QATAR UNIVERSITY

COLLEGE OF ENGINEERING

APPLICATION OF MULTI CRITERIA DECISION MAKING IN TENDER EVALUATION: A STUDY USING ANP MODEL

BY

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ABSTRACT

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Title: Application of Multi-Criteria Decision Making in Tender Evaluation: A Study Using ANP Model

Supervisor of Project: Khalid, K, Naji.

In the construction industry, clits -especially in large projects- often use tendering as their preferred method for selecting contractors to carry out the work. In most cases, clients choose the lowest bid from the technically approved tenderers, while it is simple; most construction professionals do not recommend this approach. This study aims to identify, analyze, and rank the essential factors to be considered in tendering evaluation. This study was done through different stages that included a literate review, a questionnaire distributed to construction industry professionals, and the use of Analytical Network Process (ANP) as a ranking tool for the factors. After the analysis, it was found that thirty-one essential factors are crucial for the success and performance of construction projects. Finally, the analysis results from the ANP model have shown that financial factors are the most important between the three available categories. Additionally, the ANP rank has shown that some of the factors that are usually considered unimportant have more significance due to the interdependencies and the impact they have on other factors.

DEDICATION

To my parents who have provided me with love, encouragement and have always been there for me, And to my family and friends for their continuous support and motivation

ACKNOWLEDGMENTS

In the beginning, I would like to give special thanks to my family for supporting me and encouraging me to chase my dreams and to push my limits. Also, I would like to thank my second family (my friends) for their continuous support and encouragement to me during this journey.

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Finally, I wish to thank all the Engineering Management professors for giving me the knowledge, tools, and confidence that enabled me to complete this project successfully.

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CHAPTER 1: INTRODUCTION

Construction projects usually start with an idea or need for change. Like most types of projects, construction projects are temporary enterprises that end with the handover of the project. The execution stage of projects is very critical and important because it contains many variables and changes, in addition to requiring most of the resources. Therefore, clients started to use tendering for selecting contractors to reach certain levels of quality without spending unnecessary amounts of money (Watt et al., 2009).

The tender committee has one of the most challenging jobs in the organization, which is ensuring the selection of the best and more suitable contractors from all bidders. This job becomes trickier and very difficult, especially when there is a large number of bidders or time is very limited and critical to the project, and the work must start immediately. With these constraints, many companies tend to use outdated methods to select contractors, such as weighted average and lowest bid. The use of such techniques is very risky, and it can cost the organization lots of money during the execution stage of the projects (Cheaitou et al., 2019).

The main driver for this research is to reduce the losses in time and money that are resulted from improper selection of contractors. Due to the advancements in science and the existence of more powerful and fast computing machines, this research studies the current practices in tender evaluation around the world and identifies their weaknesses. Additionally, this research is unique compared to the available literature, as it is the first to use an ANP model for ranking the tendering evaluation factors on this broad scale. This research seeks to have an insightful image of the factors related to tendering evaluation. Finally, the benefit of using ANP compared to other MCDM tools is that it incorporates the interdependencies between the factors in finding the solution, which usually has a significant impact on the final results.

1.1 Problem statement

In most of the countries around the world, open tendering is the most used type of tendering. There are many reasons behind the widespread of open tendering, such as increased transparency, fairness to all the contractors in the country, and the relatively low cost compared to the other types of tendering and delivery. Tender evaluation is the most important part of the tendering process since it ends with the awarding of the contract and the beginning of execution. Most of the clients (private and governmental) are using qualitative analysis methods in the selection of contractors. However, the used methods are insufficient for detecting the tricks and manipulation done by contractors in order to win the contracts.

Additionally, many organizations around the world are making their final decision based on the lowest bid price. In many cases, this approach was ineffective as many clients ended up paying much more than the amount they were going to save by selecting the lowest bidder.

1.2 Project Goals

This project aims to identify and rank the most important criteria for tendering evaluation and contractor selection. This goal will be achieved through using an extensive literature study, experts' opinions collected by a questionnaire, and using multicriteria analysis (an ANP model).

In addition to the main goal, there are three objectives that this project aims to achieve:

- To identify and find a list of the most important criteria to be considered while selecting a contractor that can help the clients in the future.
- To identity the interdependencies and relations between the factors.

- To construct an ANP model to find the ranking of the selected criteria of tender evaluation.

1.3 Research methodology

This research is aiming to help the decision-makers in organizations around the world to make better decisions in awarding projects to contractors and suppliers by introducing new and existing factors/criteria that should be taken into consideration while reviewing the bids other than the low bids.

Initially, several meetings were conducted with professionals in the state of Qatar to understand the current system that is being followed by the specialist in the public sector due to the large size of its projects, especially infrastructure and road projects. These interviews helped in planning the research flow and confirmed the need for improvement due to the problems faced with the current system.

There are two sources of data in this project. The first is data collection from the extensive literature review that was conducted to understand the recent developments in the subject and to the methods that researchers have addressed the different issues. The second type of data is going to be quantitative data collected from a survey that will be distributed to professionals in tendering, construction, in addition to academics from different countries. The data collected from the survey will help first in understanding the common practices used by the local companies in Qatar, mainly and the world, in addition to helping to rank the factors that were identified and collected from the literature.

Finally, an ANP model will be built to rank the factors by their importance.

1.4 Outline of the Report

This section shows the report structure and a short description of the contents of each chapter in the project.

- **Chapter 1: Introduction**

This chapter introduces the topic of this project and the problem statement, the goals of the project, research methodology, and an overview of the project contents.

- **Chapter 2: Literature Review**

The second chapter shows the previous research and literature related to the same topic to show what the literature covered before and to understand the topic better.

- **Chapter 3: Research Methodology**

The third chapter is discussing the methodology, which was followed by the author to solve the problem, and it includes the questionnaire design.

- **Chapter 4: Analysis & Results**

The fourth chapter of this study contains a discussion of survey responses, the execution of the proposed solution, and the building of the ANP model.

- **Chapter 5: Conclusion**

The final chapter in this study contains the conclusion of the performed work and the possibility of improvements in the research related to the tendering process. Additionally, this chapter discusses the possible future research for the same topic.

CHAPTER 2: LITERATURE REVIEW

At the beginning of this project, a literature review was conducted by reviewing several journals and conference papers. This chapter will talk about the progress in tender evaluation and the review methods used by researchers around the world, in addition to the uses of ANP and how beneficial it was to the users. The main keywords used for the research were: Tendering, Multicriteria decision-making, Analytical Network Process (ANP), Tender Evaluation.

2.1 Tendering Evaluation

Clients are always faced with a situation where they need to select something between several alternatives, and one of the most crucial decisions they must make is the selection of contractors, suppliers, and vendors during the process of tendering. There are many techniques used in tender evaluation around the globe Dotoli et al. (2020), stated that there are many different approaches used in tender assessment around the world such as programming approaches, AHP, ranking, DEA, fuzzy logic, and more. Besides, industries are moving from the use of weighting techniques such as weighted average and linear programming to the implementation and usage of multicriteria decision-making models (MCDM). The existence of all these methods introduces another type of tough decision for the clients to select the best practice between the existing ones. In addition to that, the use of these methods requires a clear definition of the goals and priorities in the client’s organization to make the best decision.

2.1.1 The Current Practice of Tender Evaluation

After the closure of the tendering process, a careful assessment of the bids should be undertaken to identify the most convenient and preferred tenderer, thus the need for tender evaluation teams. The tender evaluation involved identifying the lowest bidder, particularly on the supply contracts, while for construction contracts, the best value tender is selected (Dotoli et al., 2020). However, under these systems, there is a tendency for the tenderers to quote low prices and end up hiking their prices after being awarded the contract.

Therefore, because of such historical practices by bidders, the current practice of tender evaluation has changed and became much different. According to Ferk et al. (2020), the current practice seeks a bid that meets the client's needs and offers value for money, the most economically advantageous tender (MEAT) approach. Badri et al. (2001) stated that there are thirteen different approaches used in tender evaluation around the world, such as mathematical programming approaches, Analytical hierarchy process, ranking, and fuzzy logic. The common factor in these methods is that they all involve several criteria. Some of these criteria may be the price quoted, the tenderer's experience, past performances, management skills, technical skills, proposed methodology, and resource availability, among others. Some of these criteria must be evaluated at the prequalification stage. Afterward, the criteria are weighted to assess how crucial they are to the client. Then, the tenderer who scores the highest according to the needs and the given criteria is given the contract.

2.2 Tendering evaluation factors

One of the primary goals of the literature review is to identify the factors that will be included in the ANP model. to be selected, the factors must meet the following set conditions:

1- The factor/criterion must apply to the construction industry.

2- The factor/criterion must be from the client's perspective.

3- The factor/criterion must be used in three or more academic papers.

After performing the study, the following criteria were selected, and they were divided into three categories: 1- technical factors, 2- financial factors, 3- qualification and experience related factors.

Table 1. Technical tendering evaluation factors.

Code	Description	References
T01	The number of available manpower	(Leśniak et al. 2018), (Jaskowski et al. 2010), (Hassaan et al., 2013), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015), (Enshassi et al., 2013), (D.j.Watt et al. 2009)
T02	In-house equipment availability of contractors	(Jaskowski et al. 2010), (El-Sawalhi et al., 2007), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015), (Enshassi et al., 2013)
T03	Safety records of the contractors	(Dotoli et al. 2020), (Husin et al. 2019), (Liu et al. 2010), (Jaskowski et al. 2010), (Hatush & Skitmore, 1997), (Ghazali et al., 2011), (Mahdi et al., 2002), (Ibadov, 2015), (D.j.Watt et al. 2009), (Holt et al.,1994), (Lai et al., 2004)
T04	Availability of contractor's safety plan for carrying out the works	(Dotoli et al. 2020), (Husin et al. 2019), (Liu et al. 2010), (Jaskowski et al. 2010), (Hassaan et al., 2013), (Ghazali et al., 2011), (Mahdi et al., 2002), (Ibadov, 2015), (Enshassi et al., 2013)

Code	Description	References
T05	The quality management system of contractor	(Dotoli et al. 2020), (Husin et al. 2019), (Liu et al. 2010), (Jaskowski et al. 2010), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015), (Ibadov, 2015), (D.j.Watt et al. 2009), (Lai et al., 2004)
T06	The risk management system of contractor	(Dotoli et al. 2020), (Husin et al. 2019), (Jaskowski et al. 2010), (Hatush & Skitmore, 1997), (Ghazali et al., 2011), (Mahdi et al., 2002), (Ibadov, 2015), (Enshassi et al., 2013)
T07	Availability of warranty and after services by the contractor	(Dotoli et al. 2020), (Hassaan et al., 2013), (Ghazali et al., 2011)
T08	Contractor's approach/methodology to carry out the works	(Bintoro et al 2017), (Hassaan et al., 2013), (Shen et al., 2004), (Watt et al., 2010)
T09	Level of innovation by the contractor	(Bintoro et al 2017), (Diabagaté et al. 2017), (El-Sawalhi et al., 2007), (Shen et al., 2004), (Watt et al., 2010)
T10	Promised delivery date	(Liu et al. 2010), (Leśniak et al. 2018), (Shen et al., 2004), (Ghazali et al., 2011)
T11	Environmental considerations by the contractor	(Dotoli et al. 2020), (Shen et al., 2004), (Ibadov, 2015), (Enshassi et al., 2013)
T12	Contractor's procurement plan	(Shen et al., 2004), (El-Sawalhi et al., 2007), (Mahdi et al., 2002)
T13	Use of new technologies by the contractor	(Shen et al., 2004), (Mahdi et al., 2002)
T14	Proposed suppliers and vendors by the contractor	(Shen et al., 2004), (El-Sawalhi et al., 2007), (Mahdi et al., 2002)
T15	Proposed subcontractors by the contractor	(Shen et al., 2004), (Mahdi et al., 2002)

Table 2. Financial tendering evaluation factors.

Code	Description	Reference
F01	Number of contractor's ongoing projects	(Leśniak et al. 2018), (Liu et al. 2010), (Elbarkouky et al., 2013), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015),
F02	Financial stability of the contractor	(Liu et al. 2010), (El-Sawalhi et al., 2007), (Elbarkouky et al., 2013), (Holt et al.,1994), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015), (Watt et al., 2010),
F03	Contractor's offer price	(Bintoro et al 2017), (Husin et al. 2019), (Mahdi et al., 2002), (Amalia et al. 2018), (Diabagaté et al. 2017), (Hassaan et al., 2013), (Lai et al., 2004)
F04	Bid security (bond) by the contractor	(Bintoro et al 2017), (Husin et al. 2019), (El-Sawalhi et al., 2007), (Shen et al., 2004), (Mahdi et al., 2002), (Enshassi et al., 2013)
F05	Price of major works	(Amalia et al. 2018), (Diabagaté et al. 2017), (Husin et al. 2019), (Mahdi et al., 2002), (Watt et al., 2010), (Enshassi et al., 2013)
F06	Frontloading by contractor	(Bintoro et al 2017), (Amalia et al. 2018), (Husin et al. 2019), (Hassaan et al., 2013), (El-Sawalhi et al., 2007), (Mahdi et al., 2002)
F07	Liquidity (the number of liquidated assets of the contractor i.e. Available cash with the contractor)	(Leśniak et al. 2018), (Jaskowski et al. 2010), (Diabagaté et al. 2017), (Husin et al. 2019), (Liu et al. 2010), (Elbarkouky et al., 2013), (Shen et al., 2004), (Mahdi et al., 2002)

Table 3. Qualification based evaluation.

Code	Description	Reference
Q01	Contractor's certifications	(Dotoli et al. 2020), (Leśniak et al. 2018), (Hassaan et al., 2013), (El-Sawalhi et al., 2007), (Enshassi et al., 2013)
Q02	Contractor's history	(Hassaan et al., 2013), (Watt et al., 2010), (Enshassi et al., 2013), (Dotoli et al. 2020),
Q03	Qualification and experience of engineers and technical staff	(Bintoro et al 2017), (Amalia et al. 2018), (Diabagaté et al. 2017), (Husin et al. 2019), (Watt et al., 2010), (Ibadov, 2015), (Lai et al., 2004)
Q04	Contractor's experience in the region	(Leśniak et al. 2018), (Husin et al. 2019), (Liu et al. 2010), (Hatush & Skitmore, 1997), (Mahdi et al., 2002)
Q05	Contractor's experience with similar projects	(Bintoro et al 2017), (Husin et al. 2019), (Liu et al. 2010), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015), (D.j.Watt et al. 2009), (Lai et al., 2004)
Q06	Contractor's experience with other projects	(Husin et al. 2019), (Liu et al. 2010), (Hatush & Skitmore, 1997), (Mahdi et al., 2002), (Balubaid & Alamoudi, 2015)
Q07	Records of failure	(El-Sawalhi et al., 2007), (Balubaid & Alamoudi, 2015), (Holt et al.,1994)
Q08	Staff training plans/programs	(Shen et al., 2004), (El-Sawalhi et al., 2007), (Holt et al.,1994), (Dotoli et al. 2020),
Q09	Past projects performance (client's experience with the contractor)	(Jaskowski et al. 2010), (Hassaan et al., 2013), (Mahdi et al., 2002), (Watt et al., 2010), (Enshassi et al., 2013)

Table 1, Table 2, Table 3 show the obtained factors from the literature study that are going to be evaluated by the experts based on importance in the questionnaire that will be developed. After that, an ANP model will be created to rank the factors.

2.3 Multicriteria Decision-Making

Multi-criteria decision-making (MCDM) is the process of finding the best viable solution according to specific set criteria and issues that affect our everyday life (Jahan et al., 2016). MCDM is used by everyone in various aspects of our daily life. Numerous decisions are made mainly in the day to day operation of businesses. MCDM starts after clearly defining the context of analysis, identifying the available options, and deciding the objectives and selection of the right criteria that serve the value of the decision.

There are various examples of multicriteria decision-making, such as the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Analytic Network Process (ANP). TOPSIS is a method used to determine the shortest distance between the ideal solution and the farthest distance from the averse-ideal solution. AHP is a multicriteria decision-making tool developed in the 1970s to analyze and structure complex decisions (Leśniak & Radziejowska, 2017). AHP is vital in calculating the weight for the given criterion through comparison judgments. Also, ANP is a multicriteria decision-making method that inter-relates the decision elements by applying both quantitative and qualitative aspects simultaneously (Veselinović, 2014). During the tender evaluation, the three examples of multicriteria decision-making are vital.

MCDM has several benefits. First, MCDM aids people to open up about their decision opportunities, particularly about the problem to be solved. This allows all the parties to consider each point of view as crucial in decision-making (Buchert et al., 2015). Also, MCDM offers a unique opportunity for people to consider complex trade-offs during the decision-making process (van der Meer et al., 2020). People are also able to consider other best alternatives.

Multi-criteria decision making is crucial in the tender evaluation process. The viable method of tender evaluation is the TOPSIS, combined with other methods such as the AHP and ANP. The mathematical model application is feasible in finding solutions to complex decisions (Balioti et al., 2018). This is because mathematical techniques incorporate qualitative factors crucial in tender evaluation and selecting the best bidder. Multicriteria decision-making analysis qualitative and quantitative factors in the tender evaluation process to assess the cost and benefits of choosing a bidder. Ultimately, a decision is arrived at based on the best tender that is cost-effective.

2.4 Analytical Network Process (ANP)

2.4.1 Development of ANP

ANP emerged from the Analytical Hierarchy Process (AHP), which is a prevalent multicriteria decision technique that aims to reduce the complexity of the problem from a multi-dimensional into single-dimensional. AHP's general form, as shown in Figure 1 below, was introduced by Prof. Thomas Saaty in the 1970s:

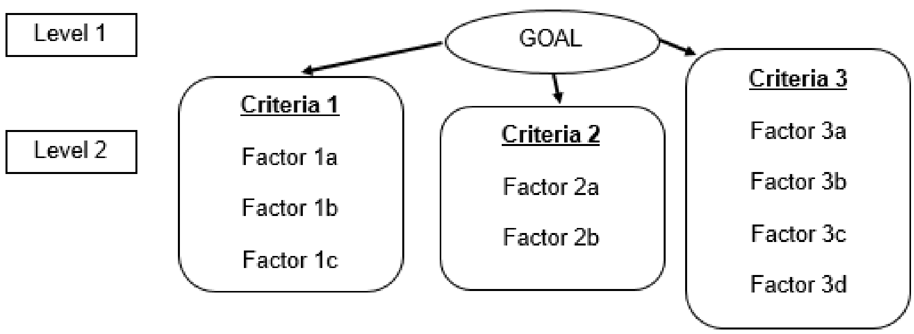

Figure 1: AHP general form

AHP calculates the relative significance of each candidate to the criteria to achieve the final hierarchy and, ultimately, the final decision (Gorener, June 2012).

In AHP, every criteria and candidate are isolated and not interacting with the others in the hierarchy. However, in reality, there are interdependencies between the elements of the decision problems, which interact with each other and affect the final decision. The existence of the interdependencies leads professor Saaty to modify his model into a general form that was later known as Analytical Network Process (ANP), (Saaty, 2005).

2.4.2 Applications of ANP

ANP is a prevalent technique due to its accurate and precise results that simplifies the decision-making process for the users using logic. (Saaty, 1982). According to Cheng and Li (2005), ANP is a new and innovative approach that can help both the academic and practical industries in many ways, such as project selection, construction approach selection, etc. The main difference between ANP and AHP is the consideration of interdependencies between the factors in ANP, which considers models as networks instead of a hierarchy. The general form of ANP is shown in Figure 2 below:

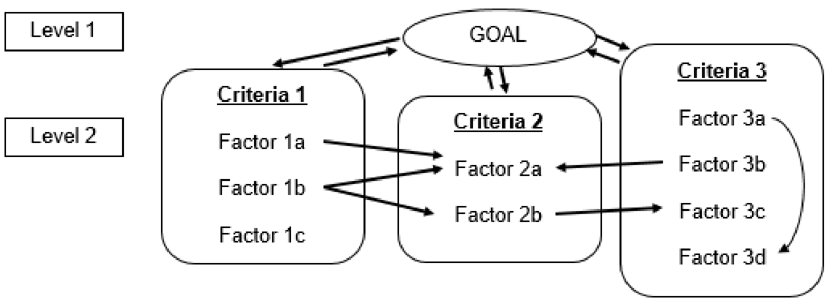

Figure 2: ANP general form

During the first two decades of the 21^{st} century, the publications related to ANP expanded into many different fields such as finance, wherein 2004, an ANP model was created to help the business and economy sectors in the prediction of any financial crisis (Niemira and Saaty, 2004). In addition to that, a different ANP model was developed to evaluate the various substitutes of fuel that may be used in residential heating buildings in Turkey. (Şenol Erdoğmuş, 2006). Moreover, 50 power plant investment projects were assessed using an ANP model (Aragonés-Beltrán et al. 2010). Two years after that, an ANP model was used to study energy efficiency in Chinese hotels (Xu and Chan, 2013). Finally, an ANP model was developed in 2020 to assess the stress level in workers as a result of heat (Matin et al., 2020). Understandably, the Analytical Network Process is a common approach for multicriteria decision making since it as a more generalized form of AHP. However, there is a lack in the use of ANP in many fields, including uses in project selection from the client's perspective (Cheng and Li, 2005).

2.5 Summary

In summary, the multicriteria decision-making techniques such as AHP and ANP have great potential in the applications related to tendering and contractor selection. There are many examples of using AHP in tendering evaluations from different countries; however, AHP assumes that all the factors are independent, which has a significant risk of having inaccurate results.

When using MCDM for tendering evaluations, the results and selected contractors may vary depending on the assumptions, the evaluation criteria, and the used technique. Therefore, all the organizations that are willing to apply such methods must have clear goals and criteria of selection to guarantee the success and correctness of the final decision.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Factor Identification

It is essential to identify the different factors considered in the selection of contractors during the tender evaluation stage, which makes this step very important and crucial for the whole research project. As a result, an extensive literature study was done to gather all the recent findings and researches in the areas related to tendering and the evaluation process. As shown in section 2.2, thirty-one factors were found from the literature review, and they were divided into three categories (technical, financial, and qualifications). To validate the results, three senior engineers have reviewed and approved the obtained factors based on validity and importance.

After identifying and confirming the results, the quantitative analysis began with the survey design and preparation.

3.2 Survey Design

To rank the identified factors, a questionnaire was made to be distributed on construction industry professionals. The responses from the questionnaire will be translated into pairwise comparisons, which are the input of the ANP model. Although this study focuses on the construction industry in the state of Qatar, the questionnaire is going to be distributed online using Google forms service without any geographic restrictions. The reason behind this decision is the similarity in the construction industry around the world. Refer to Appendix-1 for the full survey.

The other objective of the questionnaire is to understand the perspectives of the respondents based on their organization type, years of experience, and company size. As a result, the questionnaire had two main parts (respondent background information and evaluation of factors).

The factors were rated using Likert's importance scale with the values ranging from (1-5), as shown in Table 4. The Likert scale was selected because it is simpler and easier to understand by the participant compared to the other scales, such as Saaty's (1-9) scale. Satty's scale shown in Table 5 below will be used for pairwise comparisons of the ANP model in the final stage of this study. According to Saaty (1987), the reason behind using the (1-9) scale for ANP is because it helps in distinguishing the difference between the factors, especially when they are relatively large in number.

Table 4. Likert Importance Scale

Scale	1	2	3	4	5
Importance	Not at all important	Slightly important	Moderately important	Very Important	Extremely Important

Table 5. (1-9) Evaluation scale used in ANP Pairwise comparisons

Scale	Degree of importance	Reciprocal (decimal)
1	Equally important	1/1 (1.000)
2	Equally to moderately important	1/2 (0.500)
3	Moderately important	1/3 (0.333)
4	Moderately to strongly important	1/4 (0.250)
5	Strongly important	1/5 (0.200)
6	Strongly to very strongly important	1/6 (0.167)
7	Very strongly important	1/7 (0.143)
8	Very strongly to extremely important	1/8 (0.125)
9	Extremely important	1/9 (0.111)

3.3 Data Collection

The questionnaire shown in Appendix 1 was developed on the google forms platform, and it was delivered to international and local experts through different channels such as email and LinkedIn.

The questionnaire was shared with construction industry professionals from around the world. This included all stakeholders, such as clients, contractors, consultants, and subcontractors.

A total of 189 people from around the world have participated in the questionnaire.

3.4 Sample Demography

The first part of the questionnaire was about the demography and participants' background, which is going to be summarized in this section.

3.4.1 The field of work and organization's type

This part focused on the participants' field of work and his/her organization type.

Figure 3 below shows the results of these questions.

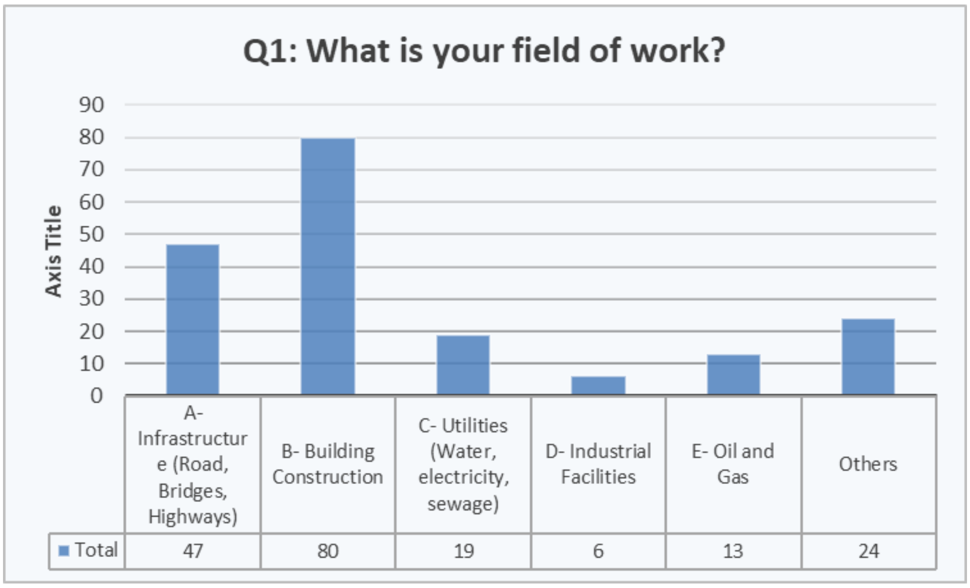

Figure 3. Questionnaire distribution by field of work

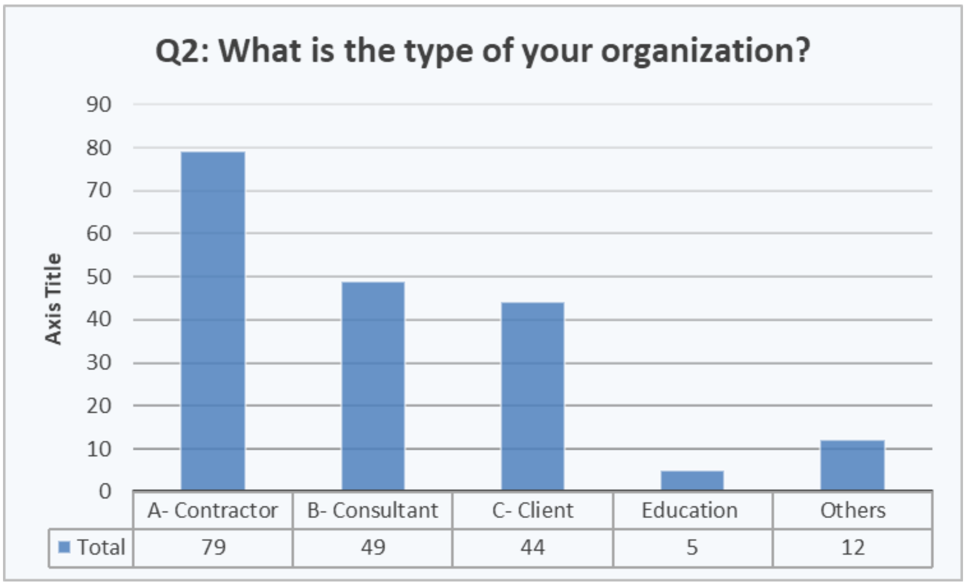

Figure 4. Questionnaire distribution by organization type

3.4.2 Job Designation and years of experience

Figure 5 and Figure 6 below show the summary of the job designation and years of experience of the respondents:

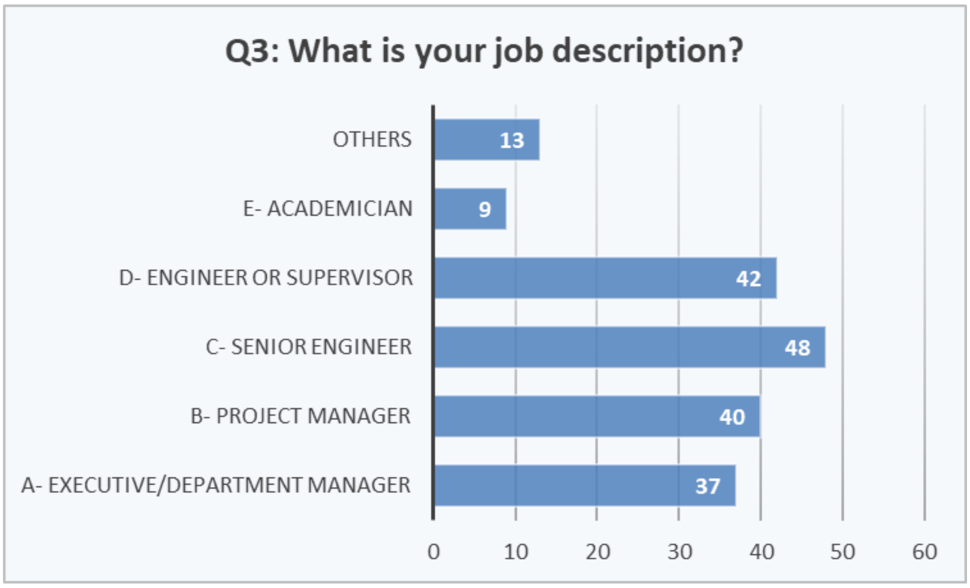

Figure 5. Questionnaire distribution by jobs

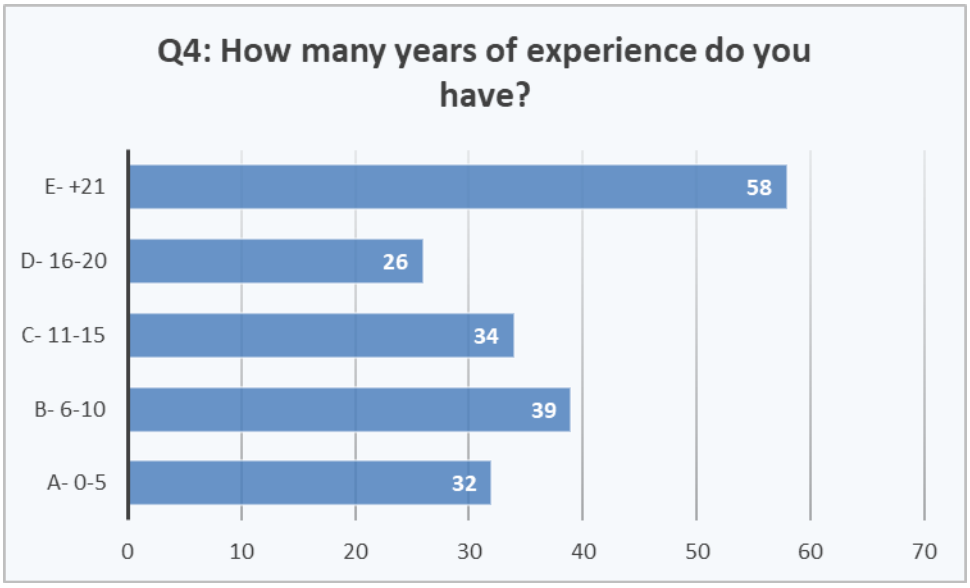

Figure 6. Questionnaire distribution by years of experience

3.4.3 Size of Organization

Table 6 and Figure 7 below summarize the questionnaire by company size:

Table 6. Questionnaire response count by company size

Q5: What is the size of your company?	
A- Small (less than 200 employees)	46
B- Medium (200-500 employees)	29
C- Large (More than 500 employees)	114
Total	189

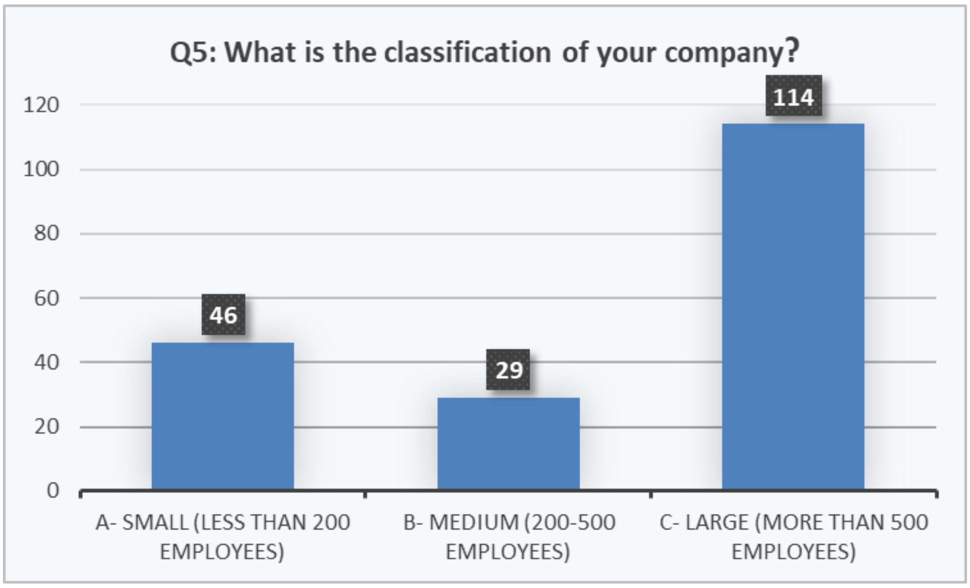

Figure 7. Questionnaire distribution by company size

3.4.4 The current method of tender evaluation

Table 7 and Figure 8 below summarize the used evaluation method in the respondents' companies:

Table 7. Questionnaire response count for the used method of tender evaluation

Q6: For technically accepted offers, your organization award the contracts based on?	
A- Lowest price	55
B- Multi-criteria decision making	131
Both A and B	2
Not sure	1
Total	189

Figure 8. Questionnaire distribution tender evaluation methods

CHAPTER 4: ANALYSIS AND RESULTS

4.1 Overview

This chapter will contain an analysis of the second part of the questionnaire, which will be used to build the ANP model and find the final rank of the obtained factors.

The first stage of the analysis is to calculate the important relative index (RII) from the questionnaire data. After that, the RII calculated results would be used to rank the factors and build the pairwise comparison matrices.

The second stage will be to build the ANP model and use it as a ranking tool to find the ultimate ranks of the tender evaluation factors.

4.2 Relative Importance Index (RII)

Many researchers implemented the RII for different purposes. In 2013, (Gunduz et al.) have used the RII approach to study the causes of project delays in Turkey. Additionally, in 2014 (Marzouk & El Rasas) have used the same principle to assess construction projects in Egypt. RII is calculated as follows:

$$RII = \frac{\sum P}{N \times H}$$

Where:

N: total number of responses (189)

H: the highest number in the used scale (5)

P: product sum of the responses with their respective count

Table 8. Factor T1 response count

No	Factor	Not at all important 1	Slightly important 2	Moderately important 3	Very Important 4	Extremely Important 5
T1	Manpower availability	6	20	54	75	34

$$RII = \frac{\sum(1 \times 6) + (2 \times 20) + (3 \times 54) + (4 \times 75) + (5 \times 34)}{189 \times 5}$$

$$= \frac{678}{945} \approx 0.71746$$

Similarly, RII was calculated for the remaining factors, as shown in Table 9 below. After that, the factors were ranked on descending order based on their RII values. The results will be discussed in the next chapter.

Table 9. Relative Importance Index ranking

No	Factor	ΣP	RII	Rank
F2	Financial stability	805	0.85185	1
F3	Offered price/Bid	801	0.84762	2
T10	Proposed delivery date	792	0.83810	3
Q5	Experience with similar projects	789	0.83492	4
Q2	Past-history	787	0.83280	5
Q3	Qualification engineers and technical staff	775	0.82011	6
T7	Warranty and after services	767	0.81164	7

No	Factor	ΣP	RII	Rank
F5	Price of major works	767	0.81164	8
T3	Safety records	766	0.81058	9
F4	Bid security (bond)	756	0.80000	10
Q4	Experience in the region	744	0.78730	11
T8	Methodology to carry out the works	737	0.77989	12
T5	Quality management system	733	0.77566	13
Q1	Certifications	732	0.77460	14
T4	Safety plan	725	0.76720	15
Q7	Records of failure	722	0.76402	16
Q9	Client's experience with the contractor	713	0.75450	17
T6	Risk management system	700	0.74074	18
T12	Procurement plan	696	0.73651	19
T2	Equipment availability	688	0.72804	20
T1	Manpower availability	678	0.71746	21
F6	Frontloading	678	0.71746	22
Q6	Experience with other projects	677	0.71640	23
T14	Suppliers and vendors	672	0.71111	24
T15	Subcontractors	670	0.70899	25
F1	Number of on-going projects	662	0.70053	26
F7	No. Of liquidated assets	660	0.69841	27
T11	Environmental considerations	639	0.67619	28
Q8	Staff training plans/programs	615	0.65079	29
T13	Use of new technologies	612	0.64762	30
T9	Level of innovation	606	0.64127	31

In Table 9 above, the assigned codes F, T, Q represent the category that each factor belongs to, which are financial, technical, and qualifications, respectively.

4.3 ANP as a ranking tool

As mentioned in the literature review chapter, AHP and ANP are very famous MultiCriteria Decision Making (MCDM) techniques that have a unique feature of transforming complex problems into simpler forms. ANP and AHP convert the problems from multi-dimensional into single-dimensional forms.

ANP was introduced in 1975 by Saaty as an improvement and generalization to AHP, which was introduced a few years before. Thomas Saaty found that it is not possible to consider and deal with all problems as linear hierarchy structures due to the existence of inter-dependencies between the criteria/factors. Therefore, Saaty came up with the concept of ANP. ANP deals with the factors as clusters in a network rather than a hierarchy. The other strength of ANP is that it represents the real-life situation of problems where there are feedback loops resulted from the connections between clusters and factors.

In this project, the process of selecting the best contractor from multiple bidders is a complex problem as many of the factors are related and have an influence on each other. Tender evaluation factors in a category such as the financial factors can be very related, and it is impossible to separate them or treat them independently like AHP. Similarly, factors from one category can influence the factors in another category. This is called the outer dependency, while the previously mentioned relation within the same category is called inner dependency. Therefore, in such situations, ANP is a great tool because it overcomes the limitations of the other techniques as it includes these relations.

Figure 9 below shows the network that was built and will be used in this project as the ANP network.

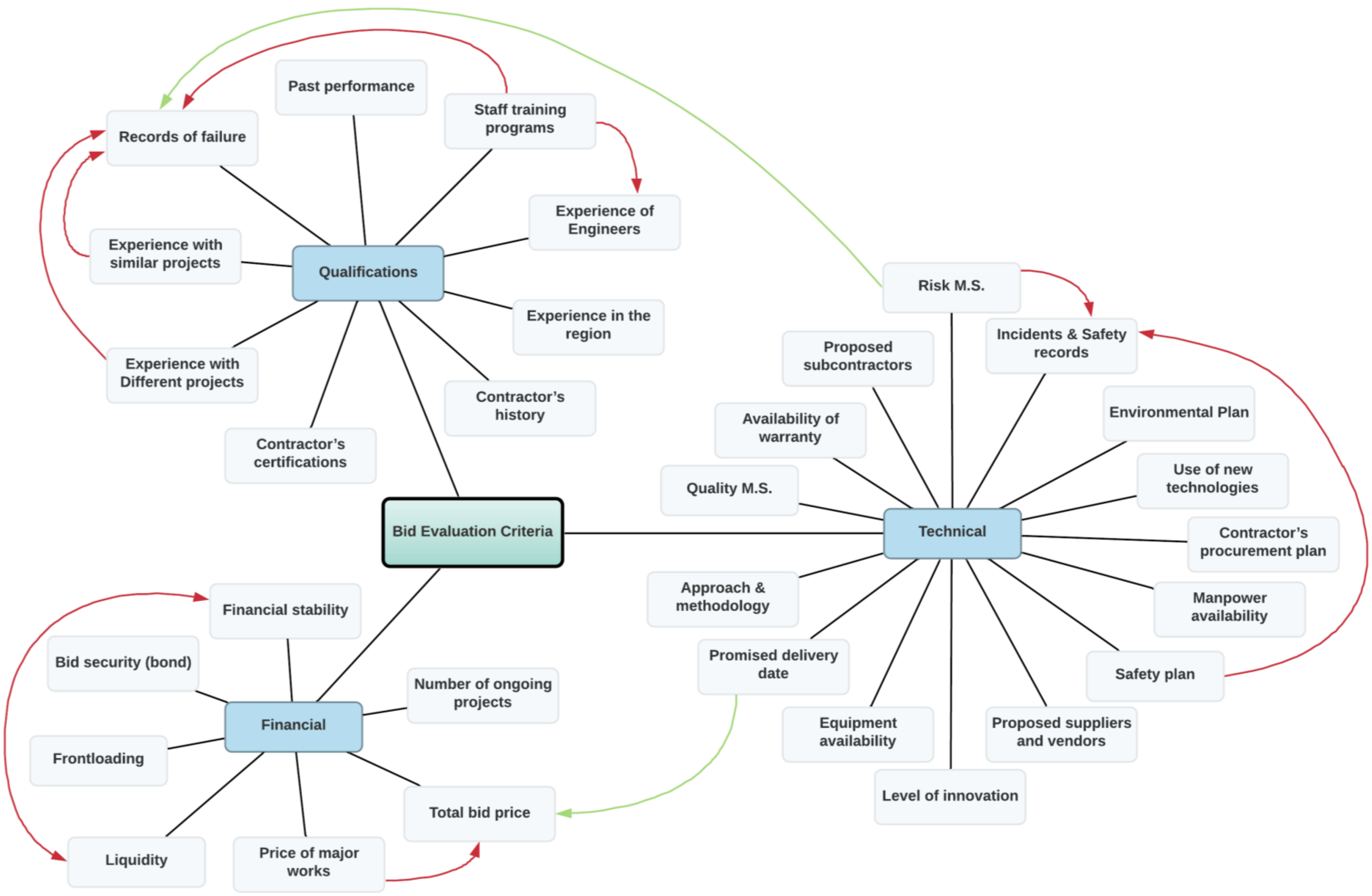

Figure 9. Factors dependency network

4.4 Steps of ANP

ANP considers any problem as a network that consists of elements and clusters. To include the dependencies and feedback loops, the elements within a cluster must be related in some form. The relations between the elements and criteria can be shown in the ANP supermatrix, which converts the whole network into a two-dimensional form. According to Saaty (2007), the new concept of supermatrix consists of a single two-dimensional matrix made. The supermatrix is made using the element-element comparisons.

Building an ANP model can be done through the following steps:

1. Identify the main goal and construct a network of elements and clusters.
2. Connect all the elements to the main goal and identify all the (inner and outer dependencies).
3. Using the Saaty (1-9) scale, conduct an element-element comparison between the factors within each cluster. This comparison between the elements will result in vectors that will be inserted into the supermatrix as columns.
4. Then, Perform a cluster-cluster comparison similar to the element-element comparison.
5. Combine the vectors of priorities resulted from the comparisons to construct the supermatrix.
6. Calculate the weighted supermatrix by multiplying the unweighted-supermatrix, and the vector resulted from the clusters-cluster comparison.
7. To achieve convergence and calculate the limiting supermatrix, raise the weighted-supermatrix to a high-power K until increasing the value of K makes no further change to the result.
8. Finally, normalize the limiting supermatrix to get the priority vector of the factors.

4.5 SuperDecisions Software

Although ANP is known to simplify complex real-life problems into a two-dimensional model, increasing the number of criteria and elements makes ANP very difficult and time-consuming to build. Since it has a systematic and mathematical approach, many solution software has been developed over the years to solve the complex ANP models in a few minutes.

SuperDecisions (http://www.superdecisions.com/) is one of the software programs specialized in building and solving AHP and ANP models. SuperDecisions has been used widely by engineering and management professionals as well as researchers due to its free availability, high capabilities, and simple user interface.

The SuperDecisions software can generate many matrices that can be useful in ANP models that are built for either ranking of criteria, or selection of alternatives, such as the unweighted-supermatrix, the limiting supermatrix, and many more matrices. To obtain the results, navigate to the Computations tab on the top of the page.

In this project, SuperDecisions will be used to develop and solve the ANP model and to find the final rank for the tendering evaluation factors.

4.6 Implementing Analysis by ANP

In this study, ANP was chosen as a ranking tool to rank the tendering evaluation factors that were obtained in the literature study. ANP will be used to re-rank the factors, and to show the effect of including the inner and outer dependencies.

The steps of building an ANP model on SuperDecisions will be explained below:

1- The first step in SuperDecisions is to create a new file and insert the first cluster, which is the goal of the whole model.

2- After that, insert the categories (financial, technical, qualification) as separate clusters and fill each cluster with the factors which as nodes.

3- Connect the clusters to build the model shown in Figure 9 above.

4- After building the model graphically, enter the pairwise comparison values between the factors within each cluster, between the clusters, and between the interconnected factors from the different clusters. The pairwise comparison can be obtained by calculating the max rank difference within each cluster and assigning the largest difference the value of 9, and the minimum difference (usually 1) the value of 2 because (1) is used for comparing the factor with its self.

The process of performing pairwise comparisons is as the following:

Table 10. Financial factors pairwise calculation example

No	Factor	RII	Rank
F2	Financial stability	0.85185	1
F3	Offered price/bid	0.84762	2
F5	Price of major works	0.81164	8
F4	Bid security (bond)	0.80000	10
F6	Frontloading	0.71746	22
F1	Number of on-going projects	0.70053	26
F7	No. Of liquidated assets	0.69841	27

From Table 10 above, it can be seen that the maximum rank difference within the category is 26, and the minimum is one, and these values can be calculated as follows:

$$Maximum\ Difference = Max\ Rank - Min\ Rank$$

$$= 27 - 1 = 26$$

$$Minimum\ difference = Min\ (Rank_{n+1} - Rank_n), where\ n = 1,2,..,7$$

$$= Min \left\{ \begin{array}{c} 2 - 1 = 1 \\ 8 - 2 = 6 \\ 10 - 8 = 2 \\ 22 - 10 = 12 \\ 26 - 22 = 4 \\ 27 - 26 = 1 \end{array} \right\} = 1$$

The same procedure was followed for the other categories, and the results are as the following:

Table 11. The rank difference within clusters

Category	**Maximum Difference**	**Minimum Difference**
Technical	28	1
Financial	26	1
Qualification	25	1

The next step is to calculate the rating equation from points (28,9) and (1,2) as follows:

$$straight\ line\ standard\ form \rightarrow y = mx + c$$

$$m = \frac{y_2 - y_1}{x_2 - x_1} = \frac{9 - 2}{28 - 1} = 0.25926$$

$$c = y - mx$$

$$\xrightarrow{by\ substituting\ in\ point\ (28,9)} c = 9 - 0.25926(28) = 1.7407$$

$$y = 0.25926x + 1.7407 \quad \text{----(1)}$$

Using equation 1, the following pairwise comparison matrices were calculated:

	Q1	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**
Q1	**1**	1/4	1/4	1/3	1/4	4	2	6	3
Q2	4	**1**	2	3	1/2	6	5	8	5
Q3	4	1/2	**1**	3	1/2	6	4	8	5
Q4	3	1/3	1/3	**1**	1/4	5	3	6	3
Q5	4	2	2	4	**1**	7	5	8	5
Q6	1/4	1/6	1/6	1/5	1/7	**1**	1/4	3	1/3
Q7	1/2	1/5	1/4	1/3	1/5	4	**1**	5	2
Q8	1/6	1/8	1/8	1/6	1/8	1/3	1/5	**1**	1/5
Q9	1/3	1/5	1/5	1/3	1/5	3	1/2	5	**1**

Figure 10. Financial factors unweighted comparison matrix

	F1	F2	F3	F4	F5	F6	F7
F1	**1**	1/8	1/8	1/6	1/6	1/3	2
F2	8	**1**	2	4	4	7	8
F3	8	1/2	**1**	4	3	7	8
F4	6	1/4	1/4	**1**	1/2	5	6
F5	6	1/4	1/3	2	**1**	5	7
F6	3	1/7	1/7	1/5	1/5	**1**	3
F7	1/2	1/8	1/8	1/6	1/7	1/3	**1**

Figure 11. Financial factors unweighted comparison matrix

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
T1	**1**	1/2	1/5	1/3	1/4	1/3	1/5	1/4	4	1/6	4	1/2	4	3	3
T2	2	**1**	1/5	1/3	1/4	1/2	1/5	1/4	5	1/6	4	1/2	4	3	3
T3	5	5	**1**	3	3	4	1/2	3	7	1/3	7	4	7	6	6
T4	3	3	1/3	**1**	1/2	3	1/4	1/3	6	1/5	5	3	6	4	4
T5	4	4	1/3	2	**1**	3	1/3	1/2	6	1/4	6	3	6	5	5
T6	3	2	1/4	1/3	1/3	**1**	1/5	1/3	5	1/6	4	2	5	3	4
T7	5	5	2	4	3	5	**1**	3	8	1/3	7	5	8	6	6
T8	4	4	1/3	3	2	3	1/3	**1**	7	1/4	6	4	6	5	5
T9	1/4	1/5	1/7	1/6	1/6	1/5	1/8	1/7	**1**	1/9	1/3	1/5	1/2	1/4	1/3
T10	6	6	3	5	4	6	3	4	9	**1**	8	6	9	7	7
T11	1/4	1/4	1/7	1/5	1/6	1/4	1/7	1/6	3	1/8	**1**	1/4	2	1/3	1/3
T12	2	2	1/4	1/3	1/3	1/2	1/5	1/4	5	1/6	4	**1**	5	3	3
T13	1/4	1/4	1/7	1/6	1/6	1/5	1/8	1/6	2	1/9	1/2	1/5	**1**	1/3	1/3
T14	1/3	1/3	1/6	1/4	1/5	1/3	1/6	1/5	4	1/7	3	1/3	3	**1**	2
T15	1/3	1/3	1/6	1/4	1/5	1/4	1/6	1/5	3	1/7	3	1/3	3	1/2	**1**

Figure 12. Technical factors unweighted comparison matrix

Since ANP takes inner and outer dependencies and cluster to cluster weights, small element-element and cluster-cluster matrices were built. Figure 13 below shows examples of the developed matrices.

	Financial	Technical	Qualification
Financial	**1**	4	2
Technical	1/4	**1**	1/2
Qualification	1/2	2	**1**

Figure 13. Cluster comparison matrix

5- By entering the pairwise comparison in the SuperDecisions software, building the ANP model is now completed, and the results can be extracted from the software.

4.7 Discussion of Results

The analysis of the tendering evaluation factors was done on two stages. The first stage of the analysis was done using the RII, which was calculated using the responses collected from construction industry professionals (189 respondents). After that, the RII rank was used to calculate the comparison matrices. The comparison matrices were inserted in the SuperDecisions software along with the ANP network to calculate the final results that incorporate the interdependencies between the factors. The ANP model results in a different and more accurate ranking than the RII rank.

4.7.1 RII results

The RII ranking for the evaluation factors based on their importance to contractor selection or their effect on the performance of the project was shown in Table 9 above. According to the results that were based on industry experts' opinions "financial stability of the contractor" is the most important factor for awarding projects, and it has the biggest impact on the performance of the project. The importance of this factor is generated from its relation to the contractor's ability to secure funds to execute the activities on time and with good quality.

Table 12 below shows the five highest factors in the RII rank. It can be noticed in the results below that three of the top five factors (Financial Stability, Experience in similar projects, the past history between the contractor and client) are related to the history of the contractor. Clients usually ignore this aspect as they focus on technical factors related to the works or related to bid price.

Table 12. Top five factors based on RII ranking

No	Factor	RII	Rank
F2	Financial stability	0.85185	1
F3	Offered price/Bid	0.84762	2
T10	Proposed delivery date	0.83810	3
Q5	Experience with similar projects	0.83492	4
Q2	Past- history	0.83280	5

It is noticeable from the results above that the percentages of the factors are very close even though there is a difference in the rank. This implies that the rest of the factors should not be ignored or given low attention as they all received high ratings from the experts. All the factors included in the study had relatively high percentages ranging between (64.1%-85.1%).

In construction, knowing the financial history of the contractor is important to ensure that he can perform the assigned tasks. Also, it helps in knowing if he has enough flow of cash and is not going to struggle with getting all the necessary equipment, materials, and workers.

For many years, clients awarded projects to contractors with the lowest bid/offer. Although this study does not support making decisions based on offered price alone, It is undeniable that the bid price is an important factor in the evaluation process. Additionally, bid prices have a major impact on the client’s decision to execute the project or not, and in the financial arrangements and plans of the project.

Taking the “proposed delivery date” into account is a new concept in the construction industry, and it can help in reducing the overall costs of projects by giving the contractors the choice of proposing delivery dates based on their capacity and available resources.

4.7.2 ANP ranking

The ANP model was used as a second stage to improve the accuracy of the RII ranking, which does not include any inner and outer dependencies between factors. Table 13 below shows the priority vector obtained from the ANP model, which was calculated by SuperDecisions software. In addition to the new ranking of the factors.

Table 13. Factors ranking based on the ANP model

No	Factor	ANP	Rank
F2	Financial stability	0.20505	1
F3	Offered price/Bid	0.15911	2
F5	Price of major works	0.08502	3
Q5	Experience with similar projects	0.07717	4
F4	Bid security (bond)	0.06704	5
Q2	Past-history	0.06278	6
Q3	Qualification engineers and technical staff	0.05250	7
T10	Proposed delivery date	0.03200	8
Q4	Experience in the region	0.03125	9
F6	Frontloading	0.02599	10
T7	Warranty and after services	0.02264	11
Q1	Certifications	0.02132	12
T3	Safety records	0.01926	13
F1	Number of on-going projects	0.01615	14
Q7	Records of failure	0.01608	15
T8	Methodology to carry out the works	0.01409	16
F7	No. Of liquidated assets	0.01307	17
Q9	Client’s experience with the contractor	0.01257	18
T5	Quality management system	0.01193	19

No	Factor	ANP	Rank
T4	Safety plan	0.00958	20
Q6	Experience with other projects	0.00735	21
T6	Risk management system	0.00685	22
T12	Procurement plan	0.00578	23
T2	Equipment availability	0.00507	24
Q8	Staff training plans/programs	0.00470	25
T1	Manpower availability	0.00449	26
T14	Suppliers and vendors	0.00317	27
T15	Subcontractors	0.00278	28
T11	Environmental considerations	0.00203	29
T13	Use of new technologies	0.00176	30
T9	Level of innovation	0.00144	31

From Table 13, it is noticed that the "financial stability of the contractor" did not change, and it is still the most important factor. Having the same first ranking factor in both stages shows how important financial stability is and how crucial it is to the success of projects. In their AHP study, Husin et al. (2019) found that the financial strength and stability of the contractor is the most important factors for the selection of the contractor. His findings are aligned with the results of the ANP model developed in this study and reflects the level of importance of the contractor's financial records for all types of projects.

Using the total price for the final project award decision is not encouraged by many construction professionals because it has many risks. Throughout the years, many unqualified contractors have lowered their offers to win the contracts. As a result, these contractors were unable to deliver the projects due to many factors like lack of experience. Therefore, many studies were made to move toward the use of other scientific techniques for bid review. Although this study encourages the clients to move toward using MCDM techniques instead of choosing contractors based on the offered bid price, the bid price remains an important factor that should not be ignored, and it was ranked in the 2nd position in the ANP results.

Like the total bid price, reviewing the prices of major activities and works is very important in the evaluation of a bidder. This factor is important in checking the manipulation of bids by contactors. Additionally, the prices of major works can represent the contractors' level of understanding for the scope and helps to ensure that the pricing of the items is aligned with the initial estimates for the project.

Reviewing the contractors' projects and years of experience in similar types of projects is very important for the success of construction projects, especially for sensitive projects such as railway projects and complex highway projects. This factor is in the 4th place in the ANP rank, which is considered very crucial for the success of projects, and it is currently emphasized in many nations, especially in large projects.

Factors such as "proposed delivery date," and "warranty services" are usually ignored in the reviewing process of contractors, yet they have scored high results in the ANP rank. On one side, clients will be offered services after the completion of projects, and on the other hand, contractors can use these opportunities to increase their chances of winning the contracts.

The construction industry is a very dangerous field that has lots of possibilities for accidents. According to BLS (2018), construction is the second-ranked industry in the number of fatal workplace injuries in the United States. Therefore, it is very important in all tenders to require a “safety plan” from all bidders and to include it in the evaluation process to reduce the possibilities for fatal and non-fatal injuries in the projects. Additionally, it is very important to require the “safety records” of each contractor for 3-5 years to reduce the risks further. Moreover, it is important to verify the provided records from the specialized authorities as these records can be easily manipulated and changed.

Finally, in this project, thirty-one factors were identified from the different papers that were reviewed during the literature review. Although some of the factors have a low rank from the ANP, such as “use of new technologies” and “levels of innovation,” they are still very important as they were mentioned in many previous studies. Additionally, there are many benefits for the contractors if they start focusing on these factors like developing a reputation and being called for closed negotiation projects instead of open tenders.

4.8 Comparison of the results

The RII was used in this study as a primary ranking tool and an input to the ANP model, while the ANP model was used in the second stage as an ultimate ranking tool because it incorporates the inner and outer dependencies of the factors. To understand the difference between the RII and ANP as ranking tools, a comparison was made, as shown in Table 14 below. From the comparison table, it is observed that the rankings of most factors have changed after the introduction of interdependencies. Additionally, the first and second-ranked factors “Financial Stability” and “Offered bid price” have not changed. This shows the importance of these factors and how critical they are to the success and performance of projects.

Table 14. RII and ANP result comparison table

No	Factor	ANP	Rank	RII	Rank	Change	MAD
F2	Financial stability	0.2051	1	0.8519	1	0	0.0000
F3	offered price/Bid	0.1591	2	0.8476	2	0	0.0000
F5	Price of major works	0.0850	3	0.8116	8	5	0.1613
Q5	experience with similar projects	0.0772	4	0.8349	4	0	0.0000
F4	Bid security (bond)	0.0670	5	0.8000	10	5	0.1613
Q2	Past-history	0.0628	6	0.8328	5	-1	0.0323
Q3	Qualification of engineers & staff	0.0525	7	0.8201	6	-1	0.0323
T10	Proposed delivery date	0.0320	8	0.8381	3	-5	0.1613
Q4	experience in the region	0.0313	9	0.7873	11	2	0.0645
F6	Frontloading	0.0260	10	0.7175	22	12	0.3871
T7	warranty and after services	0.0226	11	0.8116	7	-4	0.1290
Q1	certifications	0.0213	12	0.7746	14	2	0.0645
T3	Safety records	0.0193	13	0.8106	9	-4	0.1290
F1	Number of on-going projects	0.0162	14	0.7005	26	12	0.3871
Q7	Records of failure	0.0161	15	0.7640	16	1	0.0323
T8	methodology to carry out the works	0.0141	16	0.7799	12	-4	0.1290

No	Factor	ANP	Rank	RII	Rank	Change	MAD
F7	No. of liquidated assets	0.0131	17	0.6984	27	10	0.3226
Q9	Client's experience with the contractor	0.0126	18	0.7545	17	-1	0.0323
T5	Quality management system	0.0119	19	0.7757	13	-6	0.1935
T4	safety plan	0.0096	20	0.7672	15	-5	0.1613
Q6	experience with other projects	0.0074	21	0.7164	23	2	0.0645
T6	Risk management system	0.0069	22	0.7407	18	-4	0.1290
T12	procurement plan	0.0058	23	0.7365	19	-4	0.1290
T2	equipment availability	0.0051	24	0.7280	20	-4	0.1290
Q8	Staff training plans/programs	0.0047	25	0.6508	29	4	0.1290
T1	manpower availability	0.0045	26	0.7175	21	-5	0.1613
T14	suppliers and vendors	0.0032	27	0.7111	24	-3	0.0968
T15	subcontractors	0.0028	28	0.7090	25	-3	0.0968
T11	Environmental considerations	0.0020	29	0.6762	28	-1	0.0323
T13	Use of new technologies	0.0018	30	0.6476	30	0	0.0000
T9	Level of innovation	0.0014	31	0.6413	31	0	0.0000

1. As seen from Table 14 above, 26 out of 31 factors changed in ranking after the inclusion of the interdependencies. This change shows how important it is to include the interdependencies of the factors in the analysis and ranking of the results.
2. Each of the factors "Price of major works" and "Bid security" changed five positions and became in the top five of the ANP ranking. The change in these

factors resulted from the pairwise cluster comparison, which gave higher importance to the financial factors over the other categories.

3. The biggest change in the ranking happened to factors F1, F6, F7, where they have changed more than ten positions after including the interdependencies and cluster pairwise comparison.
4. Due to the important difference between the clusters, 13 out of 15 of the technical factors have decreased in the ranking.

4.9 Research Applicability

This study can be applied in general construction projects such as building and infrastructure projects; however, in some cases, certain projects may have special nature or requirements that make this method inapplicable like the construction of oil and gas rigs. In the oil & gas industry, the financial aspects usually have less importance compared to technical aspects such as quality and maintenance. Therefore, these results may require modifications to be used in other industries, or industry-specific research may be needed for each specific industry where the rating is done exclusively by professionals from the industry.

Additionally, applying this method requires that all designs and drawings be ready before the start of tendering; therefore, this method is more suitable for projects with the Design Bid Build delivery system (DBB). DBB is usually used in public projects where the money is the main constraint, and it is where most of the organizations are still selecting contractors based on the total price of the bid.

In Design-Build projects (DB), this method can be used partially to evaluate subcontractors or vendors. It is not advisable to fully implement this method on DB projects, because clients usually use DB when there are limited time and high budget.

Therefore, it would not be practical to perform such analysis for time-constrained projects, especially with the unavailability of designs, which is the major requirement for contractors' offer submission.

For other types of projects like Build-Own-Transfer (BOT) and Build-Own-Operate-Transfer (BOOT), this method is not very useful because the client is not financing the project and therefore has very limited control. Finally, in Construction Management Agency (CMA) and Construction Management Agency At-Risk (CMAR), this method is not recommended at all. CMA and CMAR are usually used for complex projects where the work gets divided into packages that are assigned to different subcontractors. Therefore, using this method is not recommended because it would require a long duration of time and many resources to evaluate all subcontractors.

4.10 Practical implementation of the ANP Model with a Case Study

This study has great potential for real-life uses and cases as it will enable the clients to understand better the significance of each factor in the process of evaluation for tenders. Moreover, the results of this study can be used in the evaluation of the bidders by assigning the percentages from the ANP study to each factor and evaluating them using the weighted sum. Percentage of importance were calculated using the following formula to evaluate contractors using the ANP results:

$$importance\ percentage = Normalized\ ANP\ weight \times 100\%$$

Following are the percentages of importance for each factor:

Table 15. Percentage of importance for the evaluation factors

No	Factor	Percentage of importance
T1	Manpower availability	0.45
T2	Equipment availability	0.51
T3	Safety records	1.93
T4	Safety plan	0.96
T5	Quality management system	1.19
T6	Risk management system	0.69
T7	Warranty and after services	2.26
T8	Methodology to carry out the works	1.41
T9	Level of innovation	0.14
T10	Proposed delivery date	3.20
T11	Environmental considerations	0.20
T12	Procurement plan	0.58
T13	Use of new technologies	0.18
T14	Suppliers and vendors	0.32
T15	Subcontractors	0.28
F1	Number of on-going projects	1.62
F2	Financial stability	20.51
F3	Offered price/Bid	15.91
F4	Bid security (bond)	6.70
F5	Price of major works	8.50
F6	Frontloading	2.60
F7	No. Of liquidated assets	1.31
Q1	Certifications	2.13
Q2	Past-history	6.28
Q3	Qualification engineers and technical staff	5.25

No	Factor	Percentage of importance
Q4	Experience in the region	3.13
Q5	Experience with similar projects	7.72
Q6	Experience with other projects	0.74
Q7	Records of failure	1.61
Q8	Staff training plans/programs	0.47
Q9	Client's experience with the contractor	1.26

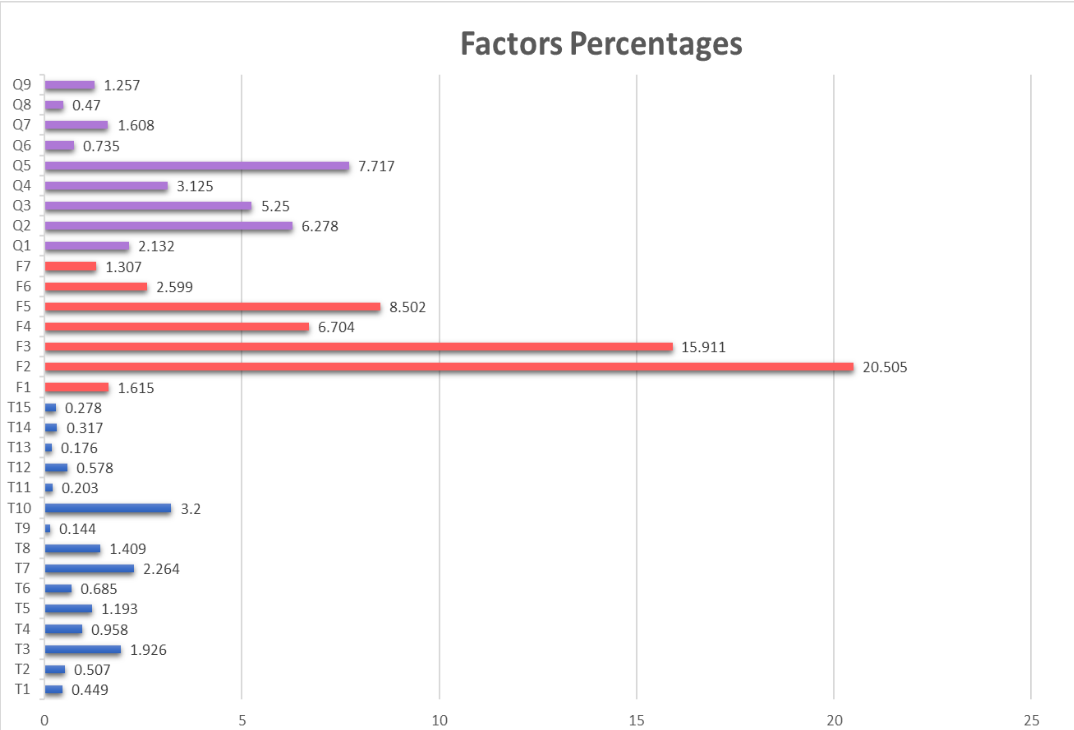

Figure 14. Percentage of the importance of the factors

The percentage from the above Table 15 and Figure 14 can be utilized as weights for each factor in the review process. The review team must assign a rating system for the factors either by using real values that must be normalized or using a standard rating system.

The example below shows how the factor percentages can be used. Assuming there are two bids (submitted by two contractors) to be reviewed for a project. In this example, the contractors are scored on a scale of 0-100 (100 being better always) as opposed to the currently used checklists or binary rating system. After reviewing both packages, the contractors' scores were recorded and tabulated, as shown in Table 16:

Table 16. Bid review sheet for contractors A & B

Evaluation Criteria	**ANP Percentage**	**Expert Rate (100)**		**Weighted Rates**	
		Contractor A	**Contractor B**	**Contractor A**	**Contractor B**
Financial stability	20.505	78	85	15.9939	17.4293
offered price/Bid	15.911	88	82	14.0017	13.0470
Price of major works	8.502	87	83	7.3967	7.0567
experience with similar projects	7.717	93	94	7.1768	7.2540
Bid security (bond)	6.704	81	87	5.4302	5.8325
past history	6.278	90	89	5.6502	5.5874
Qualification of engineers	5.250	91	88	4.7775	4.6200
Proposed delivery date	3.200	85	85	2.7200	2.7200
experience in the region	3.125	92	90	2.8750	2.8125
Frontloading	2.599	84	88	2.1832	2.2871
warranty and after services	2.264	94	92	2.1282	2.0829
certifications	2.132	87	91	1.8548	1.9401
Safety records	1.926	98	97	1.8875	1.8682

Evaluation Criteria	ANP Percentage	Expert Rate (100)		Weighted Rates	
		Contractor A	Contractor B	Contractor A	Contractor B
Number of on-going projects	1.615	90	70	1.4535	1.1305
Records of failure	1.608	95	96	1.5276	1.5437
methodology to carry out works	1.409	90	91	1.2681	1.2822
No. of liquidated assets	1.307	88	85	1.1502	1.1110
Client's experience with contractor	1.257	60	80	0.7542	1.0056
Quality management system	1.193	84	89	1.0021	1.0618
safety plan	0.958	93	96	0.8909	0.9197
experience with other projects	0.735	79	83	0.5807	0.6101
Risk management system	0.685	92	86	0.6302	0.5891
procurement plan	0.578	80	82	0.4624	0.4740
equipment availability	0.507	87	91	0.4411	0.4614
Staff training plans/programs	0.470	84	86	0.3948	0.4042
manpower availability	0.449	90	87	0.4041	0.3906
suppliers and vendors	0.317	83	86	0.2631	0.2726
subcontractors	0.278	82	80	0.2280	0.2224
Environmental considerations	0.203	84	82	0.1705	0.1665
Use of new technologies	0.176	70	63	0.1232	0.1109
Level of innovation	0.144	80	77	0.1152	0.1109
Total				85.93556	86.40457

From Table 16 above, it is found that Contractor B is the best for the job based on the provided data and factor weight calculated in this study. The above table shows how simple it is to evaluate the contractors once the weights of the factors are set and selected based on the evaluation of 189 industry professionals and academics.

The provided example shows one of the many ways that the ANP results can be used, and it was done using all identified factors; however, some factors may not apply to certain types of projects, in certain countries, or for any reason. In such cases, all not-applicable factors can be eliminated, and the ANP scores will get modified using different techniques such as normalization. Additionally, this method can be used for the elimination of low scoring contractors while final selection could be made based on in-depth contractor reviews or other factors that are specific to the client's goals. Similarly, the organization-specific criteria could be used in final selection in case there was an insignificant difference between the scores of top contractors. Finally, using this technique gives great flexibility to the clients where they can use all factors, exclude some factors, and focus on the top five or ten factors, or specifically selecting certain factors. In any of these scenarios, the clients are likely to have better decisions compared to the selection that is only based on the total bid price, which is currently used by many clients.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The selection of the best contractor is one of the most critical decisions in projects from all industries, especially the construction industry. In most cases, clients and project owners look for the contractor with the lowest bid to award the contract to him. However, in many of these cases, the contractors who were awarded the project are not suitable for the job, and usually, they were awarded the contracts as a result of an estimation error or a manipulation of the offers.

This study was made to identify, analyze, and rank the most important factors to be considered in tendering evaluation. This study was done through different stages, which included a detailed, literate study through academic papers and publications to identify the most important factors. After that, a questionnaire was prepared, and it was answered by 189 professionals from the construction industry, oil & gas, and academics. The questionnaire responses were analyzed and ranked using the RII as the first stage ranking. In addition to that, the results of RII ranking were used to build the pair comparison matrices. The matrices were used as an input for building the ANP model. Finally, an ANP model was built to find the ultimate ranking of the factors.

During the literate study, 31 factors were identified and were divided into three categories (Technical, Financial, Qualification). To be selected, the factors had to be in at least three publications from the last 10-15 years.

The Relative Importance Index was used as a ranking tool in this study, and it is shown that the financial stability of the contractor is the most important factor to be considered. After performing the Analytical Network Process (ANP) analysis, the financial stability remained in the first rank, which shows its importance to the projects. The second place in the ANP rank was for the offered bid price, which undoubtedly is a very important factor and one that should not be neglected. However, it is unwise to base the selection, and final decision on this factor alone as the potential saving might turn into a big loss. The results of this study have many potential uses, one of which was shown in section 4.10. In this study, it was illustrated how to use the percentages resulted from the ANP model to select a winning contractor between two.

To conclude, this study is proof that the price of the contract is not necessarily the most important thing to consider when selecting the contractor. The stability, experience, and history with the contractor are all very important factors that should be considered to have a smooth and good quality product at the end.

5.2 Recommendations for Owners

This project identified and ranked the essential factors that should be considered while reviewing tenderers. It is vital for clients to use MCDM techniques in the selection of contractors, and to avoid focusing only on the bid price. Clients should start using different factors in their review process, such as the factors identified in this study. Using the ANP rank that was calculated in the review process would increase the odds of success in any project since it is the outcome of a questionnaire that was filled by 189 professionals. Finally, there are many real-life scenarios where clients can benefit from the output of this study like the example provided in section 4.10, and since normalization is required to rank the contractors, clients can select the relevant factors to their projects.

5.3 Recommendations for Contractors

The construction industry is known to be slow in adopting changes and new technologies. However, many of the governmental agencies are starting to use MCDM and other scientific techniques in the reviewing process, and it is recommended for all contractors to use scientific studies like this study to improve their organizations.

Contractors can benefit significantly from the outputs of this study. As clients, the contractors can use the ANP rank to improve the quality of the submitted bids and offers, therefore increasing their chances of winning contracts.

Finally, since most of the factors are not exclusive for the construction industry, contractors with different specialties can benefit from this research to win contracts and have better bids.

5.4 Recommendations for future study

Further studies can be made focusing on different types of projects other than construction projects.

This study included the most important commonly used factors from the literature; however, a more comprehensive study can be done to include additional evaluation criteria or detailed classification and categories of the factors.

Finally, further studies can be made to classify the factors using other Multi-Criteria Decision-Making techniques or Fuzzy techniques and compare them with the results of the ANP model that was developed.

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Appendix -1: Questionnaire

The Application of Multi Criteria Decision Making in Tender Evaluation: A Study Using ANP Model

This questionnaire was prepared as a part of an on-going research in the Engineering Management Program at Qatar University under the title of "The Application of Multi Criteria Decision Making in Tender Evaluation: A Study Using Fuzzy ANP Model".
Please note that all the collected responses in this questionnaire will be completely anonymous and confidential.

Student	Advisors
Mohammad Falamarzi	Dr. Khalid Naji
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Next

PART 1: Dear Respondent, In this part, you will have to answer six questions related to you and the organization you are currently working for. Please the suitable choices to the following:

Please select the suitable choices to the following:

Q1: What is your current field of work? *

- ○ A- Infrastructure (Road, Bridges, Highways)
- ○ B- Building Construction
- ○ C- Utilities (Water, electricity, sewage)
- ○ D- Industrial Facilities
- ○ E- Oil and Gas
- ○ Other: ____________

Q2: What is your organization's type? *

- ○ A- Contractor
- ○ B- Consultant
- ○ C- Client
- ○ Other: ____________

Q3: What is your designation? *

- A- Executive/Department Manager
- B- Project manager
- C- Senior Engineer
- D- Engineer or Supervisor
- E- Academician
- Other: ____________

Q4: How many years of working experience do you have? *

- A- 0-5
- B- 6-10
- C- 11-15
- D- 16-20
- E- +21

Q5: What is the size of your company? *

- A- Small (less than 200 employees)
- B- Medium (200-500 employees)
- C- Large (More than 500 employees)

Q6: For technically accepted offers, your organization award the contracts based on? *

- A- Lowest price
- B- Multi criteria decision making
- Other: ____________

Back Next

PART 2:This Part consist of three questions where you are requested to rate the given factors according to its importance in awarding of contracts.

Q7: What is the importance of the following technical factors on the awarding of contracts? *

	Not at all important	Slightly important	Moderately important	Very Important	Extremely Important
In-house manpower availability of contractors	○	○	○	○	○
In-house equipment availability of contractors	○	○	○	○	○
Safety records of the contractors	○	○	○	○	○
Availability of contractor's safety plan for carrying out the works	○	○	○	○	○
Quality management system of contractor	○	○	○	○	○
Risk management system of contractor	○	○	○	○	○
Availability of warranty and after services by contractor	○	○	○	○	○
Contractor's approach/methodology to carry out the works	○	○	○	○	○
Level of innovation by contractor	○	○	○	○	○
Proposed delivery date	○	○	○	○	○
Environmental considerations by contractor	○	○	○	○	○
Contractor's procurement plan	○	○	○	○	○
Use of new technologies by contractor	○	○	○	○	○
Proposed suppliers and vendors by contractor	○	○	○	○	○
Proposed subcontractors by contractor	○	○	○	○	○

Q8: What is the importance of the following financial factors on the awarding of contracts? *

	Not at all important	Slightly important	Moderately important	Very Important	Extremely Important
Number of contractor's on-going projects	○	○	○	○	○
Financial stability of contractor	○	○	○	○	○
Contractor's offer price	○	○	○	○	○
Bid security (bond) by contractor	○	○	○	○	○
Price of major works	○	○	○	○	○
Frontloading by contractor	○	○	○	○	○
The amount of liquidated assets of the contractor.	○	○	○	○	○

Q9: What is the importance of the following qualification and experience related factors on the awarding of contracts? *

	Not at all important	Slightly important	Moderately important	Very Important	Extremely Important
Contractor's certifications	○	○	○	○	○
Contractor's past history	○	○	○	○	○
Qualification and experience of contractor's engineers and technical staff	○	○	○	○	○
Contractor's experience in the region	○	○	○	○	○
Contractor's experience with similar projects	○	○	○	○	○
Contractor's experience with other projects	○	○	○	○	○
Records of failure	○	○	○	○	○
Staff training plans/programs	○	○	○	○	○
Client's experience with the contractor	○	○	○	○	○

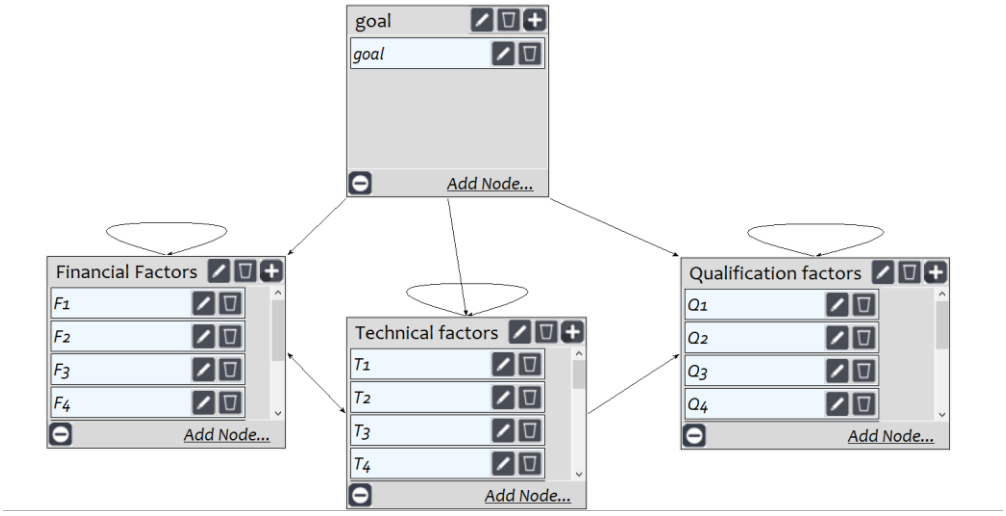
Q10: *

	Not at all important	Slightly important	Moderately important	Very Important	Extremely Important
What is the importance of technical factors on awarding of contracts?	○	○	○	○	○
What is the importance of financial factors on awarding of contracts?	○	○	○	○	○
What is the importance of the contractor's qualification and experience on awarding of contracts?	○	○	○	○	○

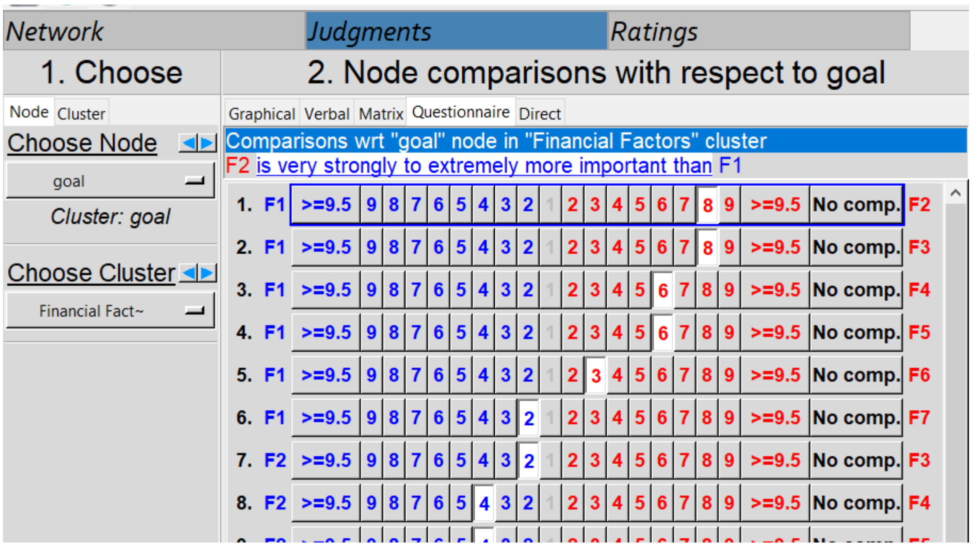
Back Submit

Appendix -2: SuperDecisions Analysis

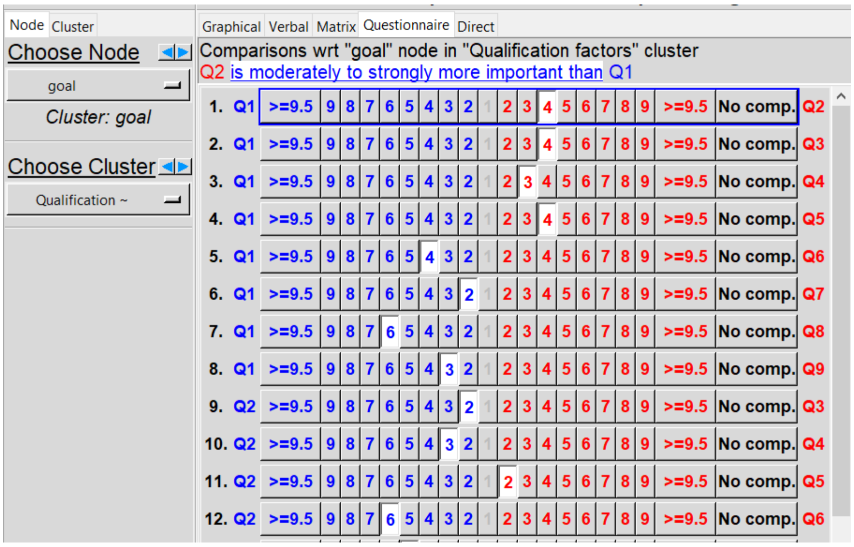
ANP network



SuperDecisions pairwise comparison for the financial factors



SuperDecisions pairwise comparison for the qualification factors



Clusters pairwise comparison