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Contractor Selection by using Analytical Network Process (ANP)

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Abstract: Nowadays, contractor selection is a critical activity of the project owner. Selecting the right contractor is essential to the project manager for the success of the project, and this cab happens by using the proper selecting method. Traditionally, the contractor is being selected based on his offered bid price. This approach focuses only on the price factor and forgetting other essential factors for the success of the project. In this research paper, the Analytic Network Process (ANP) method is used as a decision tool model to select the most appropriate contractor. This decision-making method can help the clients who work in the construction industry to identify contractors who are capable of delivering satisfactory outcomes. Moreover, this research paper provides a case study of selecting the proper contractor among three contractors by using ANP method. The case study identifies and computes the relative weight of the eight criteria and eleven sub-criteria using a questionnaire.

Keywords: *Contractor Selection, Project Management, Decision-Making, Bidding.*

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I. INTRODUCTION

The construction and infrastructure industry is essential to Saudi Arabia economy's overhaul. Before the Covid-19 pandemic, the construction and infrastructure industry in Saudi Arabia was amongst the largest in the Arab Gulf countries, with a net worth of $825 billion of unawarded and planned projects. The industry had noticed exceptional growth in the contracts awarded – from $11.2 billion in 2016 to $14.6 billion in 2018.

With an increased focus from both the public and private sectors, the need for construction and infrastructure projects will continue to grow in line with Saudi Arabia Vision 2030. One of the essential elements to accomplish the goal's vision is to execute the planned and unawarded project is to select a capable contractor to implement the work. The construction industry in Saudi Arabia faced several risks at the industry level. A study made by Bajaber and Taha reveals that insufficiently qualified contractors and the participation of unqualified contractors are some of the risks that the projects have experienced nowadays in Saudi Arabia [1]. A study conducted by Makkah province principality indicates that 18% of the government projects failed. These failures could be avoided if clients could have avoided those unqualified contractors who are likely to default. The contractor is the first one who confronts these risks. If he could not overcome them, he would fail, and no one would benefit.

The crucial component of any successful project is to select a capable contractor to carry out construction work and deliver high-quality outcomes. Selecting qualified contractors is essential to good execution, since they are responsible for core activities in the project's process. The selection process should give the client the confidence to select the capable contractor who can able to execute the project satisfactorily, but unfortunately, this is not always happening. Nowadays, the contractor selection awarding is basically based on the contractor who has the lowest tender price among the competitors. One of the essential decision should be made by the client is to select a proper contractor. The client shall select the most suitable contractor to accomplish the required outcomes of the project. Moreover, several methods attempt to estimate contractors' values using multiple selection criteria. These various methods include cluster analysis, multi-criteria decision-making (MCDM), multi attribute analysis, bespoke approaches, multi-attribute utility theory, multiple regression, multivariate discriminant analysis, and fuzzy set theory [2]. Pre-qualification and project-specific elements are the basis to quantify and identify the contractor selection criteria. Among those approaches, MCDM is fairly used in this research paper to select capable contractors.

The selection of a qualified contractor is crucial to achieving the required goals with high-quality outcomes of any construction project. Therefore, selecting a proper contractor is essential to the project's overall success. This research paper will apply multi-criteria analysis in Analytical Network Process (ANP) to identify and select the proper

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contractor for new construction projects in Saudi Arabia. This study will define the impact and influence of such selection factors on the role of the client.

In the last decade, the typical method to select a contractor is by giving the work to the contractor who proposes the lowest tender price in his offer. This practice has become known as the contractor selection based on price only, which significantly increases the project's risk of failure.

Selecting a contractor by only using the price as the main selection factor leads to having project issues such as delay, cost overruns, and quality control issues. Therefore, developing appropriate contractor selection methods is necessary to gauge the probability that a construction contractor will successfully complete the assigned work within the defined scope.

Several research types discussed using different factors other than price in selecting a contractor during the last decade. Since that time, contractor selection has been well established because of including non-price factors. Nowadays, organizations focus on applying a process of contractor selection that puts different factors other than price in consideration, generally with various weighted multi-criteria methods.

II. LITERATURE REVIEW

In this challenging era, we need to effectively manage the flow or process to get successful project construction. The demands from the competition, client, and regulatory agencies have been booming rapidly; a failure to make proper management for them can lead to obstacles for the construction team and the whole project. Several studies have revealed that overall owner satisfaction and project quality are directly related to the contractor's performance. The selection of a contractor is considered a significant challenge for the construction industry. There is a necessity for applying systematic tools before selecting the optimum alternative among different contractors. Selecting a capable contractor is an essential factor in increasing a chance to complete construction projects successfully. The selection of contractors is definitely a major aspect of delivering project outcomes in terms of cost, quality, and schedule.

Choosing a competent contractor is one of the critical aspects of the client or parties involved who successfully achieves project outcomes. Contractor selection is a challenging action because the growth and competition in the construction industry are booming worldwide. The probability of construction failure is relatively high for individual contractor. Project owners need to manage and confront these risks if they want to achieve excellent project outcomes. For further explanation, it is important to determine the decision-making tools where we can seek the best of the good options to be the best solution to the raised problem. It is recognized that failure to make an effective decision usually leads to wrong, flawed, ineffectual decisions.

This literature chapter sheds light on identifying the criteria for the decision-maker to select the proper contractor. Pre-qualification and bid evaluation processes are the most contractor selection processes used to classify the contractor selection criteria.

Pre-qualification of contractors considers as a decision making obstacle that develop quantitative and qualitative measures. When spouting such concerns, the person who has the decision may offer imprecise, undefined, and incomplete evaluations because of absence of information and also expertise deficiencies. Usually, a low-bid approach is selected for majority construction projects. Sometimes, there are variations in time and cost in the project because there was subjective bias in contractor selection. Therefore, pre-qualification involves the process involving the screen of contractors by the client where it compares the critical contractor-organizational criteria among contractors desirous of tendering. Such criteria can be methodology, his performance, and workload. Researchers have recommended valuable methods to identify contractor-organizational criteria, such as MAA. On the other hand, the evaluation of contractors can be done based on the particular criteria that can determine the contractor's suitability to implement a new project. The purpose of the contractor evaluation is different from the contractor selection. Especially, contractor assessment is the practice of measuring and investigating attributes of project requirement.

In contrast, choose the right contractor refers to aggregating the outcomes of the contractor evaluation to determine the best contractor. In common practice, group the contractor evaluation and contractor selection to produce a single process that can distinguish the good contractors from unqualified ones based on the project's specific criteria. Several proper methods are used to determine criteria based on the specific project. For instance, Multi-attribute utility theory (MAUT) and Analytic Hericaricy Process (AHP) are possible techniques, according to (Alarcon and Mourgues). MAUT and AHP techniques can be used to determine the weight of each selected criterion in selecting the contractor. The differences between these two methods are: first, AHP uses a basic record method for grade each criterion, at the same time MAUT method uses utility amount; and second, AHP method used pairwise matrix to identify and compute the weights, while MAUT method is simply using scoring technique. When the selected criteria are related to objectivity and rationalization, ANP selection decision method would be a more practical and best approach to assign weights of the selected criteria. The research paper aims not to differentiate the best method among the existing contractor selection methods. ANP is a mixture of two parts:

- Network of cluster and sub cluster that manage interactions.
- The network of influences of clusters and elements.

Hierarchies in AHP do not represent the relationship among the levels. There is no shortcoming in the ANP approach. For example, the value of criteria in AHP determines the value of alternatives but does not represent the

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value of alternatives, impacting the criteria' importance. Therefore, the linear structure of top to bottom is not appropriate for a complicated system. The main advantage of ANP is the ability to solve the problems where criteria and alternatives have such interactions that cannot be found in a hierarchy. When the decision-maker (client) chooses to model a problem as a network, it is unnecessary to state levels. A network is composed of clusters (components, criteria, or nodes) and elements (sub-criteria). The fact that the node elements produce influence for any or all the elements of any other node. Arcs symbolize relationships in a network, and the directions of arcs indicate dependence. A two-way arrow represents interdependency between two nodes, termed external dependence, and a looped arc symbolizes inner dependencies among elements in a node.

Interdependence can be implemented in several techniques: (1) uncorrelated levels in the hierarchy are compared, (2) dependence of two levels is two-way, and (3) uncorrelated elements are connected. Figure 1 shows examples of these interdependencies. A new matrix is called a "supermatrix" is produced when interdependencies are incorporated. The relative importance weights in a single matrix are adjusted because of supermatrix to build a new final matrix with priorities list of the importance weights of each criterion.

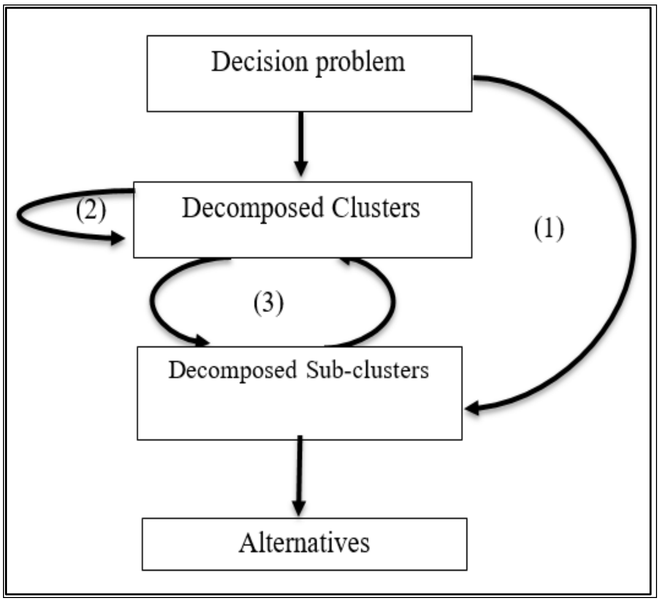

Fig 1: Example of Interdependence

III. METHODOLOGY

The research conducted regarding the usefulness of ANP incorporated a multi-criteria analysis concerned with the decision making of the project. ANP, an Analytical methodology that uses human judgment to determine the most optimal choice for business decision, was used to determine the most optimal contractor for a project.

Initially data was gathered as the output of 8 subject matter experts SMEs when they shared their expertise in regards to the selection between 3 hypothetical contractors to conduct a project. Hence, their output was complied within the process of ANP to measure analytically, which would be the most suited.

➢ *ANP uses a Multi-Criteria Analysis, which Consists of the Following:*

- Tender Price TP
- Financial Capability FC

✓ Financial Statement
✓ Financial Reference

- Past Performance PP

✓ Failure to Complete Contract
✓ Delay
✓ Cost Overrun
✓ Quality Achieved

- Past Experience PE

✓ Scale of Projects Completed
✓ Types of Projects Completed
✓ Experience
✓ Quality Achieved

- Resources R

✓ Physical Resources
✓ Human Resources

- Work Load WL
- Methodology M
- Safety Performance SP

ANP consists of two parts. The first part includes a network of criteria and sub-criteria that control the system's interactions between the set criteria [4]. Figure 2 shows the criteria being input into SuperDecisions software. The second part influences the network among the clusters and elements. The network differs from one criterion to another criterion and computes the Supermatrix of limiting influence. Figure 3 shows a view of the decision network model of the case study.

Hence, the SMEs input was gathered as their answer to a comparison between each of the criteria mentioned earlier. The SMEs were asked to compare each two factors as a scale 1-9 where 1 was characterized as ”same level of importance”, and 9 was characterized as ”extremely relatively important”. Table I shows the Satty Scale, which is used to characterize the relative importance between each of the criteria. The data was hence plotted as a matrix, where as seen in figure 3 the relationships between each of the criteria is analysed numerically [5]. Hence, at which point it is to be used within Super Decisions software to be processed.

Following the collection of the first set of data collected, a second set of data was gathered comparing the contractors to each other, in terms of how they ranked in each of the criteria used. Hence, again the data was input in Super Decisions to compare analytically between the contractors.

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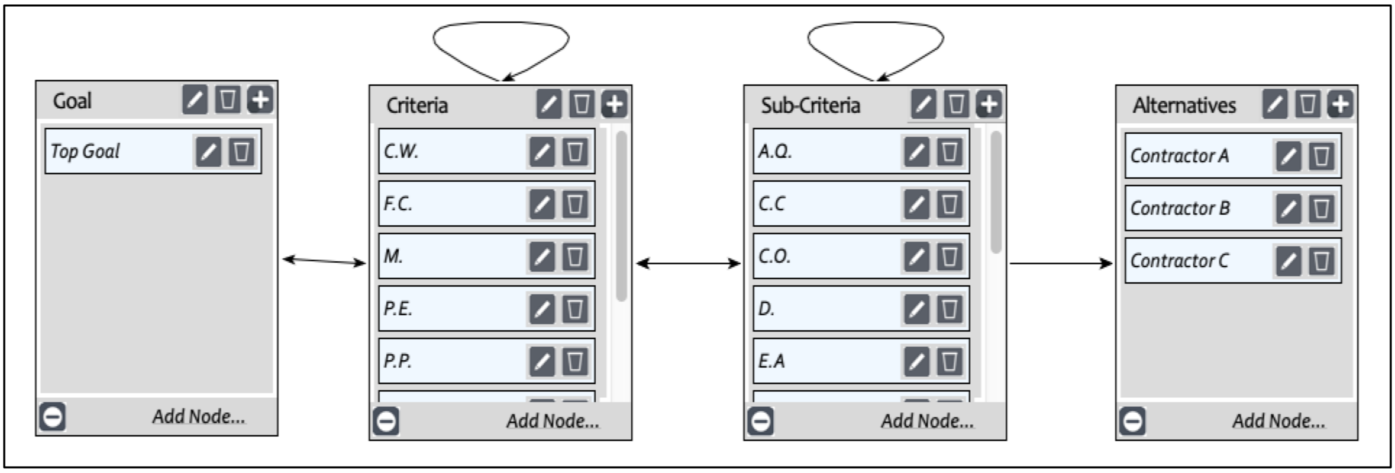

Fig 2: The Clusters of Nodes Model within Super Decisions Software

Table 1: Satty Scale

1	**Equal importance**
3	Moderate importance of one over another
5	Strong or essential importance
7	Very strong or demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values
Use reciprocals for inverse comparisons	

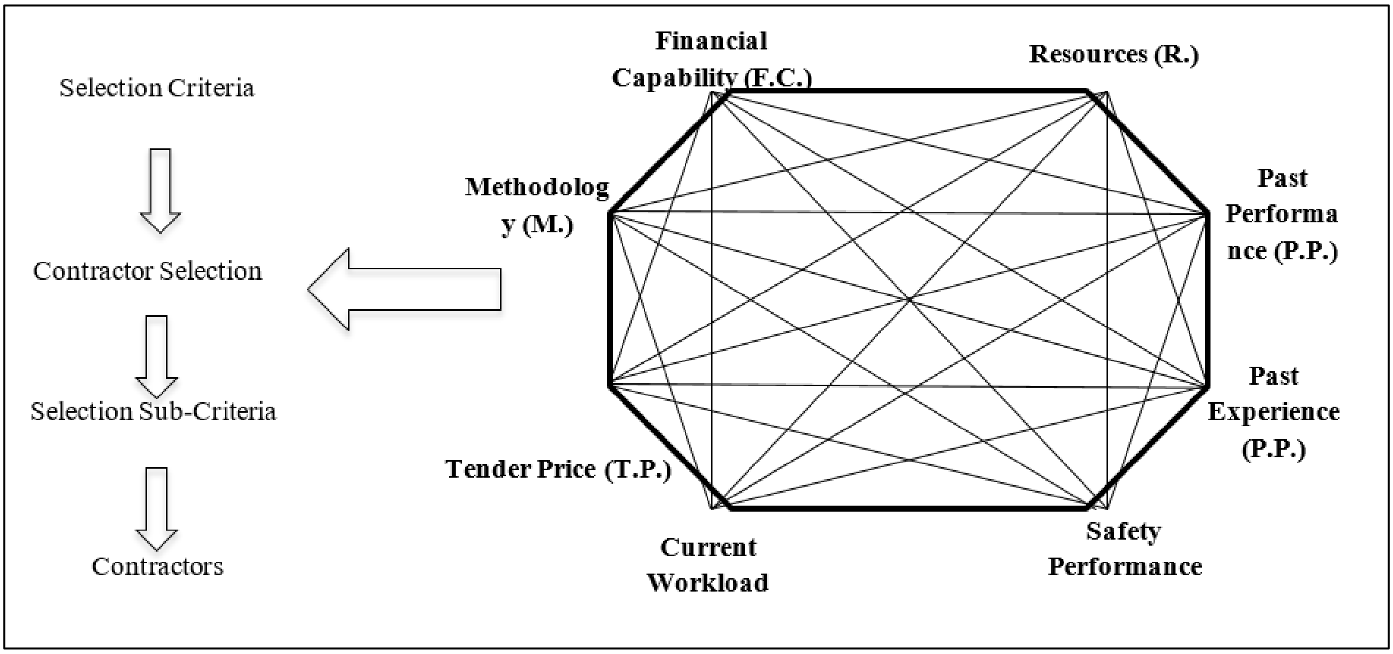

Fig 3: The Relationship between the Criteria of the Model

IV. RESULT

Initially the trade off among the criteria chosen was plotted as a matrix where the level of importance between each criterion was plotted from both perspectives. The matrix shows the relative importance using the Satty scale [6], seen in table I, to characterize the difference in importance of each criterion in comparason to all the other criteria.

Hence, the eigenvalues were calculated within the Super Decisions software and used to calculate the Consistency Index *C.I* of the matrices, where *C.I* was calculated as in equation 1. Where λ_{max} is the largest eigenvalue and *n* is the size of the square matrix.

$$C.I = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

Hence, the Consistency Ratio *C.R* was additionally calculated within the software as seen in equation 2, where it is calculated using the found *C.I* and the Random Consistency Index *R.I* for the matrix size [7].

$$C.R = \frac{C.I}{R.I} \quad (2)$$

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Table 2: Pairwise Comparison Matrix for Relative Importance of Criteria with Reference to the Ultimate Objective

Ultimate Objective	**TP**	**PP**	**PE**	**CW**	**R**	**SP**	**M**	**FC**	**e-Vector**
TP	1	2	1	3	3	1	2	6	0.20614
PP	1/2	1	1	2	2	1/2	1	4	0.12657
PE	1	1	1	3	3	1	2	4	0.18201
CW	1/3	1/2	1/3	1	1	1/4	1/2	3	0.06591
R	1/3	1/2	1/3	1	1	1/3	1/2	2	0.06382
SP	1	2	1	4	3	1	2	5	0.21003
M	1/2	1	1/2	2	2	1/2	1	3	0.11108
FC	1/6	1/4	1/4	1/3	1/2	1/5	1/3	1	0.03444
Inconsistency Ratio	0.00998								

Table 3: Pairwise Comparison Matrix for Relative Importance of Criteria with Reference to the Tender Price T.P

TP	**PP**	**PE**	**CW**	**R**	**SP**	**M**	**FC**	**eVector**
PP	1	1	3	2	1/2	3	3	0.20471
PE	1	1	3	3	1/2	3	2	0.11233
CW	1/3	1/3	1	3	1/2	2	2	0.11233
R	1/2	1/3	1/3	1	1/3	1/2	1/2	0.20471
SP	2	2	2	3	1	3	3	0.11233
M	1/3	1/3	1/2	2	1/3	1	3	0.11233
FC	1/3	1/2	1/2	2	1/3	1/3	1	0.14125
Inconsistency Ratio	**0.00985**							

The use of the *C.R* is essential as it determines the consistency of the inputs, expected to not exceed 10.

As such the matrix was plotted as a pairwise comparison as seen in table II, where the relative importance is plotted, with an addition of the eigenvalue as the right most column.

The pairwise comparison matrix is developed for establishing the relative importance of each of these criteria in the implementation of the contractor selection model clusters on the ultimate objective. Hence, each of the criteria was used exclusively to generate a comparison matrix with said criteria as being the one with ultimate importance. An example was plotted with the Tender Price as the reference criterion as seen in in table III.

Furthermore, the sub-criteria were plotted within the software to measure the relative importance between each of them, an example is shown in table IV.

Table 4: Pairwise Comparison Matrix for Relative Importance of Criteria Between Criteria with Reference to the Financial Capability F.C

FC	**FR**	**FS**	**eVector**
FR	1	1/9	0.1
FS	9	1	0.9
Inconsistency Ratio	**0**		

Hence, data regarding the three contractors interested in handling this project was plotted within the software, however due to confidentiality the contractors names were withheld, and the data provided was hypothetical. However, the data plotted was proposed to study the effectively of ANP. The data was plotted as seen in table V.

Table 5: Table Showing the Comparison of the Three Contractors for Each Criterion

Number	**Criteria/Sub-Criteria**	**Contractor A**	**Contractor B**	**Contractor C**
1	Tender Price	$6 MM	$10MM	$4 MM
2	Financial Capability	$ 20 MM	$8 MM	$ 13 MM
2.1	Financial Statement	Great Financial Position	Poor Financial Position	Good Financial Position
2.2	Financial Reference	All financial details provided	Poor financial details provided	Some financial details provided
3	Past Performance	Average	Above Average	Below Average
3.1	Delay	Rarely	No Delays	Rarely
3.2	Failure to complete contract	One Project was not completed.	Achieve All Assigned Work.	One Project was not completed.
3.3	Quality Achieved	Good	High	Poor
3.4	Cost Overrun	High Tolerance	Good Tolerance	Poor Tolerance
4	Past Experience	High Experience	Good Experience	Poor Experience

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4.1	Experience in local area	Average	Below Average	Above Average
4.2	Type of completed project	High Experience with similar projects.	Good Experience with similar projects.	Poor Experience with similar projects.
4.3	Scale of completed project	Completed 20 projects with similar scope of work	Completed 12 projects with similar scope of work	Completed 8 projects with similar scope of work
5	Resources	Below Average	Above Average	Average
5.1	Human Resources	Manpower of 50 qualified workers.	Manpower of 100 qualified workers.	Manpower of 70 qualified workers.
5.2	Physical Resources	Below Average	Above Average	Average
6	Current Workload	10 Ongoing Capital Projects at various locations	2 Ongoing Capital Projects and three projects Nearing completion	5 Ongoing Capital Projects and 1 Mega Project Underway
7	Methodology	Good Implementation Procedure	Good Implementation Procedure	Poor Implementation Procedure
8	Safety Performance	Above Average	Average	Average

This step is to set pairwise comparisons for the relative importance of each of the alternatives Contractor A, Contractor B, and Contractor C with reference to respective criteria and sub-criteria. Table V shows which alternative has the highest relative weight for each criterion.

Each supermatrix network has three supermatrices: Unweighted Supermatrix, the Weighted Supermatrix, and the Limit supermatrix. The following sections describe each supermatrix.

The Unweighted Supermatrix is basically formed from the vector priorities that are determined from the various comparison matrices. Multiplying all the parts in a block of the unweighted supermatrix's component by the corresponding criteria weight basically results the weighted supermatrix. The weighted supermatrix derives the limit supermatrix to powers by multiplying it times itself. This matrix demonstrates the weights for all the components in the supermatrix.

The unweighted, weighted and limiting matrices were calculated, and input within the SuperDecisions software, hence the priorities were calculated as seen in table VI. The three contractors A, B and C produced normalized cluster values of 0.380, 0.334 and 0.285 respectively. The values produced were normalized from the results of the limiting Supermatrix via dividing the raw results of each via the highest raw value within the same column.

Table 6: Table Showing the Priorities from Limit Supermatrix

Name	**Normalized By Cluster**	**Limiting**
Contractor A	0.38003	0.07328
Contractor B	0.33439	0.06448
Contractor C	0.28558	0.055069
CW	0.07563	0.041037
FC	0.13786	0.074806
M	0.0851	0.046179
PE	0.15439	0.083778
PP	0.13374	0.072569
R	0.10264	0.055696
SP	0.1239	0.06723
TP	0.18675	0.101334
Ultimate Objective	1	0.156973
AQ	0.04486	0.004826
CC	0.12302	0.013233
CO	0.03964	0.004264
D	0.04545	0.004889
EA	0.06074	0.006534
FR	0.07824	0.008416
FS	0.18255	0.019637
HR	0.09708	0.010443
PR	0.09708	0.010443
SC	0.12483	0.013428
TC	0.10649	0.011455

➢ *Discussion*

Based on the result from table VI, contractor A is the best choice and capable contractor to handle the project, based on the selected criteria.

Several observations can be derived from applying the ANP analysis of selecting the capable contractor:

- The result of the ANP calculations show that contractor A is the most capable contractor among the others, based on the selected criteria were developed by the subject matter experts. The project client is satisfied with the ANP analysis outcomes.
- If the selection decision were based only on the lowest tender price, contractor C would be selected.
- The highest three weights among eight criteria are safety performance, tender price, and past experience, which their weights summation equal to almost 60% of the total weights of the eight criteria.
- AHP is a popular selection decision tool nowadays. However, AHP is limited in the capability where it is only applied in the simple decision problems. At the same time, ANP provides a powerful tool in complicated decision problems.
- If the relative weight of each criterion has been changed, the final decision might be different.
- Inconsistency ratios of all pairwise comparison matrices in this study are within the acceptable range. These rations indicate that judgments from the experts are more consistent.

V. DISCUSSION

Multi-criteria selection techniques should be used and implemented in project management to select the “capable” contractor to deliver the project outcomes. Contractor selection is an important activity prior to project awarding for ensuring that a project is achieved on schedule and within budget and that the results are of high quality. Multi-criteria contractor selection aims to distinguish the “capable” contractor from other contractors using an assessment based on several election objectives. Selecting a proper contractor helps avoid any potential risks that might be encountered if the project was awarded to a less capable contractor. In this research paper, the ANP decision approach is implemented in selection the proper contractor, and ANP improves the familiar (MCDM) approach to criteria prioritization.

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