A Case Study on Selection of Contractor using Analytical Hierarchy Process

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Abstract - Contractor selection process is usually believed to be impair the quality with lots of prejudice in most developing nations, which sometimes primes to incompetent contractor being selected because it is grounded mainly on human experience and feelings. One of the crucial activities of any client is contractor selection. Without appropriate and detailed method for selecting the best contractor, the completion of a project will likely be affected. In the study, we scrutinize the use of the analytical hierarchy process (AHP) as a decision-support model for contractor selection. In this study, an AHP-based model is tested using a hypothetical situation in which contender contractors are appraised. Four criteria for the primary objective are evaluated. The criteria used for contractor selection in the model are recognized, and the significance of each criterion is determined by means of matrices. Comparisons are made by ranking the global score of each candidate based on each criterion, and the candidate with the highest score is deemed the best. The procedure can be easily enhanced to adopt specific conditions of the proposed project and also to enable the decision maker in amplifying the reasons for the elimination of excluded contractor. The Analytical Hierarchy process(AHP) delivers a flexible and computer based method for contractor selection verdict.

***Key Words*: Analytical Hierarchy Process, Multi-Criteria Decision-Making, Contractor Selection.**

1. INTRODUCTION

An important characteristic of the construction industry is that the majority of contractors involved are small-scale firms. In many countries, there are thousands of contracting firms, which range from sole traders to large firms employing a workforce of several thousands, Roger *et al* (1993). The existence of a large number of contractors in a limited number of projects and uncertain construction industry environment results in intense competition between them. Identifying the best contractor does not necessarily mean that this contractor is the most appropriate one to the project under consideration. However, the proposed method provides a systematic methodology to incorporate all relevant criteria simultaneously for the selection of the most appropriate contractor. In this context, the capability of each contractor should be evaluated based on the specific requirements of the project in hand. Further, the selection method should be simple, normally accurate and transparent so that the method can reason why a particular contractor is selected for a particular project. On the other hand, a study carried out to measure the contractors' opinions in the multi-criteria selection approach by Jennings and Holt (1998) indicated that contractors tend to agree with clients' importance levels of multi-criteria selection factors.

2. Analytical Hierarchy Process(AHP)

The analytical hierarchy process (AHP), first introduced by Thomas L. Saaty, is described by Partovi (1992) as 'a decision-aiding tool for dealing with complex, amorphous and multi-attribute decision'. Bid evaluation is one of the foremost challenges that face owners and consultants in both the public and private sectors in deciding on the finest construction contractor. Selecting the best one requires a sophisticated knowledge and experience to ensure that the contractor is technically and financially capable to accomplish the project on time, within budget, and as specified. To identify contractors with the best potential and to deliver satisfactory outcomes different process were experimented which were not based simply on the lowest bid but included some questionnaire, model testing and case studies. The model tested by a hypothetical scenario for contractor selection were made. In addition, the AHP integrates a useful technique for checking the consistency of the decision maker's assessments, thus reducing the unfairness in the decision making process. The AHP creates a weight for each evaluation criterion rendering to the decision maker's pairwise comparisons of the criteria. The higher the value, the more important the corresponding criterion. The AHP reflects a set of evaluation criteria, and a set of alternative options between which the best decision is to be made. It is significant to note that, since some of the criteria could be conflicting, it is not true in general that the finest option is the one which optimizes each single criterion, rather the one which achieves the most suitable trade-off among the diverse criteria.

3. Implementation of the AHP

The AHP can be instigated in three simple successive steps:

1) Computing the vector of criteria weights.

2) Computing the matrix of option scores.

3) Ranking the options.

Each step will be defined in detail in the following. It is assumed that m evaluation criteria are considered, and n options are to be assessed.

3.1 Computing the vector of criteria weights

In order to calculate the weights for the different criteria, the AHP starts creating a *pairwise comparison matrix* **A**. The matrix **A** is an $m \times m$ real matrix, where m is the number of evaluation criteria considered. Each entry a_{jk} of the matrix **A** characterizes the importance of the jth criterion proportional to the kth criterion. For a matrix **A**, a_{ij} signifies the entry in the ith row and the jth column of **A**. For a vector **v**, v_i denotes the ith element of **v**. If $a_{jk} > 1$, then the jth criterion is more significant than the kth criterion, while if $a_{jk} < 1$, then the jth criterion is less important than the kth criterion. If two criteria have the same importance, then the entry a_{jk} is 1. The entries a_{jk} and a_{kj} gratify the following constraint:

$$a_{jk} \cdot a_{kj} = 1. \quad (1)$$

Obviously, ajj = 1 for all j. The comparative importance between two criteria is measured according to a numerical scale from 1 to 9, as shown in Table 1, where it is assumed that the jth criterion is correspondingly or more important than the kth criterion.

Table 1: The Saaty Rating Scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgement slightly favor one over the other.
5	Much more important	Experience and judgement strongly favor one over the other
7	Very much more important	Experience and judgement very strongly favor one over the other. Its importance is demonstrated in practice.
9	Absolutely more important	The evidence favoring one over the other is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

Once the matrix **A** is built, it is conceivable to originate from **A** the *normalized pairwise comparison matrix* **A***norm* by making equal to 1 the sum of the records on each column, i.e.

Each entry $\bar{a}_{jk}$ of the matrix **A***norm* is computed as

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{i=1}^{m} a_{jk}} \quad (2)$$

As a final point, the *criteria weight vector* ***w*** (that is an m-dimensional column vector) is assembled by taking the average of the entries on each row of **A***norm*, i.e.

$$w_j = \frac{\sum_{i=1}^{m} \bar{a}_{jl}}{m} \quad (3)$$

3.2 *Computing the matrix of option scores*

The matrix of option scores is a $n \times m$ real matrix which is denoted as **S.** Each entry s_{ij} of **S** signifies the score of the ith option with respect to the jth criterion. Each entry of the matrix characterizes the evaluation of the ith option equalled to the hth option with respect to the jth criterion. 1, then the ith option is better than the hth option, while if $b_{ih}(j) < 1$, then the ith option is worse than the hth option. If two options are assessed as equivalent with respect to the jth criterion, then the entry $b_{ih}(j)$ is 1. The entries $b_{ih}(j)$ and $b_{hi}(j)$ satisfy the following constraint:

$$b_{ih}(j) . b_{hi}(j) = 1 \quad (4)$$

Second, the AHP applies to each matrix B(j) the same two-step method termed for the pairwise evaluation matrix **A**, i.e. it divides each entry by the sum of the entries in the same column, and then it averages the entries on each row, thus obtaining the score vectors $s(j)$, $j=1,...,m$. The vector $s(j)$ contains the scores of the evaluated options with respect to the jth criterion. Finally, the score matrix **S** is obtained as

$$\mathbf{S} = [s(1) \ldots s(m)] \quad (5)$$

i.e. the jth column of **S** resembles to $s(j)$.

3.3 Ranking the options

Once the weight vector ***w*** and the score matrix **S** have been figured, the AHP attains a vector **v** of global scores by multiplication of **S** and **w**, i.e.

$$\boldsymbol{v} = \mathbf{S} \cdot \boldsymbol{w} \quad (6)$$

The ith entry v_i of **v** characterizes the global score allotted by the AHP to the ith option.

3.4 Checking the consistency

The *Consistency Index* (*CI*) is obtained by first computing the scalar *x* as the average of the elements of the vector whose *j*th element is the proportion of the *j*th element of the vector **A**·***w*** to the equivalent element of the vector ***w***. Then,

$$CI = \frac{x-m}{m-1} \quad (7)$$

A perfectly consistent decision maker should permanently obtain *CI*=0, but small values of inconsistency may be endured. In particular, if

$$\frac{CI}{RI} < 0.1 \quad (8)$$

the inconsistencies are tolerable, and a unfailing result may be expected from the AHP.

4. Case Study

The case study under contemplation describes a situation where we have considered four contractors shortlisted for awarding contract. The data of the case study is the general number required for the contractors after the projects have been successfully completed. There are four contractors under consideration whose profiles we have with above criteria.

Hence we set the evaluation criteria as

- Turnover
- Projects
- Equipment
- Staff

And set of alternative options as contractors 'A', 'B', 'C', and 'D'.

4.1 Contractor's Profiles

The contractor's profiles are studied thoroughly and the vast details about their Turnover, Projects completed by them, Equipment, machines and tools owned or required by them and the technical personnel available with them are consolidated to create a short profile which gives the idea about their strength and weakness in the respective criteria under consideration. The contractors profile mentioned in tabular form as follows:

Table 2: Contractor A's Profile

Contractor A						
No of Works	Total Cost of Works (in mil INR)	No of Equipment's	No	Technical Personnel	No	Turnover for Past Years (in mil. INR)
18	1,354	Earthwork	75	Engineers	15	165
		Concreting	78	Foremen	10	222
		Aggregates	11	Supervisors	38	236
		Tools	168			430
						415

Table 3: Contractor B's Profile

Contractor B						
No of Works	Total Cost of Works (in mil INR)	No of Equipment	No	Technical Personnel	No	Turnover for Past Years (in mil. INR)
15	2,270	Earthwork	51	Engineers	46	922
		Foundation	94	Supervisors	15	1254
		Concreting	146			1402
		Tools	255			

Table 4: Contractor C's Profile

Contractor C						
No of Works	Total Cost of Works (in mil INR)	No of Equipment	No	Technical Personnel	No	Turnover for Past Years (in mil. INR)
13	365	Earthwork	22	Engineers	18	95.70
		Concreting	30	Supervisors	26	118.25
		Tools	35			140.60
		Others	8			148.23
						199.50

Table 5: Contractor D's Profile

Contractor D						
No of Works	Total Cost of Works (in mil INR)	No of Equipment	No	Technical Personnel	No	Turnover for Past Years (in mil. INR)
18	1,685	Earthwork	12	Engineers	26	88.97
		Concreting	46	Supervisors	15	117.56
		Tools	60			138.52
		Others	15			205.47

Before we proceed to the pairwise comparison, we formulate the problem and set our decision hierarchy. Here the evaluation criteria and options are set. The hierarchical structure of the problem is given in Figure 1. The figure characterizes the flow of decision making in Analytical Hierarchy Process.

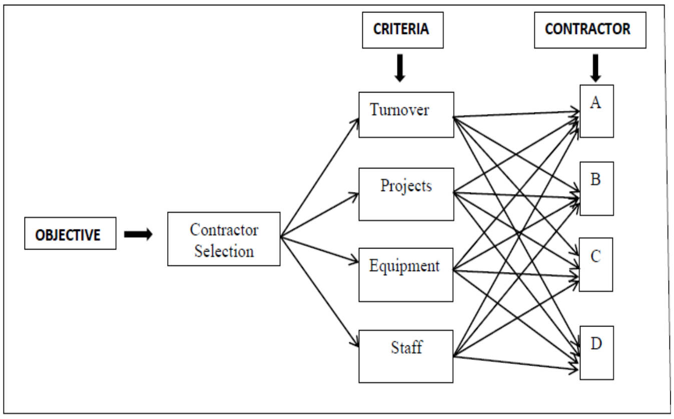

Figure 1. Contractor Selection Model.

4.2 Applying AHP

After setting the criteria a pairwise comparison is done using the Saaty's AHP scale. The Saaty's scale of comparisons in a multi-criteria decision making area as in this study gives us an idea as what importance does the alternative when compared to the other alternative.

As discussed earlier the pairwise matrix is obtained after comparing each criterion with one another.

Table 6: Pairwise Comparison of Criteria (Matrix A)

Criteria	Turnover	Project	Equipment	Staff
Turnover	1	1/3	3	3
Project	3	1	5	7
Equipment	1/3	1/5	1	3
Staff	1/3	1/7	1/3	1
Sum	**4 2/3**	**1 2/3**	**9 1/3**	**14**

e.g. Now if we take the row wise project and column wise turnover into consideration project is somewhat more important than the turnover and hence the value is taken as 3. Also for equipment and project the value is taken as 1/5 because here project is much more important than equipment. When both elements are equally important, the number will be 1. The general criteria of comparison are taken in order as,

Project > Turnover > Equipment > Staff.

Table 7: Pairwise Comparison of Criteria in Decimals

Criteria	Turnover	Project	Equipment	Staff
Turnover	1.000	0.333	3.003	3.000
Project	3.000	1.000	5.000	6.993
Equipment	0.333	0.200	1.000	3.000
Staff	0.333	0.143	0.333	1.000
Sum	**4.666**	**1.676**	**9.336**	**13.993**

Table no. 8 represents normalized pairwise criteria matrix. For this all the elements of the column are divided by the sum of the column.

Table 8: Normalized Criteria Matrix (Matrix Anorm)

Criteria	Turnover	Project	Equipment	Staff
Turnover	0.214	0.199	0.322	0.214
Project	0.643	0.597	0.536	0.500
Equipment	0.071	0.119	0.107	0.214
Staff	0.071	0.085	0.036	0.071
Sum	**1.000**	**1.000**	**1.000**	**1.000**

Table no. 9 represents criteria weight. Criteria weights are calculated by averaging all the elements in the row.

Table 9: Criteria Weight (vector *w*)

Criteria	Turnover	Project	Equipment	Staff	Criteria Wt.[Avg](vector *w*)
Turnover	0.214	0.199	0.322	0.214	0.237
Project	0.643	0.597	0.536	0.500	0.569
Equipment	0.071	0.119	0.107	0.214	0.128
Staff	0.071	0.085	0.036	0.071	0.066
Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Table no. 10 represents the consistency matrix. The consistency matrix is product of the criteria weight and each column in the pairwise comparison of criteria matrix in decimals respectively. Then the weighted sum value is calculated. It is the sum of each value in the row.

Table 10: Consistency Matrix

Criteria	Turnover	Project	Equipment	Staff	Weighted Sum value
Turnover	0.237	0.190	0.385	0.198	1.009
Project	0.712	0.569	0.640	0.461	2.382
Equipment	0.079	0.114	0.128	0.198	0.519
Staff	0.079	0.081	0.043	0.066	0.269

Here in table no. 11 the scalar *x* value is computed. It is the ratio of weighted sum value and the criteria weight and their average.

Table 11: Scalar (*x*)

Criteria	Weighted Sum value	Criteria Weight	Weighted Sum value/Criteria Weight
Turnover	1.009	0.237	4.253
Project	2.382	0.569	4.189
Equipment	0.519	0.128	4.051
Staff	0.269	0.066	4.078
		Avg(*x*)	**4.143**

Now the Consistency Index (C.I) is calculated using equation (7) which is:

C. I = (*X*-m)/m-1

= (4.143-4)/4-1

= 0.048

Finally, the Consistency Ratio (C.R) is calculated using the equation (8) i.e.

C. R = CI/RI

= 0.048/0.9

= 0.053

The value of the consistency ratio (C.R) is less than 0.10 i.e. 0.053, which is well within the acceptable range.

Similarly, for all criteria viz. turnover, project, equipment and staff each alternative i.e. contractor is compared pairwise and respective weightages, consistency index and consistency ratio are obtained for contractors A, B, C and D.

Table 12: Pairwise Comparison of Turnover Criteria

Turnover	A	B	C	D
A	1	1/3	5	6
B	3	1	7	8
C	1/5	1/7	1	3
D	1/6	1/8	1/3	1
Sum	**4 3/8**	**1 3/5**	**13 1/3**	**18**

Table 13: Normalized Criteria and criteria weightage Matrix

Turnover	A	B	C	D	Criteria Wt(Avg)
A	0.229	0.208	0.375	0.333	0.286
B	0.687	0.625	0.525	0.444	0.570
C	0.046	0.089	0.075	0.167	0.094
D	0.038	0.078	0.025	0.056	0.049
Sum	1.000	1.000	1.000	1.000	1.000

Table 14: Consistency Matrix

Turnover	A	B	C	D	Weighted Sum value
A	0.286	0.190	0.471	0.295	1.243
B	0.859	0.570	0.659	0.394	2.482
C	0.057	0.081	0.094	0.148	0.381
D	0.048	0.071	0.031	0.049	0.200

Table 15: Scalar (*x*)

Turnover	Weighted Sum value	Criteria Weight	Weighted Sum value/Criteria Weight
A	1.243	0.286	4.339
B	2.482	0.570	4.353
C	0.381	0.094	4.041
D	0.200	0.049	4.057
		Avg(*x*)	**4.197**

Consistency Index (CI) = (*x*-*m*)/m-1

= 0.066

Consistency Ratio (C.R) = CI/RI

= 0.073

The value of the consistency ratio (C.R) is less than 0.10 i.e. 0.073, which is well within the acceptable range. The values obtained for the criteria of turnover of different contractors are taken considering the order as B > A > C > D.

Similar is the case for the second criteria i.e. Projects

Table 16: Pairwise Comparison of Project Criteria

Project	A	B	C	D
A	1	1/3	5	3
B	3	1	7	5
C	1/5	1/7	1	1/5
D	1/3	1/5	5	1
Sum	4 1/2	1 2/3	18	9 1/5

Table 17: Normalized Criteria and criteria weightage Matrix

Project	A	B	C	D	Criteria Wt(Avg)
A	0.221	0.199	0.278	0.326	0.256
B	0.662	0.597	0.389	0.543	0.548
C	0.044	0.085	0.056	0.022	0.052
D	0.074	0.119	0.278	0.109	0.145
Sum	1.000	1.000	1.000	1.000	1.000

Table 18: Consistency Matrix

Project	A	B	C	D	Weighted Sum value
A	0.256	0.183	0.258	0.434	1.131
B	0.767	0.548	0.362	0.724	2.401
C	0.051	0.078	0.052	0.029	0.210
D	0.085	0.110	0.258	0.145	0.598

Table 19: Scalar (x)

Project	Weighted Sum value	Criteria Weight	Weighted Sum value/Criteria Weight
A	1.131	0.256	4.422
B	2.401	0.548	4.384
C	0.210	0.052	4.066
D	0.598	0.145	4.129
		Avg(x)	**4.250**

Consistency Index (C.I) = (x-m)/m-1

= 0.083

Consistency Ratio (C.R) = CI/RI

= 0.093

The value of the consistency ratio (C.R) is less than 0.10 i.e. 0.093, which is well within the acceptable range. The values obtained for the criteria of project of different contractors are taken considering the order as B > A > D > C.

Similarly, now is the case for Equipment.

Table 20: Pairwise Comparison of Equipment Criteria

Equipment	A	B	C	D
A	1	1/3	7	5
B	3	1	8	6
C	1/7	1/8	1	1/3
D	1/5	1/6	3	1
Sum	4 1/3	1 5/8	19	12 1/3

Table 21: Normalized Criteria and criteria weightage Matrix

Equipment	A	B	C	D	Criteria Wt(Avg)
A	0.230	0.205	0.368	0.405	0.302
B	0.691	0.615	0.421	0.486	0.553
C	0.033	0.077	0.053	0.027	0.047
D	0.046	0.103	0.158	0.081	0.097
Sum	1.000	1.000	1.000	1.000	1.000

Table 22: Consistency Matrix

Equipment	A	B	C	D	Weighted Sum value
A	0.302	0.184	0.332	0.484	1.303
B	0.907	0.553	0.379	0.581	2.421
C	0.043	0.069	0.047	0.032	0.192
D	0.060	0.092	0.142	0.097	0.392

Table 23: Scalar (x)

Equipment	Weighted Sum value	Criteria Weight	Weighted Sum value/Criteria Weight
A	1.303	0.302	4.310
B	2.421	0.553	4.374
C	0.192	0.047	4.054
D	0.392	0.097	4.042
		Avg(x)	**4.195**

Consistency Index (CI) = (x-m)/m-1

= 0.065

Consistency Ratio (C.R) = CI/RI

= 0.072

The value of the consistency ratio (C.R) is less than 0.10 i.e. 0.072, which is well within the acceptable range. The values obtained for the criteria of equipment of different contractors are taken considering the order as B > A > D > C.

Similarly, the calculations of the last criteria i.e. staff are carried out as below.

Table 24: Pairwise Comparison of Equipment Criteria

Staff	A	B	C	D
A	1	1/3	5	3
B	3	1	7	5
C	1/5	1/7	1	1/3
D	1/3	1/5	3	1
Sum	4 1/2	1 2/3	16	9 1/3

Table 25: Normalized Criteria and criteria weightage Matrix

Staff	A	B	C	D	Criteria Wt(Avg)
A	0.221	0.199	0.313	0.321	0.263
B	0.662	0.597	0.438	0.536	0.558
C	0.044	0.085	0.063	0.036	0.057
D	0.074	0.119	0.188	0.107	0.122
Sum	1.000	1.000	1.000	1.000	1.000

Table 26: Consistency Matrix

Staff	A	B	C	D	Weighted Sum value
A	0.263	0.186	0.284	0.366	1.099
B	0.790	0.558	0.398	0.609	2.356
C	0.053	0.080	0.057	0.041	0.230
D	0.088	0.112	0.171	0.122	0.492

Table 27: Scalar (*x*)

Staff	Weighted Sum value	Criteria Weight	Weighted Sum value/Criteria Weight
A	1.099	0.263	4.175
B	2.356	0.558	4.222
C	0.230	0.057	4.041
D	0.492	0.122	4.036
		Avg(*x*)	**4.118**

Consistency Index (C.I) = (*x*-m)/*m*-1

= 0.039

Consistency Ratio (C.R) = CI/RI

0.044

The value of the consistency ratio (C.R) is less than 0.10 i.e. 0.044, which is well within the acceptable range. The values obtained for the criteria of staff of different contractors are taken considering the order as

B > A > D > C.

Hence further for the total calculations criteria weightages are collectively mentioned in tabular format. The values are taken from table no. 13,17,21,25. Table no. 28 denotes the weightages of criteria with respect to contractors. Here the values are previously calculated and thus can be called as score matrix S.

Table 28: Weightages of criteria w.*r.t.* Contractors (score matrix *s*)

Weightage	Turnover	Project	Equipment	Staff
A	0.286	0.256	0.302	0.263
B	0.570	0.548	0.553	0.558
C	0.094	0.052	0.047	0.057
D	0.049	0.145	0.097	0.122

The final step is to know the most appropriate contractor and for that global score is required. Table no. 29 represents the global score of contractors.

Global score (vector *v*) = score matrix (S) * criteria weightage (*w*)

*e.g. 0.286 * 0.237 = 0.068*

Table 29: Global Score of Contractors

Weightage	Turnover	Project	Equipment	Staff	Total Score
A	0.068	0.145	0.039	0.017	0.270
B	0.135	0.311	0.071	0.037	**0.554**
C	0.022	0.029	0.006	0.004	0.062
D	0.012	0.082	0.012	0.008	0.114

5. Results

Looking at the total score we can see that among all the global scores of contractors the score of B is highest i.e. 0.554. Hence we conclude that contractor B is best option. Now one can say that by naked eye sometimes it is possible to decide which alternative is the best. But if one takes a closer look, it can be observed that there are some criteria where the top scorer alternative may be less than any or all of the other alternatives. e.g. The 'Staff' score of contractor C is more than that of contractor A, but global score of A is more than that of C. Hence we can observe that AHP takes into account individual aspects of all the criteria as well as alternatives and combines them to give the final score.

6. Conclusions

Contractor selection has been a much-debated topic over the past few decades. Some construction clients are used to accepting the lowest bids from prequalified contractors, and it is undeniable that the tender sum is a major consideration because of the instability and competitiveness of the construction industry, but should the potential to deliver an acceptable project on schedule with adequate quality standards be sacrificed.

The following conclusions are observed from the research and the case study:

- This study proposes to assist contract superintendents in healthier understanding the impact of contractor failure and to aid them in generating adequate evaluation programs prior to contract award using quantitative data.
- Final contractor selection through the AHP gives clients the flexibility to add or reduce the elements of a problem hierarchy regarding an individual project. In addition, the strengths and weakness of each eligible contractor are exposed.
- The use of a computer support system organizes the proposed evaluation process and helps to make it less complex, less time consuming and therefore easy to use.
- Literature and past research suggests that one of the reasons for this poor performance is due to the insufficiency and inappropriateness of the awarded contractor. In order to ensure a successful completion of a project, a comprehensive and careful assessment of contractor's data in a prequalification stage is required.
- The main aim of this research is to offer a rational method for selecting contractors during the prequalification stage in particular. Failure is defined in this study as a noteworthy breach of the contractor's legal responsibilities to the owner.
- The model proposed may serve as a systematic approach to tendering and bid evaluation for novice owner organizations.

Contractor selection is a perilous task for ensuring that a project is completed within budget and on schedule and that the results are of good quality. The objective of multi-criteria contractor selection is to identify the "best" contractor from a set of available options using an assessment based on multiples election objectives. Additionally, because of its flexibility and efficiency, the AHP has been chosen as a reliable instrument for decision making or problem-solving in the field of project management, particularly in contractor selection.

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