MULTI CRITERIA DECISION MAKING MODEL FOR SELECTION OF DESIGN-BUILD SUBCONTRACTORS IN EPC/TURNKEY CONTRACTS

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THESIS ACCEPTANCE CERTIFICATE

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ABSTRACT

A major proportion of construction projects are executed by subcontractors in the construction Industry. The project's success and the main contractor's ability to complete the project within specified duration, cost and quality depends highly on the capability of subcontractors. In an Engineering Procurement & Construction (EPC) and turnkey contract, the subcontracted work may also include the design of a specialized work where the main contractor lacks experience. The selection of qualified subcontractors is crucial for successful completion of a project and an accurate and realistic bid proposal as the project cost may vary significantly due to design changes. Subcontractor selection is based on a set of criteria that helps the main contractor in deciding the most suitable subcontractor for the desired job. However, there is no set of identified criteria for the selection of design-build subcontractors in EPC/turnkey contracts. This study aims to identify key qualification factors and develop a multi-criteria decision-making model for the selection of design-build specialty subcontractors in an EPC/turnkey contract. A total of 25 key factors are shortlisted by virtue of a thorough literature review and preliminary survey. Afterwards, through an extensive literature review, these factors were categorized into 7 main criteria. A pair-wise comparison of criteria and factors was carried out using Analytical Hierarchy Process (AHP). The resultant weightages were then used to develop a multi-criteria decision-making model. Results show that the key criteria include cost, management and technical ability, and reputation of a subcontractor. To validate the finding of this model, data was collected from 5 case studies of EPC/turnkey building projects. The finding indicates that 'Proposed tender price' is considered the most important factor followed by 'past success' and 'Relationship with the contractor' for awarding contract.

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LIST OF ABBREVIATIONS

Engineered, Procurement & Construction	EPC
Design Build	DB
Proposed Tender Price	PTP
Subcontractor	SC
Heating, Ventilation and Air Conditioning	HVAC
Multi Criteria Decision Making	MCDM
Analytical Hierarchy Process	AHP
Analytical Network Process	ANP
Weighted Geometric Mean Method	WGMM

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Chapter - 1

INTRODUCTION

1.1. Study Background

A Major proportion of all construction projects are handled by subcontractors in the building industry (Abbasianjahromi et al., 2013; Muhammad, 2016). The project's success and the main contractors ability to complete the project within the specified duration, cost and quality depends highly on the capability of subcontractors (Mbachu, 2008). Selection of qualified subcontractors is also important for an accurate and realistic bid proposal (Polat, 2016).

EPC contracts have imposed various responsibilities on main contractors. Many clients use design–build (DB) procurement method for complex projects whose popularity is increasing with time and is being adopted by many clients. (Palaneeswaran and Kumaraswamy, 2005). In the construction industry, a large portion of work is subcontracted by contractors who then assumes the role of construction management agents in a project (Grasso et al., 2008; Ng and Tang, 2010; Shash, 1998). Mostly, specialized work is sub-contracted by main contractors because they are not capable of executing specialist tasks e.g HVAC, electrical, automation, plumbing etc (Choudhry et al., 2012). Subcontractors may also perform design services and supply labor, materials and tools (Tam et al., 2011).

Specialty contractors have gained design knowledge through past experience on projects (Gil, 2003). Their knowledge about design can help consultant, contractor and other stakeholders in making better decisions throughout the different stages of a project. A specialist subcontractor can therefore take part in end product design, construction design, or act as a construction management agent (Shafaat et al., 2014).

In the decision making of subcontractor selection, most of the contractors consider price as the most important criteria (Hartmann and Caerteling, 2010). However, following detailed analysis of literature, a multi-parameter approach incorporating multiple criteria is recommended for the selection process because working with unqualified subcontractors may result in inefficiencies and failures (Bailey, 2016). Multiple factors are taken into consideration when subletting work to subcontractors. Usually the most important consideration is the ability of a subcontractor to perform in a project as their performance is crucial to successful project delivery. (Marzouk et al., 2013).

This study will aim to identify key attributes and establish a framework for selection of subcontractors who are responsible for both designing and execution of specialized works.

1.2. Problem Statement

In a construction project, a large proportion of work is subcontracted by main contractors (Abbasianjahromi et al., 2013; Muhammad, 2016). The decision-making process of selecting subcontractors is therefore an important concern of main contractors as it can impact outcomes of project and also result in loss of procurement costs due to selection of less-qualified subcontractors becoming eligible to bid. Improper selection of subcontractors can result in issues during execution of the projects such as poor execution practices of work resulting in reduced quality and delay in project completion (Marzouk et al., 2013).

In the building industry, EPC contractors are responsible for design, procurement & construction. Considering specialized works such as HVAC, electrical & plumbing, it is not feasible for main contractor to hire staff for each specialized task. To keep the overheads to a minimum, contractors depend on the services of subcontractors for specialized tasks such as bid proposal, design and execution of work**.** As there are no established criteria for the selection of Design-Build subcontractors, this study will aim to establish a framework for selection of subcontractors who are responsible for both designing and execution of specialized works.

1.3. Research Objectives

a) To identify and classify key factors for selection of Design-Build subcontractors in EPC/Turnkey contracts through literature review and industry survey.
b) To develop multi-criteria decision-making model for Design-Build subcontractor selection in EPC/Turnkey contracts using AHP method.
c) To validate the model through a case study.

1.4. Relevance to National Needs:

Construction projects in developing countries like Pakistan are prone to multiple challenges in effectively managing projects which ultimately cause a deviation in cost, quality and schedule of a project. A Major proportion of projects are handled by subcontractors in the local building industry. Based on the performance of subcontractors, A contractor is able to deliver the project within time, cost & quality. Due to lack of any formulated framework or tool for effectively prequalifying subcontractors based on a certain criterion, difficulties arise that hinder smooth execution of project and its success. Projects get delayed, costs overrun, quality compromised, resources wasted etc. due to improper selection of subcontractors.

In Pakistan, construction activities provide nearly 14% of total employment to labor and plays a vital role in increasing gross domestic product (FBS 2010). The construction industry contributes in reducing employment and increasing the aggregate economy. In commercial & residential building projects, the practices of subcontracting work are extensively used by contractors. However, the issues regarding the subcontractor selection are rarely acknowledged and addressed.

This study aims to provide a solution to the challenges and management issues that are faced by the contractors of local construction industry due to lack of any systematic framework for prequalifying and awarding a contract to potential subcontractors who are responsible for designing & executing specialist works. By developing a framework, this research would assist local construction professionals to effectively prequalify and award contracts to subcontractors for building projects.

1.5. Advantages

1. Factors influencing DB subcontractor selection will be identified.
2. Model for selection of DB subcontractors will be available to the construction Industry.
3. Model developed could remove or reduce the risk of subletting work, and could result in better project delivery in the construction.

1.6. Areas of Application

The model for DB subcontractor selection will be applicable to small and large building construction projects where the subcontractor will be required to design & execute specialist works ranging from a residential building to a multi-story commercial & industrial building. Moreover, this approach not only applies to private sector projects but also for public sector projects where EPC/Turnkey contracts are awarded.

1.7. Thesis Organization

This research contains five chapters and their overview has been given below.

Chapter 1 is "Introduction" which includes problem statement of the research topic and shows its significance. The scope of study has been finalized in the form of research objectives and background of the study is also discussed in detail.

Chapter 2 is "Literature Review" which includes definitions and explanation of subcontractor types and design build subcontractors' responsibilities in an EPC/turnkey contract. Previous research studies which have focused on developing subcontractor models is also discussed.

Chapter 3 is "Research Methodology" which explains the step by step methodology adopted for this research. Multi criteria decision making technique and analytical hierarchy process which has been used in this research are discussed in detail.

Chapter 4 is "Results and Discussion" which includes data analysis, model for design-build subcontractor selection and case studies for model validation.

Chapter 5 is "Conclusions and Recommendations" which summarizes the results of this study and also provide recommendations for future research.

Chapter - 2

LITERATURE REVIEW

2.1 Introduction

This chapter presents summary of various past studies, engineered procurement & construction contracts, Multi criteria decision making (MCDM), the concept of specialty subcontractors and selection criteria of subcontractors. It further explains the role of specialty subcontractors and their need in EPC contracts.

2.2 Engineered, Procurement & Construction Contract

In the growing construction industry, the project delivery method of EPC has been widely used for construction projects (Piper, 2011).

In EPC project delivery method, contractors work with designers & specialist subcontractors to combine their efforts and deliver a successful construction project under their responsibility for both design works and execution works. EPC contracts are popular particularly for its innovation in design, construction method/technology, reduced administration burden and a guaranteed performance (Engineer, 2013; Forbes and Ahmed, 2010; Kramer and Meinhart, 2004). Like any other project delivery method, EPC has some weakness too. The cost of project may change as the project design & construction evolves. The contractor is solely responsible for the project thus all the projects risks fall over his shoulders which may lead to higher costs due to uncertainty. Another issue with respect to the employer is that he has less control over design (Forbes and Ahmed, 2010; Piper, 2011). As the project's risks are high due to associated risks, it makes very challenging for the employer to select an appropriate contractor.

Therefore, EPC delivery method demands a detailed strategy for the selection of contractor based on his performance on previous projects. This process encompasses many decisions parameters such as clients objectives and contractor attributes (Edwards and Holt, 2010).

2.3 Subcontractor Types

In construction projects, contractors sublet large proportion of work to subcontractors and work as construction management agents (Abbasianjahromi et al., 2013; Shash, 1998). In the construction industry, the act of subcontracting of work is long-established which provides flexibility in the supply chain of construction. (Luu and Sher, 2006)

The three categories of subcontractors are as follow:

i. Labor only subcontractors such as skilled tradesmen
ii. Specialist subcontractors who undertake special tasks such as engineers
iii. Trade subcontractors who specializes in specific trade such as shuttering, painting etc.

2.4 Traditional Procurement Approach

A Major proportion of all construction projects are handled by subcontractors in the building industry (Abbasianjahromi et al., 2013; Muhammad, 2016). The project's success and the main contractors ability to complete the project within specified duration, cost and quality depends highly on the capability of subcontractors (Mbachu, 2008). The project's success in terms of performance is measured by time, cost and quality. These project performance components were initially identified by (Atkinson, 1999).

The traditional approach in construction projects which has been carried out for decades is the low bid approach which is only focused on the price of the bid and is usually regarded as the winning strategy (San Cristóbal, 2012; Walraven and de Vries, 2009). The contract is usually awarded to the subcontractor based on lowest price without considering several other important criteria in prequalification stage.

This results in project delivering problems such as financial loses, delays in time and poor quality (Darvish et al., 2009). To secure more profit, contractors are encouraged to award the contract based on lowest cost is to secure more profit.

In contracts, where the employer takes the responsibility of design and the contractor is given the responsibility for execution, the risk of awarding work to subcontractors without prequalification is far less compared to an engineered procurement & construction contract. In EPC contracts, the contractor sublets the specialty works to design-bid subcontractors who are responsible for both design and execution. If the selection of subcontractor in this case is made without prequalification, the risk of improper design can contribute to project's failure.

2.5 Specialty subcontracting

The demand for safer, healthier, sustainable & cost-effective facilities are forcing people to come up with new methods and technologies that are being introduced into building industry as a new trade of specialist work such as HVAC systems, automation system, prefabrication building etc. This demand has increased the contribution of specialist subcontractors in design stage of a construction project (Gray and Flanagan, 1989). These specialist works are usually outside the capability of general contractors and is also uneconomical for them to undertake. These tasks require proper coordination and involve interfacing connection with other trades of building work (Olsson and Berndtsson, 1998). The contribution of subcontractors with specialist knowledge is very important to the building industry and is not limited to manufacturing or supply & fix activities (Gray and Flanagan, 1989) and in turns create demand for selection of suitable subcontractor which is typically procured through subcontracting.

For execution of work in the most economical manner, the main contractor divides the activities of a construction project into parts consisting of specialist trades and subcontracts the part of works to several specialist subcontractors who have the upper hand in the specific trade. The comparative advantage of a specialist subcontractor is solely based on their knowledge and skills in their specific trade which may include design knowledge, management of execution activities efficiently and knowledge about procuring equipment from the right place (Cheung et al., 2002).

The benefits of subletting work for the main contractor is that his burden of management of specialist works & organizing parts of the production are shared by subcontractors. The main contractor then takes on the responsibility of management to ensure execution of activities swiftly as per construction schedule to avoid delays and increase in overhead costs.

2.6 Multi Criteria Decision Making

Selection of subcontractors is a complicated multi-criteria decision-making problem in which the decision making panel evaluates the ability of the subcontractor's to execute the project successfully against several decision criteria (Plebankiewicz, 2012; Singh and Tiong, 2005).

Among the popular multi-criteria methods, This technique uses several criteria & factors for a decision problem (Cheng and Li, 2004). Complex projects with higher requirements have demanded the use of MCDM technique for contractor/subcontractor selection (San Cristóbal, 2012). Several MCDM techniques can be used to perform a detailed evaluation and are broadly classified in terms of Multi-Objective Analysis (MOA) and Multi- Attribute Analysis (MAA) (Cheng and Li, 2004).

MCDM method typically follows the sequence below:

1. Identifying the goal/objectives which should be specific, agreed, realistic, measurable and time dependent.
2. Identifying the possibilities for achieving the goal.
3. Identifying the criteria and factors that will be used to compare the possibilities which should be measurable and should reflect the performance in meeting objectives.
4. Analysis of the options by giving them preference/weightages
5. Making the decision by selection of an option (Subcontractor)

2.7 Subcontractor Selection & Prequalification Criteria

A Major proportion of all construction projects are handled by subcontractors in the building industry (Abbasianjahromi et al., 2013; Muhammad, 2016). The performance of the project and repute of the main contractor depends largely on the subcontractor's performance in terms of cost, time and quality. As the performance of subcontractors effect the overall performance of projects, it is of prime importance to add value creation attributes into prequalification and subcontractor selection model to achieve success. The prequalification of subcontractors with specialist knowledge and skills in specific trade is very important. Selection of subcontractor involves decision making on an extensive range of criteria compromising of both subjective and qualitative information. After successful prequalification of a subcontractor, it is essential to identify the selection award criteria which could be made possible with the existence of a model.

An organization may have an array of differing prequalification attributes or intuition-based approach towards prequalification. (Abbasianjahromi et al., 2013) in his research states that prequalification can be approached in two ways. One is to introduce field managers who identify subcontractors based on their past experience with them on projects or the other way is through bidding process.

(Arslan et al., 2008) proposed a web-based subcontractor evaluation system called WEBSES by which evaluation of the subcontractors is done based on a combined criterion. This model helps the contractor to save time and select the most appropriate subcontractor during the bidding process.

(Abbasianjahromi et al., 2013) proposed a model to be used for selection the of subcontractors based on the fuzzy preference selection index. This method did not require weighting of criteria and factors which in turn would save time and cost in the subcontractor evaluation and selection.

(Polat, 2016) purposed a subcontractor selection method using an integrated decision approach in which he used analytical hierarchy process to determine the priorities of the criteria and factors. To perform sensitivity analysis, another technique known as PROMETHEE can be used which works by changing the weights of the attributes.

In another research, the author proposed a multi criteria decision-making model for subcontractor selection based on Kano and fuzzy TOPSIS. The framework developed provides a step by step approach to identify the criteria which can be used for the selection of subcontractors (Abbasianjahromi et al., 2018).

(Mbachu, 2008) surveyed main contractors and subcontractors using multi-attribute techniques for analyzing data. He found out that the most important attribute for prequalification of subcontractor was keeping quality record and the most important criteria in case of contract award was tender price. Based on his research, he proposed a framework for evaluating subcontractors.

(Ulubeyli and Kazaz, 2016) proposed a subcontractor selection model (CoSMo) using fuzzy sets method as it eliminates the subjective assessment of human judgment and helps in modeling it by means of linguistic values. This model can be used as an advisory system by main contractors to minimize risk involved in the process of subcontractor selection.

2.8 Attributes for Selection of Design-Build Subcontractors

Based on literature review regarding subcontractor and design consultant selection, 48 factors were identified which can be used for selection of design build subcontractors which compromises of both design & execution related factors. The sources included "Science Direct", "ASCE", "Emerald Insight" etc. Research publications from different journals of construction engineering and management published between the years 2000-2019 have been studied. The reason of selecting this period was to study the criteria and attributes that are relevant in this period. The identified attributes have been shown in Table 2.1.

Table 2.1: Identified Factors with their references

Sr. No.	Factors	References
1	Past Experience	(Abbasianjahromi et al., 2013) (Gransberg, 2010) (Polat, 2016)
2	Plant & Equipment	(Abbasianjahromi et al., 2013) (Mbachu, 2008) (Marzouk et al., 2013)
3	Key Personnel Experience	(Marzouk et al., 2013) (Gransberg, 2010) (Polat, 2016)
4	Credit Rating	(Alzahrani and Emsley, 2013) (Abbasianjahromi et al., 2013)
5	Working Capital	(Doloi, 2009) (Ng and Skitmore, 1999)
6	Yearly Turnover	(Doloi, 2009) (El-Sawalhi et al., 2007) (Alzahrani and Emsley, 2013)
7	Financial References	(Marzouk et al., 2013) (Talukhaba and Mapatha, 2007)

8	Debt Ratio	(El-Sawalhi et al., 2007)
9	Liquidity	(El-Sawalhi et al., 2007)
10	Profitability	(El-Sawalhi et al., 2007)
11	Timely payment to labourers	(Abbasianjahromi et al., 2013) (Xia et al., 2009) (Ng et al., 2008)
12	Completion of job within the budget	(Marzouk et al., 2013) (Al-Reshaid and Kartam, 2005) (Alzahrani and Emsley, 2013)
13	Past Performance	(Abbasianjahromi et al., 2013) (Polat, 2016) (Ulubeyli and Kazaz, 2016)
14	Experience in the region	(Doloi, 2009) (Marzouk et al., 2013) (Alzahrani and Emsley, 2013)
15	Current Workload & Commitment	(Marzouk et al., 2013) (Mbachu, 2008) (Polat, 2016)

16	Location of subcontractor office	(Ulubeyli and Kazaz, 2016) (Dissanayake, 2017) (Talukhaba and Mapatha, 2007)
17	Quality Performance	(El-Sawalhi et al., 2007) (Abbasianjahromi et al., 2013)
18	Personnel Training	(Abbasianjahromi et al., 2013) (Doloi, 2009) (Marzouk et al., 2013)
19	Quality Control	(Chan et al., 2002) (Dissanayake, 2017) (El-Sawalhi et al., 2007)
20	Quality Assurance	(Nazari et al., 2016) (Al-Reshaid and Kartam, 2005) (Palaneeswaran and Kumaraswamy, 2000)
21	Ability to complete work on time	(Polat, 2016) (Abbasianjahromi et al., 2013) (El-Sawalhi et al., 2007)
22	No of Technical & administrative staff availability	(Dissanayake, 2017) (Polat, 2016) (Abbasianjahromi et al., 2013)
23	Adequacy of labour & Material resources	(Ulubeyli and Kazaz, 2016) (Marzouk et al., 2013) (Doloi, 2009)

24	Qualification of key personnel	(Dissanayake, 2017) (Sporrong, 2011) (Xia et al., 2009)
25	Safety consciousness on the job site	(Abbasianjahromi et al., 2013) (Marzouk et al., 2013) (Mbachu, 2008)
26	Experience modification rating	(Abbasianjahromi et al., 2013)
27	OSHA incident rate	(Abbasianjahromi et al., 2013)
28	Management safety accountability	(Abbasianjahromi et al., 2013) (Mbachu, 2008) (El-Sawalhi et al., 2007)
29	Site safety Records	(Ulubeyli and Kazaz, 2016) (Alzahrani and Emsley, 2013) (Doloi, 2009)
30	Safety initiative records	(Ulubeyli and Kazaz, 2016) (Doloi, 2009) (Talukhaba and Mapatha, 2007)
31	Jobsite cleanliness	(Marzouk et al., 2013)

32	Past Success	(Abbasianjahromi et al., 2013) (Marzouk et al., 2013) (Sporrong, 2011)
33	Length of time in business	(Nazari et al., 2016) (Abbasianjahromi et al., 2013) (Sporrong, 2011)
34	Relationship with main contractor	(Polat, 2016) (Abbasianjahromi et al., 2013) (Mbachu, 2008)
35	Proposed tender price	(Ulubeyli and Kazaz, 2016) (Marzouk et al., 2013) (Doloi, 2009)
36	Tender Quality	(Marzouk et al., 2013) (Doloi, 2009)
37	Time accuracy in submitting bids	(Abbasianjahromi et al., 2013) (Doloi, 2009)
38	Methodology	(Xia et al., 2009) (Doloi, 2009) (El-Sawalhi et al., 2007)
39	Litigation History	(Ulubeyli and Kazaz, 2016) (Chan et al., 2002) (El-Sawalhi et al., 2007)

40	Creative and innovative ability	(Nazari et al., 2016) (Sporrong, 2011) (El-Sawalhi et al., 2007)
41	Approach to design process	(El-Sawalhi et al., 2007) (Xia et al., 2009)
42	Life cycle costs	(Sporrong, 2011) (El-Sawalhi et al., 2007) (Luu et al., 2005)
43	Compliance and understanding to client's brief	(Dissanayake, 2017) (Nazari et al., 2016) (Chow and Ng, 2007)
44	Quality of drawings	(Lopez del Puerto et al., 2008) (Chow and Ng, 2007)
45	Project risks being effectively covered in the design	(Chow and Ng, 2007)
46	Adequacy of cost estimate	(Chow and Ng, 2007)
47	Technology used	(Palaneeswaran and Kumaraswamy, 2000)
48	Company License for design in respective category	(Al-Reshaid and Kartam, 2005)

2.9 Grouping of Identified Factors

Out of the 48 factors identified through literature review that have significance in the process of design build subcontractor selection are shown in Table 2.1. To group these factors into categories, further literature was reviewed and these factors were grouped into 8 main criteria. Based on previous relevant research & available literature, main criteria are developed. The 48 attributes are now termed as sub-criteria. Based on quantitative and qualitative analysis as described in chapter 4, the attributes were reduced to 25. Criteria and their attributes are shown in Table 2.2.

Table 2.2: Grouping of Factors

Sr. No.	Main Criteria	Factors
1	Management & Technical Ability	Past Experience
		Past Performance
		Plant & Equipment
		Current Workload & Commitment
		Ability to complete work on time
2	Financial Soundness	Working Capital
		Yearly Turnover
3	Cost	Proposed Tender price
		Adequacy of cost estimate
		Completion of job within budget
4	Human Resource	Qualification of key personnel
		Key Personnel Experience
		Adequacy of labor resources

		No of Technical & administrative staff availability
5	Quality	Quality Performance
		Quality Control
		Quality Assurance
6	Reputation	Past success in projects
		Length of time in business
		Relationship with main contractor
7	Design Aspects	Methodology
		Approach to design process
		Compliance and understanding to client's brief
		Quality of drawings
		Project risks being effectively covered in the design
		Project risks being effectively covered in the design

Chapter - 3

RESEARCH METHODOLOGY

3.1 Introduction

The research technique being used to achieve the specified objectives is analyzed and presented in this chapter. The research methodology shows how researchers are going to carry out their studies step by step to achieve their research objectives (Saunders et al., 2007). There are several techniques which will be used to carry out this research to fulfill certain objectives. This research includes detailed literature review, preliminary survey, semi-structured interviews & questionnaire survey, use of Analytical hierarchy process as a multi criteria decision making technique, development of a model for selection of design-build subcontractors and validation of model through case studies.

3.2 Research Design

To achieve the said objectives of this research, a comprehensive research methodology is adopted which is explained in detail as under:

3.2.1 Identification of Factors for Selection of Design-Build Subcontractors

The first phase of this research is to identify key factors which would help the main contractors in selection of design-build subcontractors. In this phase, key prequalification factors for selection of subcontractors & design consultants were identified through detailed literature review. The reason for identifying prequalification factors of design consultants is to cater for the design requirement of design-build subcontractors. After detailed literature review, A total of 128 factors were identified. Owing to overlapping of factors, the factors were reviewed and shortlisted to 48.

3.2.2 Content Analysis

The short-listed factors were analyzed using content analysis technique to access qualitative and quantities score. Quantitative scores of these factors were based on their frequency of occurrence in literature and qualitative scores were based on the level of influence of each factor. Content analysis was performed in order to remove the less significant factors (Hsieh and Shannon, 2005).

3.2.3 Preliminary Survey

After shortlisting of factors from literature, A questionnaire survey was developed to take expert opinion on the priority of these factors for selection of design-build subcontractors. Questionnaire survey was distributed to industrial professionals having experience of over 6 years. In result, 30 responses were collected. The questionnaire was based on a 5-point Likert scale (1 = Not important, 2 = Slightly Important, 3 = Moderately Important, 4 = Important, 5 = Very Important). Different weighting ratios of 80/20, 75/25, 70/30 & 60/40 to field experts & literature respectively were statically tested using rank correlation & one-way ANOVA. The correlation values ranging between 0.7-0.9 and p-value of 0.9 suggest that there is no significant difference between various decision weight combinations (Ahmad et al., 2018). Giving more significance to industry professionals, a 60/40 weighting split was used to select 25 factors based on over 60% cumulative normalized score.

3.2.4 Main Survey- Questionnaire

After having shortlisted the 25 attributes, a questionnaire is developed with the main objective of calculating the weightages of attributes in decision making process of design build subcontractor selection. A multi criteria decision making technique is employed due to its significance in solving complex problems that cannot be solved directly. For this purpose, Analytical Hierarchy Process is used which is a mathematical decision-making technique used to solve problems that are complex and ambiguous (Yang and Huang, 2000). This technique was introduced by (Saaty, 2008) which helps in disintegrating problems into a hierarchy of criteria and sub-criteria with the help on comparative analysis.

3.2.5 AHP Introduction

Analytical hierarchy process is a technique which is used to structure and analyze a complex decision problem by establishing a step wise decision model in order to achieve the goal. This process includes qualitative and quantitative components.

The qualitative part includes disintegrating a complex problem into several clusters & sub clusters starting from the goal which is on the top to a set of alternatives which is at the bottom of the hierarchy. The quantitative part includes the pair-wise comparison of the attributes in clusters or sub clusters that may include criteria, sub criteria, activities, objectives etc. The purpose of pair wise comparison is to assign weights to the attributes of a cluster or sub cluster to calculate the local weights & global weights of the attributes. The relative importance is measured by using a ratio scale of 1 to 9 which measures the relative strength of the attributes within a cluster. One of the main benefits of using this technique is that it calculates the consistency ratio of the data to verify that the matrices formed are appropriate for analysis (Saaty, 1988).

AHP assumes that the relationship between clusters is unidirectional along different decision levels of the hierarchy and uncorrelated between clusters & elements within each cluster or sub cluster. If a model specifies interdependent relationships, AHP model will not suitable for it. For this purpose, Analytical Network Process is used which is an enhanced version of this tool.

3.2.6 AHP Methodology

This study focuses on the selection of a suitable design build subcontractor by an EPC contractor which can be achieved by the prioritization of the selection attributes in decision making process. As there are more than one criteria for the selection purpose, multi criteria decision making technique is used which is beneficial to solving complex problems. MCDM is only used when there are several criteria or sub criteria for decision making to select the most appropriate or suitable alternative (Cheng et al., 2005).

As the selection of a design build subcontractor is complex, it becomes challenging for the decision maker to come to a conclusion when making the choice for the selection of the best alternative. To address this issues, Analytical hierarchy process is used which is a mathematical decision-making technique developed by (Saaty, 2008) to solve such problems. Using this technique, complex problem is disintegrated into a hierarchy of criteria & sub criteria which is then followed by a comparative analysis to determine the weightages (Saaty, 1988). When the complex problem is disintegrated, it results into four levels of hierarchy with the top-level being the goal or objective. The second & third level of hierarchy as criteria & sub criteria followed by the last level as alternatives. The next step is to perform a comparative analysis to calculate the weightages of criteria & sub criteria. These priorities are then used to develop a model and help in selection of the most suitable alternative. This methodology is provided in the current literature which shows how to use this technique for calculation of priorities and ranking of criteria and their attributes (Chin and Pun, 2002).

3.2.7 AHP Steps

There are 7 steps of AHP technique which are described as follow:

Step 1:

The first step is to define the goal or objectives of the problem clearly.

Step 2:

The complex problem is decomposed into a hierarchy which consists of goal, criteria and sub criteria with the help of a decision-making technique.

Step 3:

In the third step, the decision makers perform pairwise comparison of criteria and sub criteria on a nine-point scale (1-9) through which a decision matrix is constructed (Saaty, 1994). The scale is shown in table 4.3. In the hierarchy, the factors listed under the node are compared with other factors of the same node. For example, if there are "n" factors under a node, then there will be n(n-1)/2 comparisons that will take under the same node.

Pairwise comparison of the factors resulting in their relative weights are shown in the form of a matrix. Let there be Y_1, Y_2, Y_3, ….. Y_n factors under a node "N" and their weights be W_1, W_2, W_3, …. W_n. Their comparison matrix "Z" (n x n) will represent their pairwise comparison among the factors Y_1, Y_2, Y_3, ….. Y_n

$$
Z = \begin{array}{c} \\ Y_1 \\ Y_2 \\ Y_3 \\ Y_n \end{array}
\begin{array}{c}
\begin{array}{cccc} Y_1 & Y_2 & Y_3 & Y_n \end{array} \\
\left|\begin{array}{cccc}
W_1/W_1 & W_1/W_2 & W_1/W_3 & W_1/W_n \\
W_2/W_1 & W_2/W_2 & W_2/W_3 & W_2/W_n \\
W_3/W_1 & W_3/W_2 & W_3/W_3 & W_3/W_n \\
W_n/W_1 & W_n/W_2 & W_n/W_3 & W_n/W_n
\end{array}\right|
\end{array}
$$

$$
Z = \begin{array}{c} \\ Y_1 \\ Y_2 \\ Y_3 \\ Y_n \end{array}
\begin{array}{c}
\begin{array}{cccc} Y_1 & Y_2 & Y_3 & Y_n \end{array} \\
\left|\begin{array}{cccc}
b_{11} & b_{12} & b_{13} & b_{1n} \\
b_{21} & b_{22} & b_{23} & b_{2n} \\
b_{31} & b_{32} & b_{33} & b_{3n} \\
b_{n1} & b_{n2} & b_{n3} & b_{nn}
\end{array}\right|
\end{array}
$$

Where Bij = Wi/Wj (I,j = 1, 2, … n) which represents the priorities resulting from comparative analysis among the pair of factors Yi and Yj. If i=j & bij = 1 then bji = 1/bij for bij>0.

Step 4:

In this step, the priority weights of the factors are calculated through maximum eigenvectors and eigenvalues (Saaty, 1994).

$$\boldsymbol{\lambda max} = \sum_j^i bij \frac{Wj}{Wi}$$

Step 5:

After calculating the relative weights of the factors, the next step is to check the consistency of the matrix. The inconsistency of the pairwise comparison is calculated by consistency index (CI) and coherence is calculated by the consistency ratio (CR). The formula for the computation of consistency index is as follow:

$$\mathrm{CI} = (\lambda\max - n) / (n - 1)$$

Where "n" is the rank of matrix.

After measuring the consistency index, consistency ratio is computed with the help of the given formula:

$$CR = CI/RI$$

Where 'RI' is the random index whose value depends on the rank of matrix. The value of RI is depicted in table 3.1 for corresponding values of 'n' (Saaty, 1994). The acceptable value of consistency ratio is 0.1 (Saaty, 1994). If the value is more than 0.1, the matrix formed as a result of pairwise comparison is inconsistent and discarded.

Table 3.1: Random Index Value's

N	2	3	4	5	6	7	8	9
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Step 6:

In the previous step, Priority weights of the factors were calculated which are local weights of the factors. In this step, global weights of all factors are calculated with respect to the goal defined in the AHP model.

Step 7:

After obtaining local weights of the factors, they are arranged in the decreasing order according to their global prioritization.

3.2.8 Super Decisions

This software uses the AHP and ANP technique for decision making and was developed by Dr. Thomas Saaty. This software helps the user in making dependence model to achieve the desired goal. These techniques follow the same method for prioritization of criteria and sub-criteria (Adams and Saaty, 2003).

In this study, this software will be used for developing hierarchy network, questionnaire survey, calculation of priority weights of factors and model validation by helping the user in deciding the best alternative.

Chapter 4

RESULTS AND ANALYSIS

4.1 Introduction

The results of preliminary and final questionnaire surveys are explained in this section followed by a detailed analysis of the outcome. AHP model is presented for selection of design build subcontractor in an EPC contract. Afterwards, the model is validated with the help of case studies.

4.2 Preliminary Survey

The reason for conducting preliminary survey was to take input of the construction industry by circulating the questionnaire survey among industry professional's and take their valuable input before performing content analysis. 30 responses were collected from industry professionals with over 6 years of experience.

As a result of the preliminary survey, 48 factors that were extracted from literature were ranked by field experts on a 5-point Likert scale. Average score of factors obtained from the survey are shown in table 4.1

Table 4.1: Preliminary survey results

Sr. No.	Factor	Average Score
1	Past Experience	4.73
2	Plant & Equipment	3.77
3	Key Personnel Experience	4.70
4	Credit Rating	3.50
5	Working Capital	3.73
6	Yearly Turnover	3.17
7	Financial References	3.60
8	Debt Ratio	2.83
9	Liquidity	2.97

10	Profitability	2.93
11	Timely payment to laborer's	3.63
12	Completion of job within the budget	4.33
13	Experience in the region	3.20
14	Current Workload & Commitment	4.03
15	Location of subcontractor office	2.97
16	Quality Performance	4.10
17	Personnel Training	3.80
18	Quality Control	4.13
19	Quality Assurance	3.90
20	Ability to complete work on time	4.67
21	Number of experienced technical & supervisory staff	4.17
22	Adequacy of labour	4.57
23	Qualification of key personnel	4.27
24	Safety consciousness on the job site	3.63
25	Experience modification rating	2.57
26	OSHA incident rate	2.57
27	Management safety accountability	3.00
28	Site safety Records	2.73
29	Safety initiative records	2.40
30	Jobsite cleanliness	2.67
31	Past Success	4.27
32	Length of time in business	4.03

33	Relationship with contractor	4.63
34	Proposed tender price	4.43
35	Tender Quality	3.83
36	Time accuracy in submitting bids	3.30
37	Methodology	3.73
38	Litigation History	2.57
39	Creative and innovative ability	3.73
40	Approach to design process	4.30
41	Life cycle costs	2.73
42	Compliance and understanding to client's brief	4.80
43	Quality of design & drawings	4.60
44	Project risks being effectively covered in the design	4.17
45	Adequacy of cost estimate	4.27
46	Company License for design in respective category	4.53
47	Past Performance	4.67
48	Technology Used	3.80

4.2.1 Shortlisting of factors

After analyzing the results from preliminary survey, literature score & survey score was combined using a 60/40 weighting split to select top 25 factors from a total of 53 factors. Data received from the field experts through preliminary survey was given more priority compared to literature because data received from the field experts was up to date whereas factors extracted from literature were published between the years 2000-2019.

Factors were shortlisted based on over 60% cumulative normalized score which is shown in table 4.2.

Table 4.2: Cumulative normalized score of factors

Sr. No.	Factors	Abbreviation	Normalized score (60/40)	Cumulative Score
1	Key Personnel Experience	KPE	0.031	0.031
2	Past Experience	PE	0.030	0.062
3	Past Performance	PP	0.029	0.091
4	Relationship with the contractor	RWC	0.029	0.120
5	Ability to complete work on time	ACWT	0.027	0.146
6	Adequacy of labour	AOL	0.026	0.173
7	Proposed tender price	PTP	0.026	0.199
8	Working Capital	WC	0.025	0.224
9	Number of technical & administrative staff availability	NTAS	0.025	0.249
10	Quality Control	QC	0.025	0.274
11	Compliance and understanding to client's brief	C&U	0.024	0.298
12	Qualification of key personnel	QKP	0.023	0.321
13	Completion of job within the budget	CJWB	0.023	0.343
14	Quality Assurance	QA	0.023	0.366
15	Past success	PS	0.022	0.388
16	Length of time in business	LTB	0.022	0.410
17	Plant & Equipment	P&E	0.022	0.432
18	Quality of drawings	QD	0.022	0.454
19	Approach to design process	ADP	0.021	0.475

20	Methodology	MD	0.021	0.496
21	Current Workload & Commitment	CW&C	0.021	0.517
22	Yearly turnover	YT	0.021	0.538
23	Adequacy of cost estimate	ACE	0.020	0.558
24	Quality Performance	QP	0.019	0.577
25	Project risks being effectively covered in the design recommendations	PRCDR	0.019	0.596

4.3 Spearman's Rank Correlation test

Spearman's rank correlation test is a statistical method which is used to identify and test the relationship's strength between any 2 data sets for approving or disapproving a hypothesis.

The formula used for its calculation is as follow:

$$r = 1 - \frac{6£\mathrm{d}^2}{n^3 - n}$$

Where r = spearman's co-efficient

d = rank difference

n = number of samples

After using the above equation, the value of 'r' comes out to be 0.716. To verify if the 'r' value is significant, the spearman's rank graph is used which can be seen in figure 4.1.

As shown in the figure, the black line meets the red line at 1% significance level meaning that there is around 99% chance that the relationship between ranking from literature and from survey is significant.

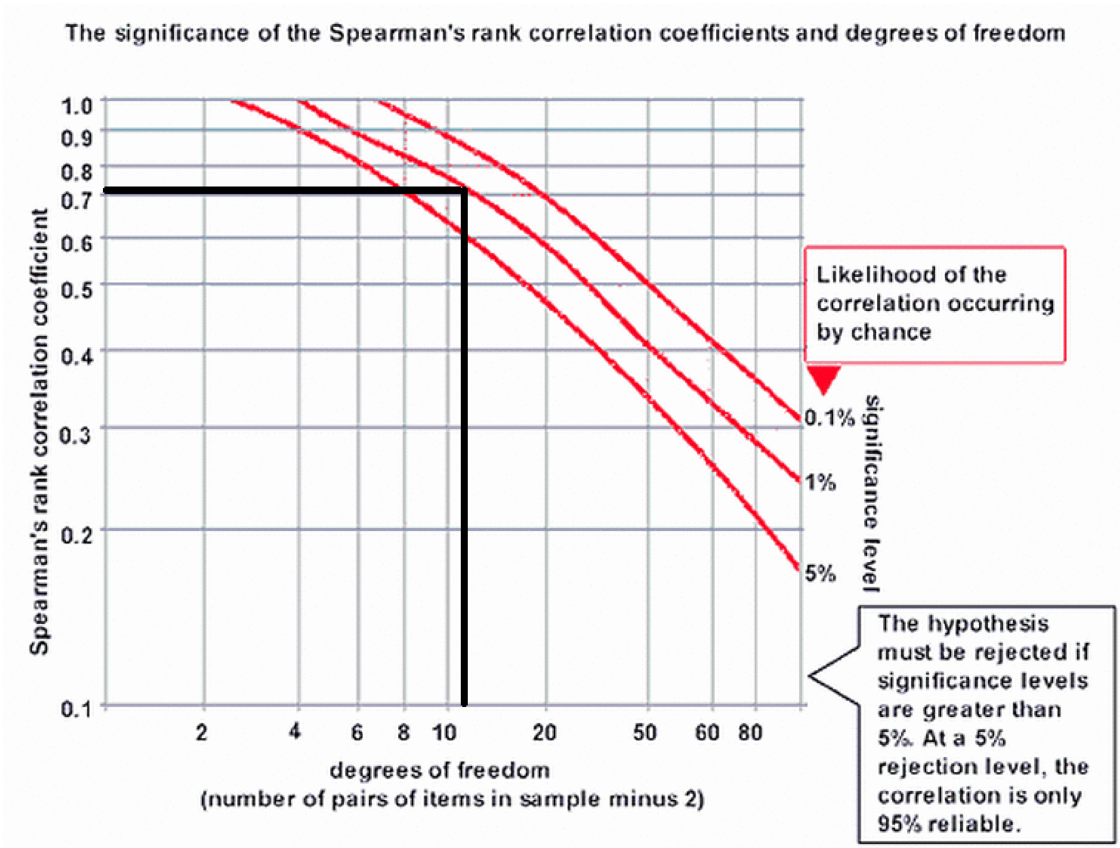

Figure 4.1: Spearman Rank Correlation Graph (Sen and Mamtani, 2006)

4.4 Prioritization of design build factors for subcontractor selection

The first step is to develop a hierarchy structure of the problem by defining the goal of the study followed by the related criteria and sub-criteria. Hierarchy structure can have several levels depending upon the nature of problem and managerial decision. A hierarchy structure of the problem can be developed by creative thinking, recollection and use of people's perception (Saaty, 2000).With the help of guidelines recommended by (Saaty, 2000), a hierarchical structure is formed to accomplish the goal of the study for which AHP technique will be used to calculate the priorities of factors. Figure 4.2 shows the hierarchy structure based on AHP. For data gathering, random sampling might be the most efficient choice to gather responses that would represent the population (Stenhouse, 1980). However, due to limited subject matter experts (SME) in the local construction industry, it was best considered to adopt judgmental and snowball sampling to gather as much data as possible on the subject (Dissanayake, 2017; Kim et al., 2018).

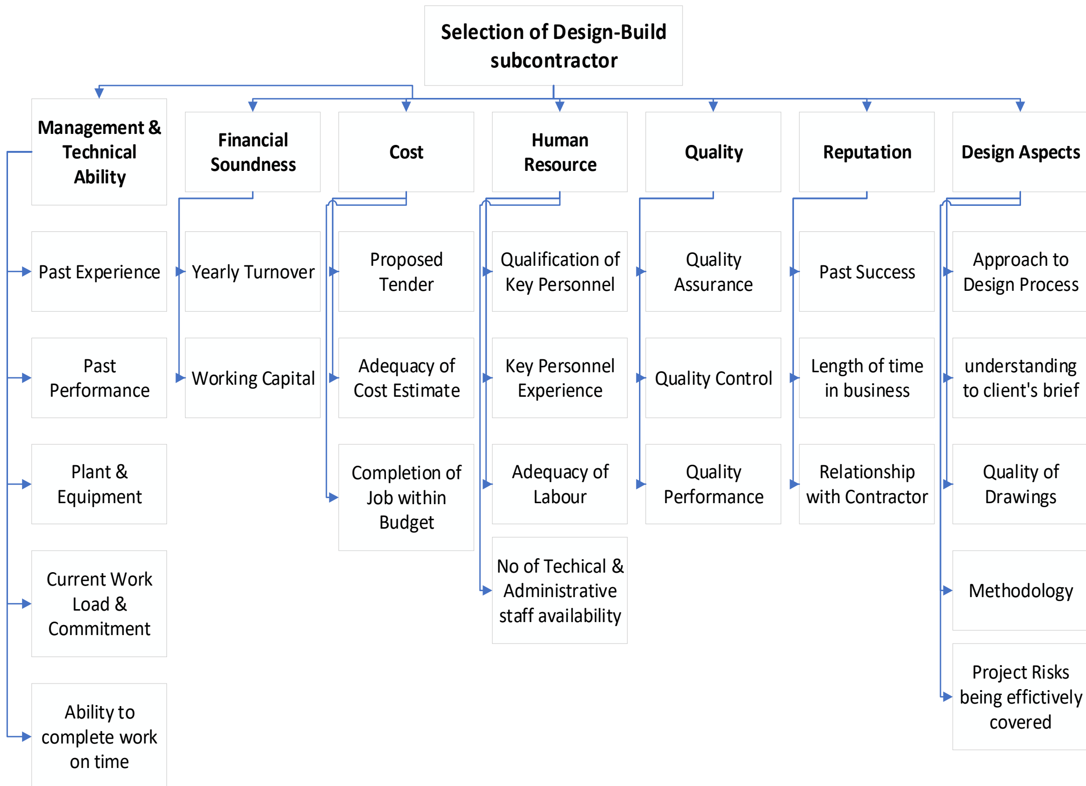

Figure 4.2: An AHP based model for selection of design-build subcontractor in EPC contract

4.4.1 Approach of Assigning Weightages

As it can be seen in figure 4.2, respondents are required to compare the criteria with one another and sub criteria with each other under a single node. After the respondent assign relative weights to factor's, a comparison matrix is formed which shows the priority of factors in relative terms. A nine-point scale proposed by (Saaty, 1988) is used for assigning values to factors to show their relative importance with respect to another factor keeping the goal in mind. The relative scale is shown is figure 4.3. A matrix is formed as a result of pairwise comparison where diagonal values are equal to 1 and other factors have a reciprocal value. For example, if factor 'i' is "q times" important than another factor 'j', then factor 'j' is "1/q times" important than factor 'i'.

Table 4.3: Scales of comparison

Explanation	Numeric Values
If both factors are equally important	1
If one factor is moderately more important than the other	3
If one factor is strongly more important than the other	5
If one factor is very strongly more important than the other	7
If one factor is extremely more important than the other	9
Intermediate values	2, 4, 6, 8

4.4.2 Aggregation of Responses

Generally, the response of a person varies from one another due to their opinion build on the basis of their experience. In group decision making, there are several decision makers who may consider some factors important or less important and rate them differently as compared to others. Therefore, it is important to reach consensus based on a method (Dong et al., 2010).

Once the responses from 64 construction industry professionals were received, the next step was to reach consensus of pair wise comparisons. Among several techniques for aggregation of responses, one of the most popular technique is the weighted geometric mean method (WGMM). (Aczél and Saaty, 1983; Benjamin et al., 1992; Saaty and Kearns, 2014; Willett and Sharda, 1991).

To reach consensus, weighted geometric mean of the responses was calculated for criteria and sub criteria pairwise comparisons (Xu, 2000).

4.4.3 Pairwise Comparison of Criteria

To determine the weightages of criteria for selection of design build subcontractor, the seven criteria are compared with each other and their priorities are calculated. The matrix formed as a result of pairwise comparison is shown in table 4.4.

Table 4.4: Pairwise comparison of criteria

	Design Aspect	Financial soundness	Cost	Human Resource	Quality	Reputation	Management &Technical ability
Design Aspect	1.00	2.84	0.89	0.80	1.64	0.82	0.69
Financial soundness	0.35	1.00	0.31	0.42	0.44	0.33	0.36
Cost	1.12	3.23	1.00	1.90	1.40	1.20	1.19
Human Resource	1.24	2.37	0.53	1.00	1.62	1.02	0.86
Quality	0.61	2.26	0.72	0.62	1.00	0.61	0.63
Reputation	1.22	3.06	0.83	0.98	1.63	1.00	0.87
Management &Technical ability	1.44	2.79	0.84	1.17	1.58	1.14	1.00

4.4.4 Pairwise Comparison of Sub Criteria

The subcontractor selection attributes grouped into 7 main criteria are compared in a similar pairwise comparison manner as discuss above. All attributes under a single node are compared to determine their priority weightages.

The criteria and their attributes are shown in Table 2.2. The pairwise comparison matrix of design aspect, management & technical ability, financial soundness, cost, human resource, quality & reputation attributes are shown in table 4.5, 4.6, 4.7, 4.8, 4.9, 4.10 and 4.11 respectively.

Table 4.5: Pairwise comparison of "Design Aspect" attributes

	ATDP	C&U	QD	MD	PRCDR
ATDP	1.00	0.38	0.51	0.58	0.68
C&U	2.62	1.00	1.42	1.83	1.75
QD	1.95	0.70	1.00	1.51	1.68
MD	1.72	0.55	0.66	1.00	1.36
PRCDR	1.46	0.57	0.59	0.74	1.00

Table 4.6: Pairwise comparison of "Management & technical ability" attributes

	PE	PP	P&E	CW&C	ACWT
PE	1.00	0.81	0.88	1.53	1.11
PP	1.23	1.00	1.40	1.83	1.65
P&E	1.14	0.71	1.00	1.36	1.43
CW&C	0.65	0.55	0.74	1.00	0.77
ACWT	0.90	0.60	0.70	1.30	1.00

Table 4.7: Pairwise comparison of “Financial Soundness” attributes

	YT	WC
YT	1.00	0.38
WC	2.65	1.00

Table 4.8: Pairwise comparison of “Cost” attributes

	PTP	CJWB	ACE
PTP	1.00	1.58	2.09
CJWB	0.63	1.00	1.45
ACE	0.48	0.69	1.00

Table 4.9: Pairwise comparison of “Human Resource” attributes

	QKP	KPE	AOL	NTAS
QKP	1.00	0.85	1.20	1.52
KPE	1.18	1.00	1.80	1.95
AOL	0.83	0.56	1.00	1.08
NTAS	0.66	0.51	0.93	1.00

Table 4.10: Pairwise comparison of "Quality" attributes

	QA	QP	QC
QA	1.00	1.54	1.26
QP	0.65	1.00	0.86
QC	0.80	1.16	1.00

Table 4.11: Pairwise comparison of "Reputation" attributes

	PS	LTB	RWC
PS	1.00	1.89	1.13
LTB	0.53	1.00	0.55
RWC	0.89	1.81	1.00

4.4.5 Normalized Matrix

To calculate the weightages of criteria & attributes, the numbers in the matrix are normalized to take into account the overall values. The columns of matrix are summed and then each element of the matrix of that particular column is divided by the sum of column to obtain a normalized matrix.

The normalized matrix of criteria comparison, design aspect, management & technical ability, financial soundness, cost, human resource, quality & reputation attributes are shown in table 4.12, 4.13, 4.14, 4.15, 4.16, 4.17 and 4.18 respectively.

Table 4.12: Normalized matrix of criteria

	Design Aspect	Financial soundness	Cost	Human Resource	Quality	Reputation	Management &Technical ability
Design Aspect	0.14	0.16	0.17	0.12	0.18	0.13	0.12
Financial soundness	0.05	0.06	0.06	0.06	0.05	0.05	0.06
Cost	0.16	0.18	0.20	0.28	0.15	0.20	0.21
Human Resource	0.18	0.14	0.10	0.15	0.17	0.17	0.15
Quality	0.09	0.13	0.14	0.09	0.11	0.10	0.11
Reputation	0.17	0.17	0.16	0.14	0.18	0.16	0.16
Management &Technical ability	0.21	0.16	0.16	0.17	0.17	0.19	0.18

Table 4.13: Normalized matrix of “Design Aspect” attributes

	ATDP	C&U	QD	MD	PRCDR
ATDP	0.11	0.12	0.12	0.10	0.11
C&U	0.30	0.31	0.34	0.32	0.27
QD	0.22	0.22	0.24	0.27	0.26
MD	0.20	0.17	0.16	0.18	0.21
PRCDR	0.17	0.18	0.14	0.13	0.15

Table 4.14: Normalized matrix of "Management & Technical ability" attributes

	PE	PP	P&E	CW&C	ACWT
PE	0.20	0.22	0.19	0.22	0.19
PP	0.25	0.27	0.30	0.26	0.28
P&E	0.23	0.19	0.21	0.19	0.24
CW&C	0.13	0.15	0.16	0.14	0.13
ACWT	0.18	0.16	0.15	0.19	0.17

Table 4.15: Normalized matrix of "Financial Soundness" attributes

	YT	WC
YT	0.27	0.27
WC	0.73	0.73

Table 4.16: Normalized matrix of "Cost Factors" attributes

	PTP	CJWB	ACE
PTP	0.47	0.48	0.46
CJWB	0.30	0.31	0.32
ACE	0.23	0.21	0.22

Table 4.17: Normalized matrix of “Human Resource” attributes

	QKP	KPE	AOL	NTAS
QKP	0.27	0.29	0.24	0.27
KPE	0.32	0.34	0.37	0.35
AOL	0.23	0.19	0.20	0.19
NTAS	0.18	0.18	0.19	0.18

Table 4.18: Normalized matrix of “Quality” attributes

	QA	QP	QC
QA	0.41	0.42	0.40
QP	0.27	0.27	0.28
QC	0.33	0.31	0.32

Table 4.19: Normalized matrix of “Reputation” attributes

	PS	LOTIB	RWC
PS	0.41	0.40	0.42
LOTIB	0.22	0.21	0.21
RWC	0.37	0.39	0.37

4.4.6 Local Weights & Global Weights

When the matrices are normalized, the weights of attributes are calculated with respect to their criteria and with respect to the goal of the study which are known as local weights and global weights respectively. The local weight of an attribute is its weight or priority with respect to its node placed one level above the hierarchy also known as criteria. In this case, local weight of an attribute termed as sub criteria is with respect to its particular criteria. After local weights are calculated, the next step is to calculate the weight of the attribute with respect to the main goal. These values of weights are called global weights. Global weights for any element in the hierarchy are calculated by weighing local priority by global priority assigned to the element at the preceding level (Davies, 1994).

4.4.7 Ranking the Criteria and Sub-Criteria:

The next step after calculating global weights with respect to the goal of the model is to rank the design build subcontractor selection attributes in the descending order. In this way, it becomes easier for the decision makers to identify the most important attributes affecting the decision more significantly. The priority weights of attributes in descending order are shown in table 4.20.

Table 4.20: Global and Local weights for criteria & sub criteria

Criteria	Local weights of criteria	Factors	local weights of factors	Global Weights
Cost	0.196	Proposed tender price	0.472	0.093
		Completion of job within budget	0.309	0.061
		Adequacy of cost estimate	0.219	0.043
Management & Technical Ability	0.176	Past Performance	0.271	0.048
		Plant & Equipment	0.214	0.038
		Past Experience	0.203	0.036
		Ability to complete work on time	0.170	0.030
		Current workload & commitment	0.142	0.025

Reputation	0.164	Past Success	0.412	0.068
		Relationship with main contractor	0.375	0.062
		Length of time in business	0.213	0.035
Human Resources	0.151	Key personnel experience	0.346	0.052
		Qualification of key personnel	0.270	0.041
		Adequacy of labour resources	0.204	0.031
		No of technical & administrative staff availability	0.181	0.027
Design Aspect	0.147	Compliance and understanding to client's breif	0.309	0.045
		Quality of Design	0.242	0.036
		Methodology	0.182	0.027
		Project risks being effectively covered in the design	0.154	0.023
		Approach to design process	0.113	0.017
Quality	0.109	Quality assurance	0.409	0.045
		Quality control	0.320	0.035
		Quality performance	0.271	0.030
Financial Soundness	0.056	Working capital	0.726	0.041
		Yearly turnover	0.274	0.015

This study provides a technique for ranking of attributes for selection of design build subcontractor that affects the decision making significantly and hence contract award. To achieve this, Analytical hierarchy process is used which calculate the weightages of attributes by doing a pairwise comparison and calculating the significance of attributes upon each other. This method has accomplished results that are based on the assessment of local industry experts. The assessment of experts has resulted in calculation of priorities of attributes which are shown in figure.

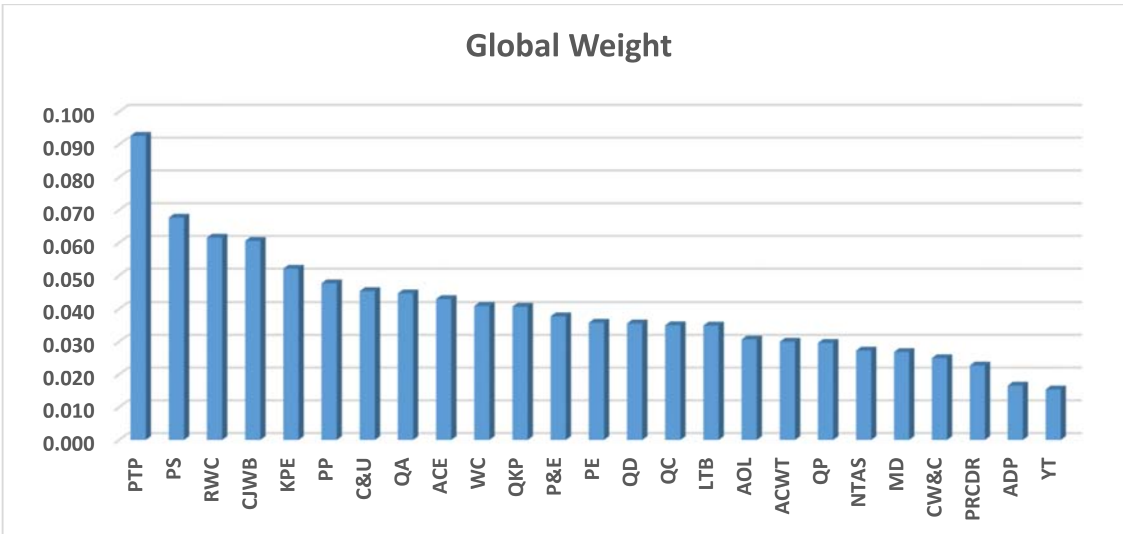

Figure 4.3: Bar Chart of Priority weights of factors in descending order

The priorities shown in the above figure are the global weights of the attributes that are shown in table 4.20. The local weights of criteria that are shown in the second column shows that the most important criteria among the rest is cost with an overall priority weight of 19.6%. The result reveals that cost is the most important criteria for selection of design build subcontractor as it is important for the main contractor to keep his bid to the lowest possible to win the tender. The attributes of cost include “Proposed tender price”, “Completion of job within budget” and “Adequacy of cost estimate”. The factor “Proposed tender price” holds the highest weightage among others as this factor is directly related to the bid price of the contractor. The attribute “Completion of job within budget” can be linked with the “Past performance” of the subcontractor in terms of cost which is a sub-criteria of “Management and technical ability”. This factor shows if a subcontractor has completed the jobs within budget in his past performances. The other factor “Adequacy of cost estimate” is significant for selection of subcontractor as it is used to measure the accuracy of quoted price by the subcontractor. If the subcontractor makes a mistake in quoting price, the contractor can judge it by comparing it with their estimate of the job.

The second most important criteria is “Management and technical ability” with an overall priority weight of 17.6% which shows the ability of a subcontractor to execute a certain task based on his past performances and experience. The factor's that holds relativity high weightage under this category includes "Past Performance", "Plant & Equipment" and "Past Experience". The most important factor among the rest in this category is "Past Performance" as it measures the performance of the subcontractor in his previous completed projects in terms of time and quality. The second factor "Plant and Equipment" holds importance as it specifies the required tools and machinery required to execute the project as per specifications keeping in mind the quality of project and time for completion. The third factor "Past Experience" shows the nature of project that the subcontractor has completed in past. If the subcontractor has experience of jobs that are similar in nature to the requirement, the contractor can expect him to execute the said job as per specifications.

The third most important criteria is "Reputation" of subcontractor with a priority weight of 16.4%. The difference between weightage of the criteria "Management and technical ability" and "Reputation" is marginal showing that the criteria "Reputation" holds high weightage in the decision making. In an EPC contract, key risks that may interfere with the performance of projects sits with the contractor. If the performance of the project is affected by the performance of the subcontractor, the contractor will be held responsible and his reputation will be badly affected by it. To reduce the risk in the selection process of the subcontractors, contractors usually rely on the reputation of the subcontractor. If the subcontractor has worked with the contractor in the past and has performed well, the contractor can trust him to deliver the job as per specifications. In cases where contractor is not familiar with subcontractor's in terms of past relationship, the main attributes that play vital role in selection of subcontractors are "Past Success" and "Length of time in business". "Past Success" factor serves as a strong indicator for the performance of subcontractors.

As per Global weightages, the attribute "Proposed tender price" has the highest priority weight of 9.3% followed by "past success" with a weightage of 6.8% and "Relationship with the main contractor" with priority weight of 6.2%.

This shows that the attribute "Proposed tender price" matters the most for a contractor. The reason as explained earlier is the competitiveness nature of bidding in the construction industry i.e to win the project by quoting the lowest price for design and execution of the job. In the construction industry, the practice being followed in government organizations and in most private organizations as well is to award the contract to the contractor with the lowest bid. To increase the chances of winning a tender, the contractor must quote the lowest possible price for the project.

The second and third most important attributes among the 25 factors are "Past success" and "Relationship with the main contractor" as the decision maker feels more comfortable in awarding the task of a project to the subcontractor who has already worked with him in the past.

The attributes “completion of job within budget”, “Key personnel experience”, “past performance” and “plant and equipment” acquires a relatively higher weightage in the selection of a design bid subcontractor.

4.4.8 Equation for Design-Build Subcontractor Selection using AHP

Using the AHP method, priority weights of all criteria and factors have been calculated which highlights the importance of factors in decision making for selection of design build subcontractor in an EPC/Turnkey project. The equation for design build subcontractor selection has been proposed as follow:

$$\text{Subcontractor Score (SC)} = \sum_{i=1}^{25} Bi * Xi$$

Where ‘Bi’ is the priority weight of the factor which has been calculated in the previous section and ‘Xi’ are the variables with values ranging from 1 to 9. The decision maker will decide the value of the variable based of the capability of the subcontractor against each factor separately.

4.5 Model Validation through Case Studies of EPC Building Projects

The model presented above is applied on five case studies of EPC building projects to demonstrate the multi-criteria nature of selecting a suitable design build subcontractor. The criteria and their attributes that will be used in decision making have already been discussed and their priority weights have already been calculated. Proposed model will be applied on all case studies which comprises of EPC building projects undertaken by “M/S Kashmir Pre-Engineered Construction (Pvt) Ltd” and “M/S Pre-Engineered Building Industries (Pvt) Ltd”. These 2 firms are registered contractors with Pakistan engineering council (PEC) and execute EPC contracts with both government & private departments.

4.5.1 Cast Study 1

The details of project are shown in Table 4.21.

Table 4.21: Details of Project

Project Name	Pakistan Kidney Liver Institute Clinic (PKLI)
Employer	Infrastructure Development Authority of Punjab (IDAP)
Contractor	Kashmir Pre-Engineered Construction (Pvt) Ltd. (KAPEC)

Project Cost	PKRs. 100 Million
Project Commencement	December 20th, 2015
Project Completion	March 1st, 2016
Project Duration	70 days
Area	8,800 sft
Work Description	Design & Installation of HVAC system
Subcontractor A	SN Associates
Subcontractor B	Mia Corporation (Pvt) Ltd.
Subcontractor C	Yazdan Engineering Services

The pairwise comparison was done between the selection attributes enlisted in table 4.20 and the alternatives. Prequalified subcontractors were ranked on a scale of 1-9 based on their capability against a particular attribute and their total score was calculated as per proposed model using super decisions software. The super matrix which includes weighted, unweighted & limiting matrix generated as a result of pairwise comparisons.

The weightages of criteria used in case study are shown in figure 4.4.

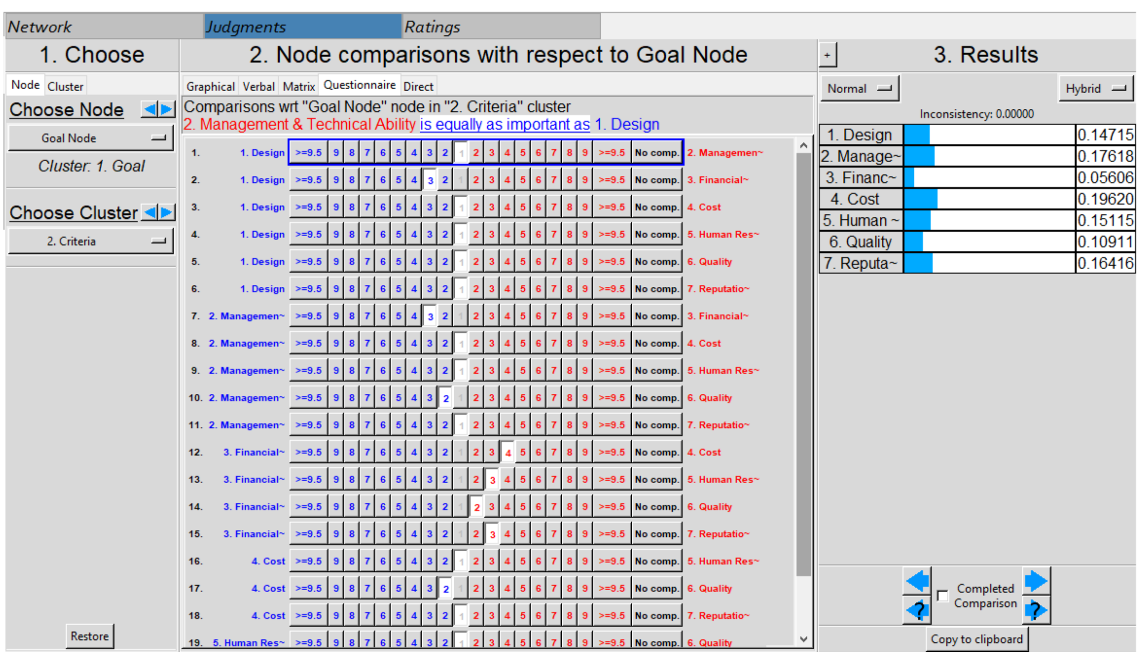

Figure 4.4: Priority weights of criteria

After the formation of super matrix, the priorities of alternatives are generated in super decisions. The priorities of subcontractor's are demonstrated in a form of bar chart which shows the most suitable subcontractor according to the proposed model.

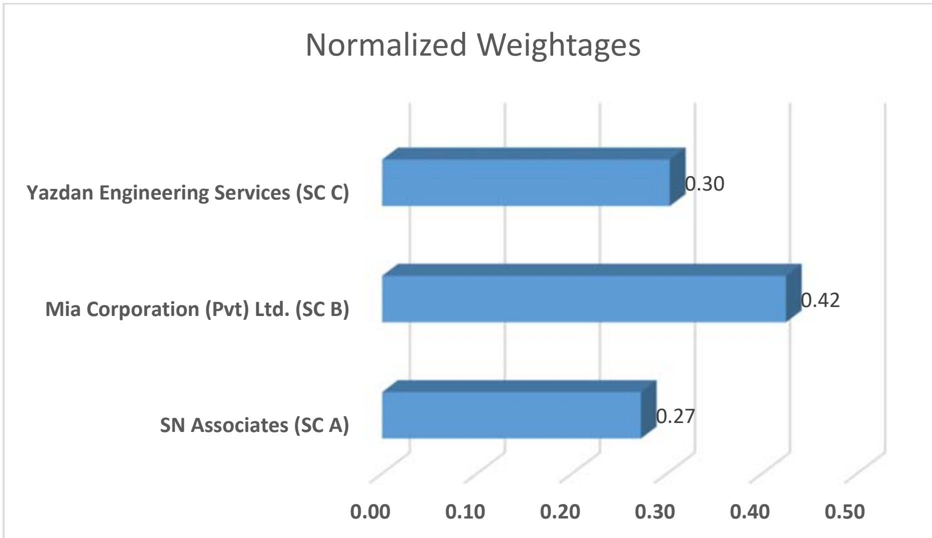

Figure 4.5: Normalized Weightages of Subcontractors of Case Study 1

Subcontractor B has the highest score of 0.42 followed by Subcontractor C with a score of 0.30. Subcontractor A has the lowest score of 0.27.

The project was also awarded to subcontractor B. As per contractor, the duration of the project was only 70 days in which the contractor had to design and construct the building. Due to short duration, one of the prime considerations of the contractor for selection of subcontractor was his ability to complete the work in specified duration. Other reason for consideration included contractor past relation with the subcontractor and low proposed tender price and his ability to complete work on time. According to the model, Subcontractor B scores the highest in all the considerations of the contractor at the time of awarding the contract.

4.5.2 Cast Study 2

The details of project are shown in Table 4.22. The same procedure for analysis was conducted as discussed in case study 1. The super matrix which includes weighted, unweighted & limiting matrix generated as a result of pairwise comparisons.

Table 4.22: Details of Project

Project Name	Hybrid Steel Structure of Pathology lab at Jinnah Hospital
Employer	Infrastructure Development Authority of Punjab (IDAP)
Contractor	Kashmir Pre-Engineered Construction (Pvt) Ltd. (KAPEC)
Project Cost	PKRs. 210 Million
Project Commencement	January 1st, 2017
Project Completion	May 30th, 2017
Project Duration	150 days
Area	21,000 sft
Work Description	Electrical works
Subcontractor A	SN Associates
Subcontractor B	Taj Mechanical Company
Subcontractor C	Tulip Engineering (Pvt) Ltd.

After the formation of super matrix, the priorities of alternatives are generated in super decisions. The weightages of subcontractor's are demonstrated in a form of bar chart which shows the most suitable subcontractor according to the proposed model.

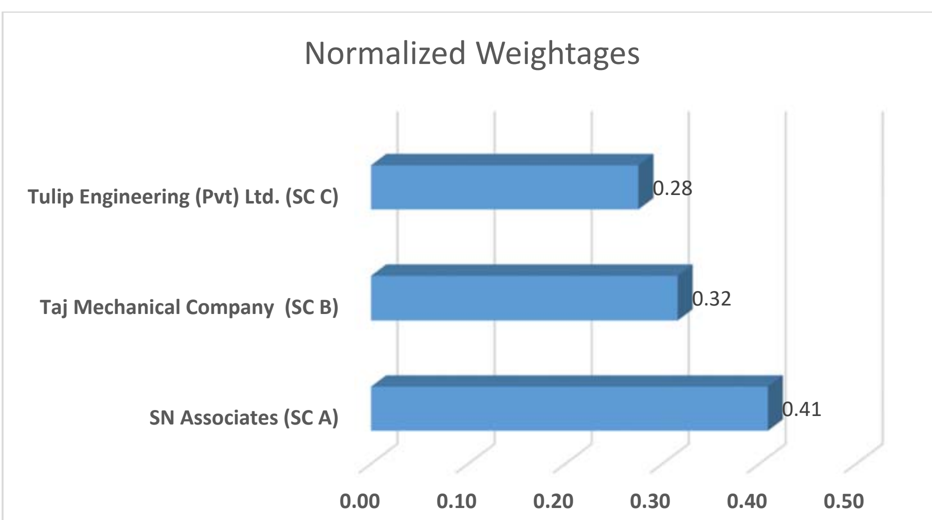

Figure 4.6: Normalized Weightages of Subcontractors of Case Study 2

Subcontractor A has the highest score of 0.41 followed by Subcontractor B with a score of 0.32. Subcontractor A has the lowest score of 0.28.

The project was also awarded to subcontractor A. However, analysis of this sort was not necessarily implemented at the time of awarding contract. As per contractor, the main reasons for awarding the contract to 'Subcontractor A' were solely based on their relationship with the subcontractor. The proposed tender price of 'Subcontractor A' was also the lowest in this case but it wasn't the prime consideration of the contractor. Moreover, due to short duration for completion of project, the contractor had shown more trust on the capabilities of 'Subcontractor A'.

4.5.3 Cast Study 3

The details of project are shown in Table 4.23.

Table 4.23: Details of Project

Project Name	THQ Hospital
Employer	Head Quarter 16 Division, Pano Aqil Cantt.
Contractor	Kashmir Pre-Engineered Construction (Pvt) Ltd. (KAPEC)
Project Cost	PKRs. 502 Million
Project Commencement	February 01st, 2018
Project Completion	August 30th, 2018
Project Duration	7 Months
Area	72,000 sft
Work Description	Electrical & IT Works
Subcontractor A	Extreme Engineer's & Contractors
Subcontractor B	K.N. International
Subcontractor C	SN Associates

The same procedure for analysis was conducted as discussed in case study 1. The super matrix which includes weighted, unweighted & limiting matrix generated as a result of pairwise comparisons.

After the formation of super matrix, the priorities of alternatives are generated in super decisions. The weightages of subcontractor's are demonstrated in a form of bar chart which shows the most suitable subcontractor according to the proposed model.

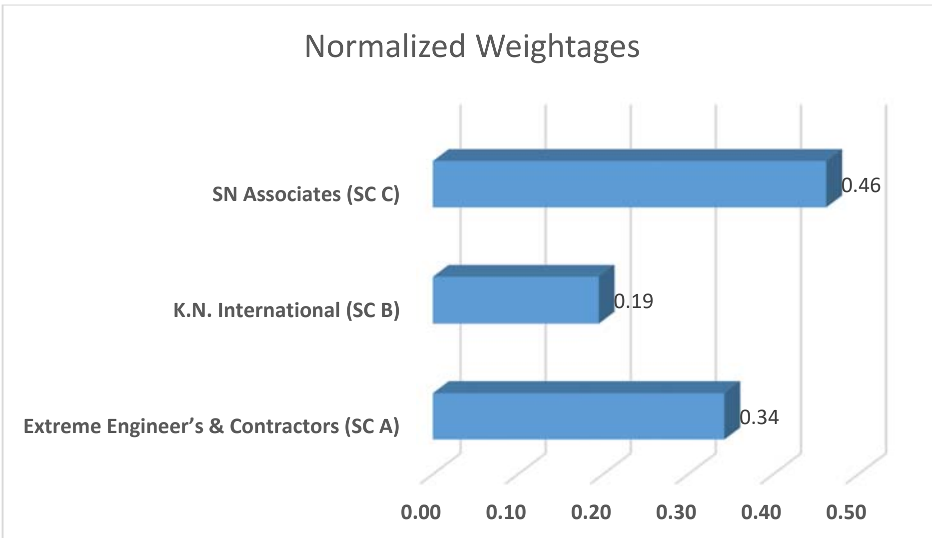

Figure 4.7: Normalized Weightages of Subcontractors of Case Study 3

Subcontractor C has the highest score of 0.46 followed by Subcontractor A with a score of 0.34. Subcontractor A has the lowest score of 0.19.

As per proposed model, the contract should be awarded to 'Subcontractor C'. However, in actual the project was awarded to 'Subcontractor A'. According to the contractor, they were also more comfortable in working with 'Subcontractor C' because of their past relation with the subcontractor and their capability to execute the project within cost & time but the reason of awarding the contract to 'Subcontractor A' was due to their low proposed tender price and their head office location which was in the region of project. The contractor felt that in this way coordination and management of the project would be better. Nonetheless, the contractor faced some issues during execution due to changes in preliminary design as the subcontractor lacked experience in similar work and the project got delayed by 45 days.

4.5.4 Cast Study 4

The details of project are shown in Table 4.24. The same procedure for analysis was conducted as discussed in case study 1. The super matrix which includes weighted, unweighted & limiting matrix generated as a result of pairwise comparisons.

Table 4.24: Details of Project

Project Name	DHQ Hospital
Employer	Health Department, Government of Sindh.
Contractor	Pre-Engineered Building Industires (Pvt) Ltd.
Project Cost	PKRs. 732 Million
Project Commencement	June 13th, 2012
Project Completion	December 13th, 2013
Project Duration	18 months
Area	200,000 sft
Work Description	Design & Installation of HVAC system
Subcontractor A	Fast Associates (Pvt) Ltd.
Subcontractor B	Malik Brothers
Subcontractor C	Techno Point Engineers

After the formation of super matrix, the priorities of alternatives are generated in super decisions. The weightages of subcontractor's are demonstrated in a form of bar chart which shows the most suitable subcontractor according to the proposed model.

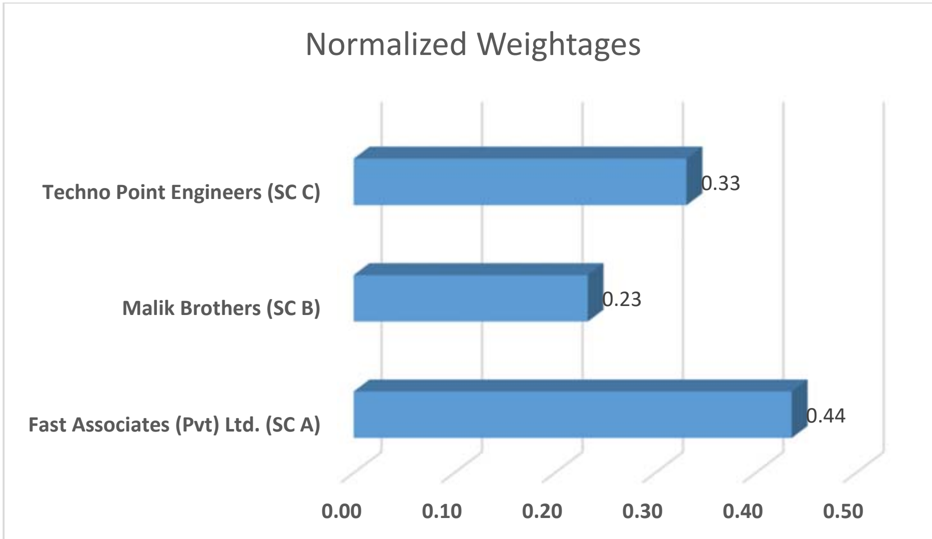

Figure 4.8: Normalized Weightages of Subcontractors of Case Study 4

‘Subcontractor A’ has the highest score of 0.44 followed by ‘Subcontractor B’ with a score of 0.33. ‘Subcontractor A’ has the lowest score of 0.23.

Figure 4.7 suggests that Subcontractor A should be selected as it has the highest score among the rest. In actual, the contract was also awarded to Subcontractor A based on his lowest bid, past performance and past success in similar projects.

4.5.5 Cast Study 5

The details of project are shown in Table 4.25. The same procedure for analysis was conducted as discussed in case study 1. The super matrix which includes weighted, unweighted & limiting matrix generated as a result of pairwise comparisons.

Table 4.25: Details of Project

Project Name	Design office
Employer	Frontier Works Organization
Contractor	Pre-Engineered Building Industries (Pvt) Ltd.
Project Cost	PKRs. 110 Million
Project Commencement	December 01st, 2018

Project Completion	May 30th, 2019
Project Duration	6 months
Area	38,000 sft
Work Description	Design & Installation IT, CCTV and Fire fighting system
Subcontractor A	G.F Logics (Pvt) Ltd.
Subcontractor B	K.N. International

After the formation of super matrix, the priorities of alternatives are generated in super decisions. The weightages of subcontractor's are demonstrated in a form of bar chart which shows the most suitable subcontractor according to the proposed model.

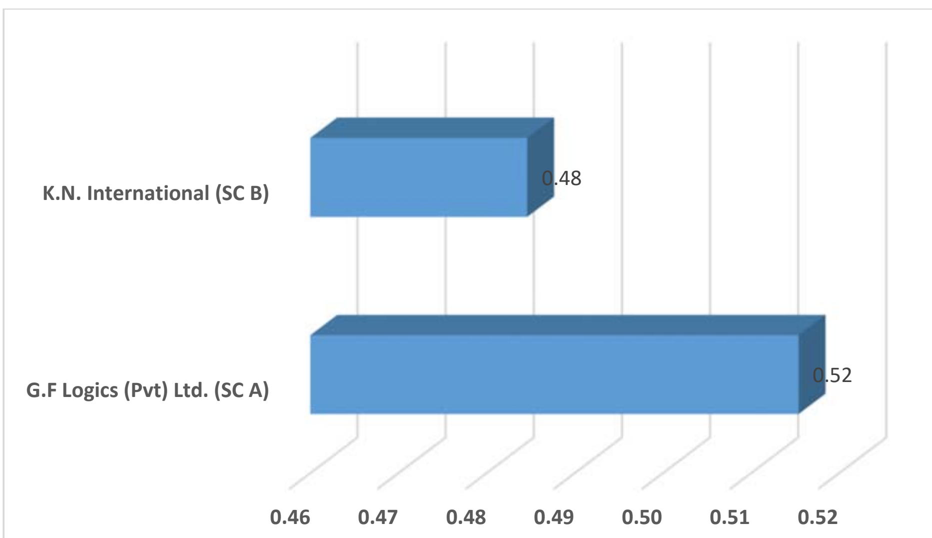

Figure 4.9: Normalized Weightages of Subcontractors of Case Study 5

Out of 4 Subcontractors, only 2 were prequalified for the purpose of selection. 'Subcontractor A' got the highest score of 0.52 followed by 'Subcontractor B' with a score of 0.48. The difference between the scores is marginal but since one subcontractor has to be selected, the model suggests subcontractor A to be selected based on his score. The contractor also made the same choice by awarding the contract to Subcontractor A. As per the contractor, both of these subcontractors were capable of doing the job. However, contractor had previously worked with Subcontractor A on several projects. Based on past relations with the subcontractor, the contract was awarded to subcontractor A.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the findings of this research and provide recommendations for future research.

5.2 Review of Literature

A thorough review of literature was done to find out the factors that affect the performance of design build subcontractor in an engineered, procurement and construction contract or a turnkey contract. Many researches have conducted studies on best value procurement, prequalification and selection of subcontractors and have proposed models and frameworks for their selection by using various techniques. The literature shows that research has not been carried out specifically on the selection of design build subcontractors to whom work is subcontracted by main contractors with responsibility of design and execution of a specialist task that the contractor cannot undertake himself due to lack of knowledge. This research focuses on the knowledge gap by developing a model for the use of EPC contractor that would help them in selecting a suitable design build subcontractor.

It can be seen in literature that in most of the cases, cost is considered the single most important criteria in the selection of subcontractor's without focusing on other criteria's which can affect the performance of a project. Selection of lowest bid without considering other criteria can result in selection of an unqualified subcontractor that could result in low quality, increased cost and time delays which directly affects the performance and reputation of the contractor on a project.

In this study, a total of 48 factors were identified after a detailed literature review. Preliminary survey was conducted to prioritize the factors on Likert scale. On obtaining results from survey, the factors were reduced to 25 with the help of qualitative and quantitative analysis. These factors were then grouped into 7 criteria based on literature. To determine the weightages of criteria and factor's, AHP was used which is a multi-criteria decision-making technique that helps in solving complex problems.

5.3 Determination of Priorities of Design-Build Subcontractor Attributes by using AHP

One of the main objectives of this research was to calculate the priority weights of the identified factors and develop a MCDM model to calculate the total scores of subcontractors participating in a bid using AHP. A questionnaire was developed with the aim to gather information on relative importance of factors by industrial professionals having experience in this field. On obtaining data, weightages of criteria and factors were calculated by using AHP technique. Results indicate that 'Cost' is still the most important criteria followed by 'Management & technical ability' and 'Reputation' of subcontractor.

After calculation of criteria weights, global weights of factor's were calculated to determine the importance of factors. The results indicate that the most important factor is 'Proposed tender price' followed by 'Past success' and 'Relationship with the contractor'. The result's as well as case studies performed for validation of model suggests that EPC contractors rely heavily on their past encounter's with subcontractor's on projects. The trust built by working with subcontractor's in the past who have successfully performed in the projects are very important for the contractor and hence holds relatively higher weightage in the eye of decision maker for after the 'Proposed tender price'.

'Super decisions' software that is based on AHP and ANP technique has been used in this research. The software plays an important role for the proposed model acceptance in the industry due to its user-friendly interface which makes it easier for the industrial professionals to understand. AHP technique that has been applied in the proposed model has already been applied by many researcher's in various real-world applications. The adoption of this technique makes it easier for the decision maker to understand the complex problem once it is decomposed into a hierarchy consisting of goal, criteria, sub criteria and alternatives. This technique also helps decision makers who are working in groups to understand the relationship among elements of the hierarchy and address the concerned issue. Another advantage of using AHP is that it does not require for the user to use any specific software for computation of priorities of factors. These calculations can easily be performed on spread sheet with which many people in the construction industry are familiar with.

5.4 Recommendations

In the proposed model, the weightages of factor's and criteria have been calculated on the basis of 64 responses from industrial professionals having considerable experience in the field of procurement, design and project management. Given the nature of project, the selection criteria and the weightages can be modified to suit the requirement of the project. The decision makers can use the same technique for calculation of priorities and use the model for selection of the most suitable design build subcontractor as per project requirement.

The limitation of this model is that it has been applied to 5 case studies for its validation among which the projects considered for case studies were already completed. A better way to validate and improve the model would be to apply it on projects from planning stage to completion stage by measuring performance of the design build subcontractor throughout the project to identify the issues that could be addressed at the selection stage.

References

Abbasianjahromi, H., et al. (2013). A framework for subcontractor selection in the construction industry. *Journal of Civil Engineering and Management, 19*(2), 158-168.

Abbasianjahromi, H., et al. (2018). A decision-making framework for subcontractor selection in construction projects. *Engineering Management Journal, 30*(2), 141-152.

Aczél, J., and Saaty, T. L. (1983). Procedures for synthesizing ratio judgements. *Journal of mathematical Psychology, 27*(1), 93-102.

Adams, W., and Saaty, R. (2003). Super decisions software guide. *Super Decisions, 9*, 43.

Ahmad, Z., et al. (2018). Building information modeling as a risk transformer: An evolutionary insight into the project uncertainty. *Automation in construction, 92*, 103-119.

Al-Reshaid, K., and Kartam, N. (2005). Design–build pre-qualification and tendering approach for public projects. *International Journal of Project Management, 23*(4), 309-320.

Alzahrani, J. I., and Emsley, M. W. (2013). The impact of contractors' attributes on construction project success: A post construction evaluation. *International Journal of Project Management, 31*(2), 313-322.

Arslan, G., et al. (2008). Improving sub-contractor selection process in construction projects: Web-based sub-contractor evaluation system (WEBSES). *Automation in Construction, 17*(4), 480-488.

Atkinson, R. (1999). Project management: cost, time and quality, two best guesses and a phenomenon, its time to accept other success criteria. *International Journal of Project Management, 17*(6), 337-342.

Bailey, J. M. (2016). *Subcontractor Selection in the Construction Industry-Development of a research approach to investigate selection criteria, methods, value creation initiatives and supply chain management.* NTNU.

Benjamin, C. O., et al. (1992). Planning facilities at the University of Missouri-Rolla. *Interfaces, 22*(4), 95-105.

Chan, A. P., et al. (2002). Framework of success criteria for design/build projects. *Journal of Management in Engineering, 18*(3), 120-128.

Cheng, E. W., and Li, H. (2004). Contractor selection using the analytic network process. *Construction Management and Economics, 22*(10), 1021-1032.

Cheng, E. W., et al. (2005). The analytic network process (ANP) approach to location selection: a shopping mall illustration. *Construction Innovation, 5*(2), 83-98.

Cheung, F. K., et al. (2002). Multi-criteria evaluation model for the selection of architectural consultants. *Construction Management & Economics, 20*(7), 569-580.

Chin, K. S., and Pun, K. F. (2002). A proposed framework for implementing TQM in Chinese organizations. *International Journal of Quality & Reliability Management*.

Choudhry, R. M., et al. (2012). Subcontracting practices in the construction industry of Pakistan. *Journal of Construction Engineering and Management, 138*(12), 1353-1359.

Chow, L. K., and Ng, S. T. (2007). A fuzzy gap analysis model for evaluating the performance of engineering consultants. *Automation in construction, 16*(4), 425-435.

Darvish, M., et al. (2009). Application of the graph theory and matrix methods to contractor ranking. *International Journal of Project Management, 27*(6), 610-619.

Davies, M. A. (1994). Using the AHP in marketing decision-making. *Journal of Marketing Management, 10*(1-3), 57-73.

Dissanayake, D. (2017). *Fuzzy multi-attribute analysis (FMAA) model for Engineering-Procurement-Construction (EPC) contractor selection.* Queensland University of Technology.

Doloi, H. (2009). Analysis of pre-qualification criteria in contractor selection and their impacts on project success. *Construction Management and Economics, 27*(12), 1245-1263.

Dong, Y., et al. (2010). Consensus models for AHP group decision making under row geometric mean prioritization method. *Decision Support Systems, 49*(3), 281-289.

Edwards, D. J., and Holt, G. D. (2010). The case for “3D triangulation” when applied to construction management research. *Construction Innovation*.

El-Sawalhi, N. I., et al. (2007). Establishing relative weights for contractor prequalification criteria in a pre-qualification evaluation model. *Establishing relative weights for contractor prequalification criteria in a pre-qualification evaluation model*.

Engineer, E. (2013). *EPC-Engineering Procurement Construction*. Retrieved from

Forbes, L. H., and Ahmed, S. M. (2010). *Modern construction: lean project delivery and integrated practices*: CRC press.

Gil, N. (2003). Product-process development simulation to support specialty contractor involvement in early design.

Gransberg, D. D. (2010). Framework for performance-based contractor prequalification. *Transportation Research Record, 2151*(1), 46-54.

Grasso, B., et al. (2008). Nature and extent of domestic construction program outsourcing. *Journal of Construction Engineering and Management, 134*(12), 1002-1010.

Gray, C., and Flanagan, R. (1989). *The changing role of specialist and trade contractors*: Chartered Institute of Building Ascot.

Hartmann, A., and Caerteling, J. (2010). Subcontractor procurement in construction: the interplay of price and trust. *Supply chain management: an international journal, 15*(5), 354-362.

Hsieh, H.-F., and Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research, 15*(9), 1277-1288.

Kim, M.-H., et al. (2018). Detail engineering completion rating index system (DECRIS) for optimal initiation of construction works to improve contractors’ schedule-cost performance for offshore oil and gas EPC projects. *Sustainability, 10*(7), 2469.

Kramer, S. R., and Meinhart, T. J. (2004). Alternative contract and delivery methods for pipeline and trenchless projects *Pipeline Engineering and Construction: What's on the Horizon?* (pp. 1-10).

Lopez del Puerto, C., et al. (2008). Comparative analysis of owner goals for design/build projects. *Journal of Management in Engineering, 24*(1), 32-39.

Luu, D., and Sher, W. (2006). Construction tender subcontract selection using case-based reasoning. *Construction Economics and Building, 6*(2), 32-43.

Luu, D. T., et al. (2005). Formulating procurement selection criteria through case-based reasoning approach. *Journal of Computing in civil engineering, 19*(3), 269-276.

Marzouk, M. M., et al. (2013). Factors influencing sub-contractors selection in construction projects. *HBRC Journal, 9*(2), 150-158.

Mbachu, J. (2008). Conceptual framework for the assessment of subcontractors' eligibility and performance in the construction industry. *Construction Management and Economics, 26*(5), 471-484.

Muhammad, J. A. (2016). *Improving selection practices of subcontractors on building construction project in Nigeria.* Universiti Tun Hussein Onn Malaysia.

Nazari, A., et al. (2016). Fuzzy AHP model for prequalification of engineering consultants in the Iranian public procurement system. *Journal of Management in Engineering, 33*(2), 04016042.

Ng, S., and Skitmore, R. (1999). Client and consultant perspectives of prequalification criteria. *Building and environment, 34*(5), 607-621.

Ng, S. T., et al. (2008). Delineating criteria for subcontractors registration considering divergence in skill base and scales. *International Journal of Project Management, 26*(4), 448-456.

Ng, S. T., and Tang, Z. (2010). Labour-intensive construction sub-contractors: Their critical success factors. *International Journal of Project Management, 28*(7), 732-740.

Olsson, J., and Berndtsson, R. (1998). Temporal rainfall disaggregration based on scaling properties. *Water science and technology, 37*(11), 73-79.

Palaneeswaran, E., and Kumaraswamy, M. M. (2000). Contractor selection for design/build projects. *Journal of Construction Engineering and Management, 126*(5), 331-339.

Palaneeswaran, E., and Kumaraswamy, M. M. (2005). Web-based client advisory decision support system for design–builder prequalification. *Journal of Computing in civil engineering, 19*(1), 69-82.

Piper, D. (2011). EPC contracts in the power sector. *Asia Pacific Projects Update*, 4-5.

Plebankiewicz, E. (2012). A fuzzy sets based contractor prequalification procedure. *Automation in construction, 22*, 433-443.

Polat, G. (2016). Subcontractor selection using the integration of the AHP and PROMETHEE methods. *Journal of Civil Engineering and Management, 22*(8), 1042-1054.

Saaty, T. L. (1988). What is the analytic hierarchy process? *Mathematical models for decision support* (pp. 109-121): Springer.

Saaty, T. L. (1994). How to make a decision: the analytic hierarchy process. *Interfaces, 24*(6), 19-43.

Saaty, T. L. (2000). *Fundamentals of decision making and priority theory with the analytic hierarchy process* (Vol. 6): RWS publications.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences, 1*(1), 83-98.

Saaty, T. L., and Kearns, K. P. (2014). *Analytical planning: The organization of system* (Vol. 7): Elsevier.

San Cristóbal, J. R. (2012). Contractor selection using multicriteria decision-making methods. *Journal of Construction Engineering and Management, 138*(6), 751-758.

Sen, K., and Mamtani, M. A. (2006). Magnetic fabric, shape preferred orientation and regional strain in granitic rocks. *Journal of Structural Geology, 28*(10), 1870-1882.

Shafaat, A., et al. (2014). *Decision-making model by specialty subcontractors in construction projects.* Paper presented at the Construction Research Congress Construction in a Global Network.

Shash, A. A. (1998). Bidding practices of subcontractors in Colorado. *Journal of Construction Engineering and Management, 124*(3), 219-225.

Singh, D., and Tiong, R. L. (2005). A fuzzy decision framework for contractor selection. *Journal of Construction Engineering and Management, 131*(1), 62-70.

Sporrong, J. (2011). Criteria in consultant selection: public procurement of architectural and engineering services. *Construction Economics and Building, 11*(4), 59-76.

Stenhouse, L. (1980). The study of samples and the study of cases. *British Educational Research Journal, 6*(1), 1-6.

Talukhaba, A., and Mapatha, M. (2007). *Selection framework for domestic subcontractors by contractors in the construction industry.* Paper presented at the CIB World Building Congress.

Tam, V. W., et al. (2011). Impacts of multi-layer chain subcontracting on project management performance. *International Journal of Project Management, 29*(1), 108-116.

Ulubeyli, S., and Kazaz, A. (2016). Fuzzy multi-criteria decision making model for subcontractor selection in international construction projects. *Technological and Economic Development of Economy, 22*(2), 210-234.

Walraven, A., and de Vries, B. (2009). From demand driven contractor selection towards value driven contractor selection. *Construction Management and Economics, 27*(6), 597-604.

Willett, K., and Sharda, R. (1991). Using the analytic hierarchy process in water resources planning: Selection of flood control projects. *Socio-Economic Planning Sciences, 25*(2), 103-112.

Xia, B., et al. (2009). Identification of key competences of design-builders in the construction market of the People's Republic of China (PRC). *Construction Management and Economics, 27*(11), 1141-1152.

Xu, Z. (2000). On consistency of the weighted geometric mean complex judgement matrix in AHP. *European Journal of Operational Research, 126*(3), 683-687.

APPENDIX 1

Factors for Selection of Design-Build Subcontractors by Main Contractor in an Engineering, Procurement and Construction Contract

A Major proportion of all construction projects are handled by subcontractors (SC) in the building industry.

In Engineering, Procurement & Construction (EPC) contracts, EPC contractors are responsible for design, procurement & construction. Considering specialized works such as HVAC, electrical & plumbing, it is not feasible for main contractor to hire staff for each specialized task. To keep the overheads to a minimum, contractors rely heavily on the specialized services of subcontractors for bid proposal, design and execution of work.

This survey aims to take expert opinion and input from construction industry professionals about important pre-qualification factors required for selection of design-build subcontractors involved in a construction project.

Development of Survey

Research papers published in top journals were studied to extract pre-qualification factors that play significant role in selection of subcontractors in construction projects. The common factors mentioned in these papers are presented in this survey to determine experts' opinion on their importance and validity.

1. Respondent name ______________________________
2. Name of organization ______________________________
3. Country of experience ______________________________
4. Field of experience ______________________________
5. Job Title ______________________________
6. Qualification ______________________________
7. Years of experience ______________________________
8. Organization Type ______________________________

9. How important are the following factors for Pre-qualification & Selection of Design-Build Subcontractors by Main Contractor in an Engineering, Procurement & Construction Contract.

Factors	Not Important	Slightly Important	Moderately Important	Important	Very Important
Past Experience					
Plant & equipment					
Past Performance					
Key Personnel experience					
Financial Stability					
Credit Rating					
Working Capital					
Yearly Turnover					
Financial References					
Debt Ratio					
Liquidity					
Profitability					
Timely payment to labourers					
Completion of job within budget					
Experience in the region					
Current workload and commitment					
Location of subcontractor office					
Ability to complete work on time					
Quality performance					

Quality Control					
Quality Assurance					
Personnel training					
No of technical & administrative staff availability					
Adequacy of labour					
Qualification of key personnel					
Safety consciousness on job site					
Experience modification rating					
OSHA incident rate					
Management safety accountability					
Site safety records					
Jobsite cleanliness					
Past success					
Length of time in business					
Relationship with the contractor					
Proposed tender price					
Tender quality					
Time accuracy in submitting bids					
Methodology					

Litigation history					
Creative and innovative ability					
Approach to Design					
Life cycle costs					
Compliance and understanding to client's brief					
Quality of drawings					
Project risks being effectively covered in the design					
Adequacy of cost estimate					
Company license for design in respective category					
Technology used					

APPENDIX 2

Selection of Design-Build Subcontractors in an Engineering, Procurement & Construction (EPC) Contract using AHP

In EPC contracts, Contractors are responsible for design, procurement & construction. Considering specialized works such as HVAC, Automation etc, it is not feasible for main contractor to hire staff for each specialized task to design and execute the said works. To keep the overheads to a minimum, contractors rely heavily on the specialized services of subcontractors for bid proposal, design and execution of work.

This survey aims to take expert opinion and input from industry professionals for the purpose of prioritizing factors that have reasonable contribution in design build subcontractor selection process.

Personal Information

This section of survey deals with personal information of the respondents. Please be assured that your personal data and information will only be used for study purpose and no personal information will be disclosed and shared at any forum.

- **Name**

____

- **Name of Organization**

____

- **Please indicate your organization type**

☐ Client

☐ Consultant

☐ Contractor

☐ Specialist Subcontractor

☐ Other: _____________

- **Please indicate your field of work**

☐ Architectural

☐ Design

☐ Procurement

☐ Contracts

☐ Execution

☐ Infrastructure management

☐ Construction management

☐ Quantity surveying

☐ Project Management

☐ Finance

☐ Accountant

☐ Other: _____________

- **Construction industry experience**

☐ 1 to 3 years

☐ 3 to 6 years

☐ 7 to 9 years

☐ 9 to 12 years

☐ 13 to 15 years

☐ 16 to 18 years

☐ 19 to 21 years

☐ More than 21 years

- **Position Title**

____

- **Highest academic qualification**

☐ Diploma / B-Tech

☐ Bachelors

☐ Masters

☐ Doctorate

Prioritization of Criteria & Factors for Design-Build Subcontractor Selection

In this section respondents based on their professional experiences and knowledge are required to rate importance of pre-qualification factors which are required for selection of design-build subcontractors in an Engineered, Procurement Construction contract where subcontractor is responsible for both design & execution of works.

The scales of comparison have been shown in following table:

Table: Scales of Comparison

Explanation	Numeric Values
If Option A and Option B are equally important: Mark/Insert	1
If one option is moderately more important than the other: Mark/Insert	3
If one option is strongly more important than the other: Mark/Insert	5
If one option is very strongly more important than the other: Mark/Insert	7
If one option is extremely more important than the other: Mark/Insert	9
Use even numbers for intermediate judgements	2, 4, 6, 8

Using the scale from 1 to 9 (where 9 is extremely important and 1 is equally important), please indicate the relative importance of options A (left column) to options B (right column).

1. Criteria Comparison																		
IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Design																		Financial Soundness
Design																		Cost
Design																		Human Resource
Design																		Quality
Design																		Reputation
Design																		Management & Technical Ability
Financial Soundness																		Cost
Financial Soundness																		Human Resource
Financial Soundness																		Quality
Financial Soundness																		Reputation
Financial Soundness																		Management & Technical Ability
Cost																		Human Resource
Cost																		Quality
Cost																		Reputation
Cost																		Management & Technical Ability
Human Resource																		Quality
Human Resource																		Reputation
Human Resource																		Management & Technical Ability
Quality																		Reputation
Quality																		Management & Technical Ability
Reputation																		Management & Technical Ability

2. Design Criteria factors relative importance																	
IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT							
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Approach to design process																		Compliance & understanding to client's brief
Approach to design process																		Quality of design & drawings
Approach to design process																		Methodology
Approach to design process																		Project risks being effectively covered in the design
Compliance & understanding to client's brief																		Quality of design & drawings
Compliance & understanding to client's brief																		Methodology
Compliance & understanding to client's brief																		Project risks being effectively covered in the design
Quality of design & drawings																		Methodology
Quality of design & drawings																		Project risks being effectively covered in the design
Methodology																		Project risks being effectively covered in the design

3. Management & technical ability factors relative importance																		
IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Past Experience																		Past Performance
Past Experience																		Plant & Equipment
Past Experience																		Current workload & commitment
Past Experience																		Ability to complete work on time
Past Performance																		Plant & Equipment
Past Performance																		Current workload & commitment
Past Performance																		Ability to complete work on time
Plant & Equipment																		Current workload & commitment
Plant & Equipment																		Ability to complete work on time
Current workload & commitment																		Ability to complete work on time

4. Financial Soundness factors relative importance																		
IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Option B**
Yearly Turnover																		**Working Capital**

5. Cost factors relative importance																		
IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Proposed Tender price																		Completion of job within budget
Proposed Tender price																		Adequacy of cost estimate
Completion of job within budget																		Adequacy of cost estimate

6. Human Resource factors relative importance																		
IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Qualification of Key Personnel																		Key Personnel Experience
Qualification of Key Personnel																		Adequacy of Labour
Qualification of Key Personnel																		No of Technical & administrative staff availability
Key Personnel Experience																		Adequacy of Labour
Key Personnel Experience																		No of Technical & administrative staff availability
Adequacy of Labour																		No of Technical & administrative staff availability

7. Quality factors relative importance

IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Quality Performance																		Quality Assurance
Quality Performance																		Quality Control
Quality Assurance																		Quality Control

8. Reputation factors relative importance

IF "*OPTION A*" IS RELATIVELY IMPORTANT										IF "*OPTION B*" IS RELATIVELY IMPORTANT								
Option A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Option B
Failure to complete contract / Past failures																		Length of time in business
Failure to complete contract / Past failures																		Relationship with contractor
Length of time in business																		Relationship with contractor