedure on Turn-over of Site/Joint Survey with Excavation Contractor	b. Clarify if in cost offer soil bear test is included as it is identified in method statement.			
			(2) Proposed work schedule should be validated by a pre-established calculations, with specific work flow-sequence	(2) Included in submittal.	(2) With proposal for: a. Basis of Calculation of Projected Milestones	(2) Conflict in schedule is identified in MEPF/ Equipment Works; should be rechecked.	1	0	
			(3) Construction Procedures and Method Statements to be included (but not limited to):	(3) Included in submittal.	(3) General Method Statements given as:	(3) Schematics on methods shown and detailed-out particularly on concrete pour works, which is tailored-fit with the project			
			(a) Mobilization		a. Noted		1	1	
			(b) Site Preparation; Temfacil,including equipment		b. Noted		1	1	
			(c) Formworks		c. Noted; with illustrations	c. Use of FUVI for formworks for better qu	1	1	
			(d) Concrete Works		d. Noted; with illustrations		1	1	
			(e) Basic Architectural Works and MEPF Works (including interface works)		e. Noted; with illustrations		1	1	
			(f) Curtain Wall Works		f. Noted; with illustrations		1	1	
			(g) Project Close-out and Demobilization		g. Noted.		1	1	
			(4) Interfacing with and Attendance to other Work Packages	(4) Included in submittal.	(4) Noted in proposal.		1	1	
			(5) Submittal Schedule	(5) See remarks.	(5) Not included in proposal.	(5) Clarify Submittal-Schedule preparation.	1	1	
			(6) Preparation of CSDs	(6) See remarks.	(6) Not clearly defined in proposal.	(6) Clarify attendance for CSDs preparation.	1	0	
			(7) Compliance to Drawings and Specifications	(7) See remarks.	(7) Noted in proposal.		1	1	
							13	11	8.46
2.00	Temporary Facility Layout	3%	(1) At least one (1) established control point for egress and ingress at site	(1) Identified in submittal.	(1) With two (2) egress/ingress points.	(1) Two egress/ingress points with identified and security at site	1	1	
			(2) Orientation of temfacil should consider the actual location of VMU which will have a direct effect on the layout	(2) Identified in submittal.	(2) VMU location indicated not as per actual conditions.	(2) Check if ocular visit was conducted. Temfa layout may be revised accordingly.	1	0	
			(3) A proposed floor layout of the offices should be defined and presented, including the contractor's laydown area, storage areas, waste disposal unit(s), etc.	(3) See remarks.	(3) With defined layout/floor plan for PM's Site Office and Gencon's Office, etc.	(3) Confirm location of waste disposal units	1	0	
			(4) Accesway to the building from the temfacil/offices to the construction site should be properly identified, including the the equipment to be used during operations/construction	(4) See remarks.	(4) Accessway to activity area/site and Alimak clearly defined and identified in layout.	(4) Access layout is acceptable as identified in proposal.	1	0	
			(5) Office requirement for the Owner/Owner's Rep. should be at least 270sqm, with Conference Room (cap. Min. 20 people)	(5) See remarks.	(5) Noted. Included in proposal.	(5) Complying with requirements (with floor la including MEP plans).	1	1	
			(6) Office layout of Gencon should be presented, identifying the proposed location and layout of each departments in line w/ the proposed organization chart/manpower requirements.	(6) See remarks.	(6) Noted. Included in proposal.	(6) Complying with requirements (with floor la including MEP plans).	1	0	
							6	2	1.00
3.00	Construction Schedule	10%	(1) Project Schedule should cover a maximum 24-month timeline	(1) Stipulated in submittal.	(1) Noted. With 24-month project timeline.	(1) With diagrams and illustrations on sequen works, only, conflict with MEPF/Equipment Schedule should be refined with main works.	1	1	1
			(2) Set on a minimum of +/-200sqm per day of concrete works, shell of the building should be about on a 3 to 3.5 floors/month or about 10 to 12 months for the superstructure and relatively 5 to 6-months duration for the substructure (was based on completed similar projects)	(2) See remarks.	(2) Noted. Target daily or weekly accomplishment not specifically detailed-out and presented.				
					(2) Structural is set at 17-months to top-off, 12 mos. for superstructure and 5.0 mos. for substructure.	(2) Proposal is set at 2.83 floors ave. per mont superstructure which is within the expected timeline; substructure is still within expected timeline.	1	1	1
			(3) Established timeline for CWU is 3 to 4 floors/month, or about Eight (8) to Nine (9) months duration, with building seal-off set at 6 months before project hand-over	(3) See remarks.	(3) CWU is at 3F/mo; 11mos to complete, from October 2010 to August 2011.	(3) Within anticipated target of 3-4 floors per month. However, there is conflict with presented schedule vs. illustration (i.e. CWU works in reference with Concrete Works)	1	0	0
			(4) Project Schedule Calculations & Parameters were based on:	(4) See remarks.	(4) Noted.	(4) Proprosed schedule subject for presentation.			
			(a) Target Site Hand-over to Gencon - mid November 2009			(a) Within the parameter set.	1	1	
			(b) Gencon's Day 1 at Site - 3rd Week November 2009			(b) Within the parameter set.	1	1	
			(c) Top-off - April 2011		(c) Expected top-off by March 2011.	(c) Within te parameter set.	1	1	
			(d) Building Seal-off - Mid-year 2011		(d) Expected to seal-off by August 2011.	(d) Water tightness of bldg. is inconsistent w CWU completion and removal of Alimak.	1	0	
			(e) Testing and Commissioning by September 2011			(e) Review Equipment Schedule Installations Confirm early procurement-installation sched.	1	0	
			(5) Primavera Project Planner (and S-curve) or equivalent with Monthly Projected Accomplishments	(5) See remarks.	(4) Noted included in proposal.	(4) Proprosed schedule subject for presentati	1	1	1
							9	6	6.67
4.00	Quality Policy & Procedure	10%	(1) With written Quality Policies, which will include the company's Quality Plan, Quality Control and Quality Assurance	(1) Included in submittal.	(1) Noted in proposal.	(1) With established Quality Program and Polic	1	1	
			(2) With established Quality Systems which is ISO 9001:2000 Certified	(2) See remarks	(2) Noted.	(2) With certification.	1	1	
							2	2	10.00
5.00	Safety Policy and Manual	10%	(1) With written Environment, Health and Safety Plan covering the following (but not limited to):	(1) Included in submittal.	(1) Noted in proposal.	(1) With established Safety Program and Polic	1	1	
			(a) Company EHS Policies and Program			(a) Included.	1	1	
			(b) Housekeeping			(b) Included.	1	1	
			(c) Accident, Emergency and Fire Prevention/Control Plan			(c) Included.	1	1	
			(d) Environment Management			(d) Included.	1	1	
			(e) Site and Building Security Measure and Program			(e) Included.	1	1	
			(2) With established Safety Manual which is ISO 14001 Certified and DOLE Accredited	(2) See remarks.	(2) Noted.	(2) With certification.	1	1	
							7	7	10.00
6.00	Manpower Loading	4%	(1) Use of Approximation to Manpower Loading to check Validity of proposal:	(1) Included in submittal.	(1) Noted; with illustrations.		1	1	
			(a) The maximum manpower at site is 160% of the average manpower site		(a) Max. manpower alloted is 745.	(a) As per calculations, max. manpower shou 745 (at peak), hence, acceptable.	1	1	
			(b) The maximum manpower at site first occurs after 40% of the total manpower requirement has been expended.		(b) Max. manpower alloted is at 7th month.	(b) As per calculations, max. manpower is at n 10 also, hence, acceptable.	1	1	
			(c) The period of maximum manpower at site accounts for 40% of the Total Manpower Requirement		(c) Max. manpower alloted is at 5,272 from month 7 to month 14	(c) As per calculation max. manpower is at 47 during the peak period, hence, acceptable.	1	1	
			(d) The maximum manpower at site first occurs when 50% of the project time has elapsed.		(d) Max. manpower alloted is at 12th month	(d) As per calculation max. manpower is at mo 12 also, hence, acceptable.	1	1	
			(e) The period of maximum manpower at site occurs for 25% of the project time.		(e) Max. manpower alloted is in 8 months, from month 7 to month 14.	(e) As per calculation max. manpower is abou 33.33%, hence, acceptable.	1	1	
							6	6	4.00

APPENDIX 3. Sample Survey Data

NAME: JONATHAN BIONA
COMPANY: DESIGN COORDINATES, INC.
POSITION: QCMD HEAD

Instruction: Put a "x" mark on the box provided for your answers. Choose only one (1) answer for every question.

No.	Question	1 Equally preferred	2 Equally to moderately	3 Moderately preferred	4 Moderately to strongly	5 Strongly preferred	6 Strongly to very strongly	7 strongly preferred	8 strongly to	9 Extremely preferred
1	Which criteria between Financial Capability and Past Performance do you think is best in contractor selection?						X			
2	Which criteria between Financial Capability and Past Experience do you think is best in contractor selection?							X		
3	Which criteria between Financial Capability and Resources do you think is best in contractor selection?				X					
4	Which criteria between Financial Capability and Current Workload do you think is best in contractor selection?					X				
5	Which criteria between Financial Capability and Safety Performance do you think is best in contractor selection?					X				
6	Which criteria between Past Performance and Past Experience do you think is best in contractor selection?						X			
7	Which criteria between Past Performance and Resources do you think is best in contractor selection?			X						
8	Which criteria between Past Performance and Current Workload do you think is best in contractor selection?				X					
9	Which criteria between Past Performance and Safety Performance do yopu think is best in contractor selection?	X								
10	Which criteria between Past Experience and Resources do you think is best in contractor selection?	X								
11	Which criteria between Past Experience and Current Workload do you think is best in contractor selection?	X								
12	Which criteria between Past Experience and Safety Performance do you think is best in contractor selection?	X								
13	Which criteria between Resources and Current Workload do you think is best in contractor selection?	X								
14	Which criteria between Resources and Safety Performance do you think is best in contractor selection?		X							
15	Which criteria between Current Workload and Safety Performance do you think is best in contractor selection?	X								