**NEAR EAST UNIVERSITY**

**INSTITUTE OF GRADUATE STUDIES**

**DEPARTMENT OF CIVIL ENGINEERING**

# MULTI-CRITERIA DECISION MAKING FOR CONTRACTOR SELECTION USING ANALYTICAL HIERARCHY PROCESS (AHP): A CASE STUDY IN ERBIL

**MASTER THESIS**

**DLVEEN ALI HUSSEIN**

**Nicosia**

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**MASTER THESIS**

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**January, 2022**

# Approval

We certify that we have read the thesis submitted by **DLVEEN ALI HUSSEIN** titled **" MULTI - CRITERIA DECISION MAKING FOR CONTRACTOR SELECTION USING ANALYTICAL HIERARCHY PROCESS (AHP): A CASE STUDY IN ERBIL "** and that in our combined opinion it is fully adequate , in scope and in quality , as a thesis for the degree of Master of Educational Sciences.

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I hereby declare that all information in this document has been obtained and presented by academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I hadfully cited and referenced all material and results that are not original to this work.

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**To my parents…**

## ABSTRACT

It is known that the success of any engineering project relies on the whole process of selecting a suitable contractor , a contractor who will be capable and reliable enough to handle all the aspects of any project and any obstacles they may come across with their capabilities. The following research focuses on developing a decision-making model to assist in the selection of a competent contractor concerning the given project factors by applying the Analytical Hierarchy Process as a scientific base for the selection mechanism. The established model assessed by utilizing the model in a realistic scenario, in which the contractors participating in the tender will be subject to the assessment process to determine the competent contractor for the suggested project. To obtain the research objective, the criteria utilized in this research were identified through constructive interviews and survey questionnaires, which were designed to define the criteria and their quantitative weights. In the first questionnaire, the respondents were required to judge the significance of the criteria. The second questionnaire was utilized to allow respondents to make pair-wise comparisons constructed on the Analytical Hierarchy Process method to identify the weights of the selected criteria. Based on the results acquired, the contractor selection model was established. The criteria were structured concerning the Geometric Mean (GM) and Saaty's Linear Scale. The weights of the selected criteria were computed through the Open Decision Maker (ODM) software to determine the winning (competent) contractor. Based on the results acquired in the following research, the criteria which obtained the highest rank was Past Performance, whereas the most commonly relied-on factor during contractor selection is Price Bid.

**Keywords:** Decision-making, Analytical Hierarchy Process, Geometric Mean, Saaty's Linear Scale, Open Decision Maker

# ÖZET


Herhangi bir mühendislik projesinin başarısının, uygun bir yüklenici , herhangi bir projenin tüm yönlerini ve sahip oldukları yeteneklerle karşılaşabilecekleri engelleri ele alabilecek kadar yetenekli ve güvenilir olacak bir yüklenici seçme sürecine dayandığı bilinmektedir. Aşağıdaki araştırma, Analitik Hiyerarşi Süreci'ni seçim mekanizması için bilimsel bir temel olarak uygulayarak, verilen proje faktörleriyle ilgili yetkin bir yüklenicinin seçilmesine yardımcı olacak bir karar verme modeli geliştirmeye odaklanmaktadır. Kurulan model, ihaleye katılan yüklenicilerin önerilen proje için yetkili yükleniciyi belirlemek üzere değerlendirme sürecine tabi tutulacağı gerçekçi bir senaryoda model kullanılarak değerlendirilecektir.

Araştırma amacını elde etmek için, bu araştırmada kullanılan kriterler, kriterleri ve nicel ağırlıklarını tanımlamak için tasarlanmış yapıcı görüşmeler ve anket anketleri ile belirlenmiştir. İlk ankette, katılımcıların kriterlerin önemini değerlendirmeleri gerekiyordu. İkinci anket, katılımcıların seçilen ölçütlerin ağırlıklarını belirlemek için Analitik Hiyerarşi Süreci yönteminde oluşturulan çift açısından karşılaştırmalar yapmalarına izin vermek için kullanılmıştır. Elde edilen sonuçlara göre yüklenici seçim modeli oluşturulmuştur. Kriterler Geometrik Ortalama (GM) ve Saaty'nin Doğrusal Ölçeği ile ilgili olarak yapılandırılmıştır.

Seçilen kriterlerin ağırlıkları, kazanan (yetkin) yükleniciyi belirlemek için Açık Karar Verici (ODM) yazılımı aracılığıyla hesaplanmıştır.

Aşağıdaki araştırmada elde edilen sonuçlara dayanarak, en yüksek dereceyi elde eden kriterler Geçmiş Performans olurken, yüklenici seçimi sırasında en çok güvenilen faktör Fiyat Teklifi'dir.



**Anahtar Kelimeler:** Karar Verme, Analitik Hiyerarşi Süreci, Geometrik Ortalama, Saaty'nin Doğrusal Ölçeği, Açık Karar Verici

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# LIST OF ABBREVIATIONS

**AI:** Artificial Intelligence

**ANN:** Artificial Neural Network

**BRT:** Boosted Regression Tree

**FA:** Factor Analysis

**FRSA:** Feature Removal Sensitivity Analysis

**KMO:** Kaiser-Mayer-Olkin

**LRM:** Logistic Regression Model

**PCA:** Principal Component Analysis

**RTA:** Road Traffic Accident

**SA:**SensitivityAnalysis

**SISO:** Single-Input Single-Output

**SVM:** Support Vector Machine

**WHO:** World Health Organisation

# CHAPTER I

# INTRODUCTION

Many factors influence the success of a project. One of the main factors that affect the success of a project is the availability and presence of a suitable and competent contractor. Choosing a well-fit candidate as a contractor for any project is the most vital aspect in determining the success of the project at hand. When determining the success of a project, various elements are taken into consideration such as cost (budget), quality, safety, and time duration. For a project to meet these requirements, it is necessary that a qualified jury or individual, who is well educated and experienced, select the most competent contractor for the project. It is essential to utilize decision-making in contractor selection to guarantee that the contractor selected has the capability of implementing the project appropriately. Various methods are commonly used to choose a qualified contractor. These methods depend on the decision-making of choosing the appropriate candidate by considering the following factors; lowest bid price, the experience of the contractor, or the client's desire to select a certain contractor. The last factor is usually considered a biased decision and leads to an unfair assessment among the other participants. Due to the many disadvantages that result from the common methods applied, an innovative method in decision-making was presented. This method is referred to as the Analytical Hierarchy Process (AHP) approach. The AHP was first proposed by Professor Thomas L. Saaty (1960). It is recognized as an effective method that can be applied to complicated decision-making problems to assist the decision-maker to prioritize their initial judgment. The AHP works by reducing complex decisions through pairwise comparisons to determine the best alternative. Moreover, the method incorporates a useful approach to evaluate the tenacity of the decision-makers assessments to prevent any bias during the process.

The AHP considers the criteria and set of possible alternatives that will be used to evaluate the contractors, which will ensure that the appropriate decision will be made. For every contactor criterion available, the method presents a weight based on the decision-makers pairwise comparison. The criterion that obtains the highest weight is considered the better alternative. Many types of research have shown that the common complications that hinder the success of construction projects in Iraq are mostly contractor-related issues. Some of the most reoccurring causes related to contractor selection were awarding contracts to the lowest bidder, the inadequate experience of the contractor, financial difficulties from the contractor, problems with contractors and sub-contractors, and so on. For construction projects in Erbil, a Governorate in Iraq, it has been observed that the most common methods used to select contractors for projects usually rely on the lowest budget. Therefore, the following thesis was focused on applying the Analytical Hierarchy Process as the fundamental approach to use in contractor selection for local projects in the Erbil Governorate.

### 1.2 Research Problem

To ensure that a project is delivered successfully, a competent contractor must be selected to implement the project and deliver the desired outcomes. Generally, contractors are chosen based on the preference of the client's selection priorities, which may vary from one client to another. Some clients depend on selecting contractors with the lowest bid and ignore the other factors, which might influence performance. Whereas other clients select contractors according to the contractor's experience within the field while observing their past works that are effective and successful. When selecting a competent contractor for any project, the client is capable of avoiding many factors that result in project failure. Some of these factors include project delays (time overruns), budget variations (cost overruns), disputes between workforces in the project, and the quality of the work delivered. All these factors are a result of selecting an incompetent contractor. Therefore, the Analytical Hierarchy Process (AHP) will be introduced to simplify the decision-making process. The AHP mechanism acknowledges all the factors that are considered by the client when selecting a competent contractor. The process will consider all the factors, equally, which will lead to the selection of a competent contractor for the project-based judgmental priorities of the client.

According to the previously stated problem, various researches and observations will assist in identifying the criteria (factors) selected when determining the competent contractor, which influences the success of a project. As a result, the primary question that should be considered at all times is 'How do the selected criteria affect the success of a project concerning the perception of a principal organization?' The outcomes that were gathered resulted in defining the main set of criteria that are taken into consideration when selecting a contractor. The criteria that were chosen are 'bid price', 'firm's background', 'financial capability', 'technical capability', 'construction capability', and 'experience'.

## 1.3 Models Applied for Contractor Selection

There are two phases undertaken when selecting contractors. The initial phase is recognized as the pre-qualification phase and the second phase is known as the final contractor selection phase. For both phases, there have been various selection models proposed. The following models were identified by Jeffrey S. Russell (1992).

### 1.3.1 Financial Model

The Financial model is composed of a formula that integrates the financial framework to acquire the highest quantity of uncompleted work that a contractor is capable of having at any one time while under contract. The formula integrates structures from financial statements or balance sheets to obtain the maximum capacity of uncompleted works for a contractor. Typically, when judgmental priorities are computed, factors such as safety and past performance are employed.

### 1.3.2 Linear Model

The linear model is recognized as the most commonly known and implemented approach when solving problems. The method demands that all decision criteria be weighted and ranked by the decision-maker. Generally, the criteria that obtain the highest weight and ranking are determined to be the most significant alternative.

### 1.3.3 Fuzzy Sets Model

The fuzzy set's model assesses contractors by using several criteria and determines the fuzzy weight for each criterion. A triangular fuzzy number is applied to identify the suitability relevant to the selected criteria. The approach is utilized in the evaluation and selection process, which allows the obtained data to be applied by using various degrees of experience. Some applications of this approach are found in Brown and Yao (1983).

### 1.3.4 Statistical Model

There are various tactics, which can be utilized to develop decision-making models and they are factor assessment, discriminant assessment, and regression assessment. Such models assist in the prequalification phase (contractors) that use a logical regression approach, which determines the extent of success for a certain project. The models depend on the following factors in a project: management, planning, safety, and employers.

## 1.4 Research Objectives

The research objectives that will assist in obtaining the research hypothesis are:

- To determine the significant criteria that are acknowledged in the decision-making process for the selection of contractors locally (in Erbil)
- To establish a contractor selection model for the decision-making process by utilizing the Open Decision Maker (ODM) and the Analytical Hierarchy Process (AHP) approach.
- To integrate scientific methods with the AHP to resolve the contractor selection problems.
- To offer a guideline that assists in assigning scores to contractors based on each criterion following the AHP model.

## 1.5 Thesis Importance

In general, all research ever performed were founded on acquiring a specific objective/target. This is also recognized as the significance of the study. The following study was able to identify the significance and impact on society, the public sector (government), and interested researchers in the same field of work. These factors are briefly discussed below.

### 1.5.1 The Significance of the Thesis to Society

The significance of this thesis handles sensitive matters that influence all members of society and acknowledges the engineering features and construction projects that largely advance the community.

### 1.5.2 The Significance of the Public Sector (Government)

According to previous researchers, we were able to observe that the majority of the consultant offices, firms, and public sectors depend on the ‘lowest bid price’ when selecting a competent contractor for any given project. An all-inclusive integrated technique founded on a scientific basis must be proposed to meet the demands, as well as be in line with the regulations of the district, which encompasses all the details that may be unavailable in the current selection approach. The weights that will be employed in the selection process will be examined, assessed, and standardized to validate their precision and effectiveness in determining the aim of this process, which is determining the better alternative.

### 1.5.3 The Significance of the Thesis to the Interested Researchers in the Work Field

Since there are many complications that the majority of the consulting offices face when selecting contractors, the following study will greatly influence the development of knowledge and experience for researchers in this field. The research offers valuable and useful information by using modern qualitative methods in decision-making.

## 1.6 Research Hypothesis

The hypothesis of this research considered examining the validity of each of the following:

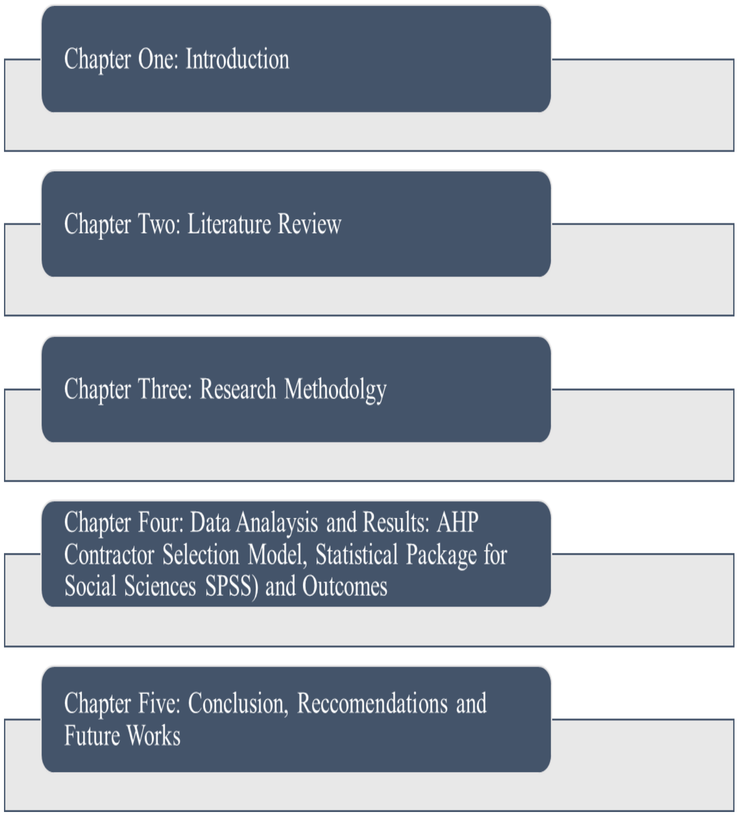
Null Hypothesis (Ho): The AHP has no positive impact on the decision-making process for contractor selection and utilizes the conventional assessment methods that acknowledge various significant factors like cost, quality, past performance, financial ability, and technical capability. Alternative Hypothesis (H1): The AHP has a positive impact on the decision-making process for contractor selection and utilizes the conventional assessment methods that acknowledge various significant factors like cost, quality, previous performance, financial ability, and technical capability.

## 1.7 Structure of Thesis

The following thesis will be divided into five chapters. The chapters are briefly discussed below. Figure 1, shown below, illustrates the chapters and their titles respectively.

**Figure 1.**

**Thesis Structure**




Chapter One 'Introduction': The introductory of this thesis identifies the problem, contractor selection, which will be the central focus of this research, and the importance of selecting competent contractors for projects. It will also discuss the various models that are applied in the selection process. The chapter will also discuss the research hypothesis, research objective, and methodology that will be followed in this research.

Chapter Two 'Literature Review': This chapter focuses on gathering previous studies and works that relate to the subject of this research. The previous studies were relevant to the generalized multi-criteria decision-making methods. Additionally, some studies centralized on the Analytical Hierarchy Process method/theory and determined the important criteria for contractor selection.

Chapter Three ‘Research Methodology’: The third chapter will discuss the research method applied in the study and identify the tactics utilized to determine the criteria. The AHP will be discussed in detail along with several other approaches used in decision-making. The decision-making process does not only rely on selecting the better alternative but also considers the alternatives, possibilities, and risks. To determine the criteria, the opinions of experts and their judgments were depended upon, as well as to determine the preference and relative importance for the criteria utilized in contractor selection and verifying the consistency of the pairwise comparison matrices. This section discusses the calculation process in detail to simplify the comprehension of the results attained.

Chapter Four ‘Data Analysis and Results’: In this chapter, the contractor selection model is proposed and applied by using the Statistical Package for Social Science (SPSS) and the AHP. The findings gathered from the questionnaires relevant to the preference of the criteria are structured into a hierarchy, where the relative weights are computed from the pairwise comparison matrices. To verify the workability of the established model, a sample problem for contractor selection was introduced. The problem consisted of five contractors and was structured into the model and implemented along with the sensitivity analysis process.

Chapter Five ‘Conclusion, Recommendations and Future Works’: The concluding chapter of this thesis was centralized on determining the major findings achieved from carrying out this study. The recommendations will be proposed in regards to the application method of the established contractor selection model and recommend future works.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Introduction:

Not all contractors are completely qualified for a particular project; one contractor may be better suitable than another based on the distinctive requirements of the project. All the contractors have unique advantages and disadvantages, where the best contractor is governed by the conditions of the particular project. The following section will discuss the information gathered on the Analytical Hierarchy Process, the methods applied in contractor selection, the criteria applied in selecting and evaluating contractors, and the application of the AHP to contractor selection problems.

## 2.2 The Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process was introduced by Thomas L. Saaty in the year of 1970. The theory is viewed as one of the vital multi-criteria approaches applied. The presence of the concept of AHP allowed researchers to study the advantages and disadvantages of the methodology, look for improvements and modifications, which will be briefly discussed below.

Wind (1987) intended to apply the AHP framework and concept to the design and evaluation of a market-driven business and corporate strategy. The market-driven strategic plan in this study was defined based on the AHP method and fixated on the hierarchy to attain the process and outcomes. The functional requirements are weighted and assessed according to their capability to acquire the desired market range. The study ascertained the value of the AHP approach for producing and assessing market-driven business and corporate strategy. The results suggested that the process is easily applicable and offers a simple method for the business and planning procedure.

Saaty in 1987, presents the AHP method as an approach of measurement and discusses concepts relative to this process. The author defines how the AHP theory may be applied to derive ratio scales from discrete and continuous pairwise comparisons; hence, the theory can be applied to actual measurements or a fundamental scale. The AHP was introduced through two hierarchical structures, given axioms and the central theoretical underpinnings of the theory. The study also discussed the ideas relevant to the theory and its application related to the AHP.

Zahedi in 1993, attempted to study the foundation of the AHP theory and define the conditions in which the alternative selection is consistent with the maximization of the respondent's utility function. The study was performed using the utility functions of the types: uni-attribute, multi-attribute, additive and non-additive. It verifies that the AHP is consistent with maximizing criteria when the fundamental utility function is uni-attribute. An interesting result acquired from the research was that the unconditional nature of the ability opens up an interesting and rare researched area for combining the AHP and utility theory resolving issues in the selection procedure. The importance of aggregation approaches applied in combining relative weights to obtain global relative work was highlighted throughout this analysis. The AHP method is alternative dependent, which implies that the relative weights and final rankings of the comparisons are a function of a set of alternatives given to the decision-maker.

Bhushan and Rai  in 2004, introduce the AHP process and discuss the problems that might be encountered during the decision-making procedure. Decision strategies that were applied in the past were found to mathematical or theoretical and not effective on the problems faced today. Previous approaches have been used and developed in the fields of mathematics, operations research, cybernetics, etc. to assist in decision-making, which resulted in a large expansion of quantitative alternatives using standard methods. Furthermore, the study lists the different complications of decision-making and informs how to derive weights, rankings, or significance of a set of alternatives depending on their impact on the situation and objective. The AHP assists the decision-makers ideas and organizes the obstacles faced in a much simpler manner so that it is easy to follow and analyze. The method proved to be successful through its capability of obtaining results that correspond with anticipations and assessments.

Melvin 2012, applied the SAS/IML to implement AHP using personal, medical, and business decision-making examples, which produces outputs that include criteria measures and significance of selection and consistency of data. To manage the problems and critiques that might influence the AHP, modifications were recommended in this study to handle these problems. The solutions incorporated methods of computing, synthesizing pair-wise comparisons and normalizing the weighing factors.

## 2.3 Methods Applied In Contractor Selection:

Contractor selection is an essential procedure in the decision-making process. Numerous approaches have been examined, which discuss the possibilities available for contractor selection. The previous studies applied in this division will highlight the various conceptions used to resolve these complications.

### 2.3.1 Graph Theory and Matrix Technique

Darvish, Yasaei and Saeedi in 2009, utilized both the graph theory and matrix techniques to render how they can function as decision analysis tools for selection. These two techniques acknowledge any number of quantitative and qualitative features simultaneously. The study presented an alternative assessment and allowed the visualization of several criteria using a graphical representation. The results are gathered to rank the alternatives and allow for better assessment. The outcomes of the study revealed that the approach is highly preferred and can be utilized on several projects given that it provides more actual and specific results due to its integration of interdependent associations.

### 2.3.2 TOPSIS and VIKOR Technique

Ramón in 2012, generally debate the various approaches applied in contractor selection. A case study was also presented in this study, which uses two approaches that are the technique for order preference by similarity to ideal solution (TOPSIS) and the vlsekriterijumska optimizacija I kompromisnoresenje (VIKOR) in Serbian. These two approaches handle complications within decision-making through different perspectives, in which the TOPSIS approach assists decision-makers in the selection of an alternative that makes profits and avoids risks as much as possible. Contrarily, the VIKOR approach befits decision-makers that seek maximum profit without considering the risks. The two approaches were applied in this study to help in the contractor selection process for a road construction project. The VIKOR and TOPSIS methods are integrated with AHP for the qualitative criteria and the weight assigning. The outcomes gathered revealed the two methods to be applicable within the process of contractor selection.

### 2.3.3 Delphi Approach and Analytical Network Process (ANP)

Jeng-Hsiang and Chien-Jou in 2016, presented a study in which the fuzzy Delphi approach and the Analytical Network Process (ANP) were exploited to resolve the complications faced when selecting an optimum construction project. The Delphi technique was utilized to define the factors that affect the selection results and develop some evaluation criteria. The ANP was utilized through the application of the quantitative procedures to pinpoint the relationships between the candidate projects, the objective, and the evaluation criteria. The ANP method structures the problem into a hierarchical form and offers a systemized process of analysis, which determines the weight of each criterion, its significance, and the possibility of successfully reaching the objective. A framework was provided in this study to determine the most vital criteria from a scope of alternatives and the results revealed that the ANP might be applied as an effective decision-making model, capable of analyzing construction projects and selecting the optimal project.

### 2.3.4 Qualification Based Selection Technique

Ikbal in 2015, examined the complications of the contactor selection process and introduced a significant methodology for this process. The proposal advocates a new model development through utilization of the Qualification Based Selection approach. The prevailing system applied for contractor selection is inadequate when identifying the pre-qualifications and using the lowest bid selection techniques are the weaknesses of this process. Through the application of the QBS system, targets improving and benefiting the existing methodologies.

### 2.3.5 The Fuzzy Analytical Hierarchy Process (AHP)

Noktehdan, Zare, Adafin,Wilkinson and Shahbazpour in 2020, conducted a study on the ranking and selection of innovation in infrastructure project management by applying the Fuzzy Analytic Hierarchy Process (AHP). The researchers advocated the use of a procedure to determine the weights of the alternative innovations within the FAHP that is established on the anticipated values of the fuzzy numbers and their produces. The outcomes revealed that the innovations identified have several important ranks within infrastructure projects. The research also included a case study on an infrastructure rebuild that reported over 500 innovations was analyzed. The study portrays the classification process that can be applied by project owners, the application of mechanisms to impact the development and adoption of construction innovations, as well as informing professionals on the method of maximizing productivity performance within infrastructure projects through the classification of innovations.

**2.4 Previous Works:**

Typically, there have been a majority of research conducted on the Analytical Hierarchy Process (AHP). Moreover, there have been studies that mainly target the use of the AHP method in contractor selection. Some of these studies are briefly discussed below.

Hatush and Skitmore in 1997, focused their study on classifying the global criteria for prequalification and bid assessment as well as the methods by which various emphasis can be developed to accommodate the client's and project's demands. The outcomes gathered revealed the most common criteria recognized by procurers during prequalification and bidding procedures are those about financial soundness, technical ability, management capability, and the health and safety performance of contractors.

Cheng and Heng Li in 2004, analyzed the various contractor selection approaches through mathematics. The study proved that the analytic hierarchy process (AHP) could only be applied to hierarchical decision models, as for the complicated decision models, the analytic network process (ANP) is highly suggested.

Anagnostopoulos and Vavatsikos in 2006, recommended the use of a multi-criteria decision-making approach, established on the Analytic Hierarchy Process (AHP), to support public authorities throughout the contractor prequalification process. The decision problem was divided into qualitative criteria that were further evaluated in quantitative indicators on which the selected contractors were evaluated. The model reduced the required pairwise comparisons, which was considered a major fault of AHP.

Khodadadi and Kumar in 2013, merged the risk management procedure and the comparative logic, which are utilized to specify and rank the risks of contractors. After identifying the risk factors and the evaluation through the AHP logic, it was advocated that once the weight is obtained, the criteria and competence score for every individual contractor is calculated. This applied model can help the employers conclude if the execution of the project by the chosen contractor would encounter minimal risk.

## 2.5 Criteria Applied In Selection And Evaluation:

During the selection and evaluation process, the criteria is an essential component. Numerous studies have been carried out to identify the criteria that would be considered appropriate for the model at hand. The objective of analyzing these researches assists in acquiring an outline of criteria selection.

Banaitene and Banaitis in 2006, analyzed the criteria for the evaluation of contractors' qualifications. The research studied companies and assessed their complications on the criteria for the evaluation process and the importance of the criteria's weight. A qualitative analysis was compiled by identifying the main objectives and developing a survey (questionnaire). Respondents were required to identify the size and activity of the company, the tendering process they applied for contractor selection, and the method used to determine their selection criteria. The results showed that qualifications must be assessed by defining and classifying the appropriate criteria and contractors should not be selected based on the lowest price but according to the highest weight.

Hemanta in 2009, examined the ability of contractor selection depending on their previous capability of successful project delivery. A set of questions were designed to determine the selection method and the impacts for predominant success were evaluated by applying the Statistical Package for Social Science (SPSS) software package. Forty-three attributes were taken and simplified into ten broader titles; which were as follows; respondent details, project-specific, management expertise, quality control systems, flexibility, experience/past projects, success and failures, financial viability, relationships, and tender price and quality. The list of attributes utilized in the questionnaire covered most attributes applied in the contractor selection for construction projects. The data collected was used to establish a quantitative analysis according to the responses to work out a consequential relationship among the attributes. Respondents were required to provide their results on a scale of varying degrees of agreement or disagreement adapted from the Likert scale. The respondents were all experienced, having worked on projects with contractors and subcontractors. There were 155 surveys sent out, with a 43.2 % response rate, and based on the outcomes, the most critical factors influencing the contractors' ability to obtain time, cost, and quality success are the soundness of business and strength of the workforce of the contractor.

Watt, Kayis and Willey in 2010, conducted a study to determine the importance of the criteria utilized during selection processes. The researcher depended on exploiting the Discrete Choice Experiment (DCE) in this study. In which the respondents respectively assess the contractor's features as a function based on the level or value given to the individual criteria. The objective of such a structure is to avoid the domination of one alternative over other criteria, which encourages respondents to make sensible trade-offs. This study was able to present an efficient and secondary technique to develop criteria importance regarding contractor selection. The results obtained showed that the most significant criteria when selecting a contractor depends on previous project performance, expenses, and technical expertise respectively of organizational experience, workload, and reputation, which were considered the least important criteria.

Puri and Tiwari 2014, studied the familiar theatrical approaches applied in contractor assessment and examined the actual criteria for contractor selection. This study targeted the evaluation of the criteria for contractor selection and bid evaluation techniques, where different alternatives were considered to suit the project and client demands. To complete this study a questionnaire was established and sent to various project managers. There was a 72% response rate, which was remarkably high. The results collected revealed that the majority of the respondents generally chose one criterion to qualify a candidate, which criterion was typically the contractor's experience. To minimize the risks that construction projects might encounter, complete and broad contractor evaluations preceding selection is recommended.

Hasnain, Ullah, Thaheem and Sepasgozar in 2017, incorporated Best Value (BV) as a procurement approach rather than the traditional low bid process. The BV procurement approach is an effective and competent system that considers cost and other factors for evaluation and selection, which enhances the ongoing value of construction and performance. This study aimed at identifying the best value contributing factors for contractor selection and assisting decision-makers by determining the factors vital to successful procurement. The AHP method was used to identify and prioritize the contributing factors influencing the decision-making process for contractor selection. The outcomes showed that performance and cost criteria are the top factors representing their importance in decision-making.

## 2.6 Applying AHP to Contractor Selection Problem:

The AHP theory has been applied to a wide range of fields. There are various works on the application of AHP to contractor selection complications. Some of these works have been studied and discussed below.

Zala in 2011, targeted their research on the assessment and selection criteria of contractors. Several companies and the criteria used for evaluating the contractors' prequalification and how they determined the significance of the weight of each criterion, were also analyzed. The AHP methodology was taken into consideration to apply this strategy to the selection problem (based on the Indian context). The complications encountered in this process were the prequalification of contractors and the selection and evaluation for the process of multi-criteria decision-making. Data was gathered and utilized to develop a hierarchical structure model that represents the AHP. By using this strategy, an approach for contractor selection was generated to assist in the selection process.

Balubaid and Alamoudi 2015, analyzed the effectiveness of the AHP regarding the selection of contractors. The AHP approach was employed as a decision support model, which allowed clients to recognize the contractors that will offer better and more satisfying results. The model was tested by utilizing a hypothetical framework, which assessed six criteria for the participant contractors. Every criterion was assessed according to the main objective of the selection process. For data collection and identifying the significance of each criterion, a questionnaire was distributed to specialists in the project management field. The criteria were compared and given a score, where the alternative with the highest score is judged the best candidate. The model was proved efficient in selecting the adequate contractor depending on other alternatives by employing the analytical hierarchy process rather than the traditional lowest bid method.

Oyatoye and Odulana 2016, determined the complications of contractor selection in the area and aimed to develop a model utilizing the AHP approach to enhance the selection procedure. In the area studied, contractors are selected depending on personal associations with the presence of favoritism for personal advantages. Sequentially, this process for selection negatively influences the project's overall performance. An approach was established to solve the evaluation process that is generally applied. Depending on the AHP as the foundation of the approach applied, data was collected and assessed for the selection process to distinguish the main criteria. Once the situation is identified, a model system is established by distinguishing the application and operation framework. The alternatives were then rated and the alternative with the highest rank was selected. The study showed that by identifying the criteria, and alternatives for the AHP model, the selection and evaluation process becomes easy.

# CHAPTER 3
# RESEARCH METHODOLOGY

## 3.1 Introduction

Daily, we are required to make decisions. The decision-making process necessitates us to identify the objective required and select one of the alternatives that appropriately fit the situation. Generally, the implementation of any project requires the participants to make absolute definitive decisions by following the same process. Numerous approaches have been developed to resolve decision-making problems, with time; these approaches have been improved and modified to adjust to the problems that have progressed. A few of these decision-making methods encountered a crucial problem, which was the precise evaluation of the collected data. This led researchers to alter these methods to become more consistent and adaptable.

The concept of decision-making is not only selecting the right alternative/compromise but also, the procedure of considering alternatives, risks, and probable possibilities where a decision is required. Many approaches were established and applied in numerous fields such as business, science, and technical, which assisted in simplifying the decision process. Some of these approaches include the Analytical Hierarchy Process (AHP), Analytical Network Process (ANP), Fuzzy, Graph Theory, and Matrix Method. All the methodologies that were established have been further researched, analyzed, and altered. Moreover, some approaches were combined to acquire better results. An example of such a combination can be seen in the Fuzzy logic, where it has been applied with both the Analytical Hierarchy Process (AHP) and the Analytical Network Process (ANP). This section will explain the AHP method in detail, as well as provide a brief explanation of the other decision-making approaches.

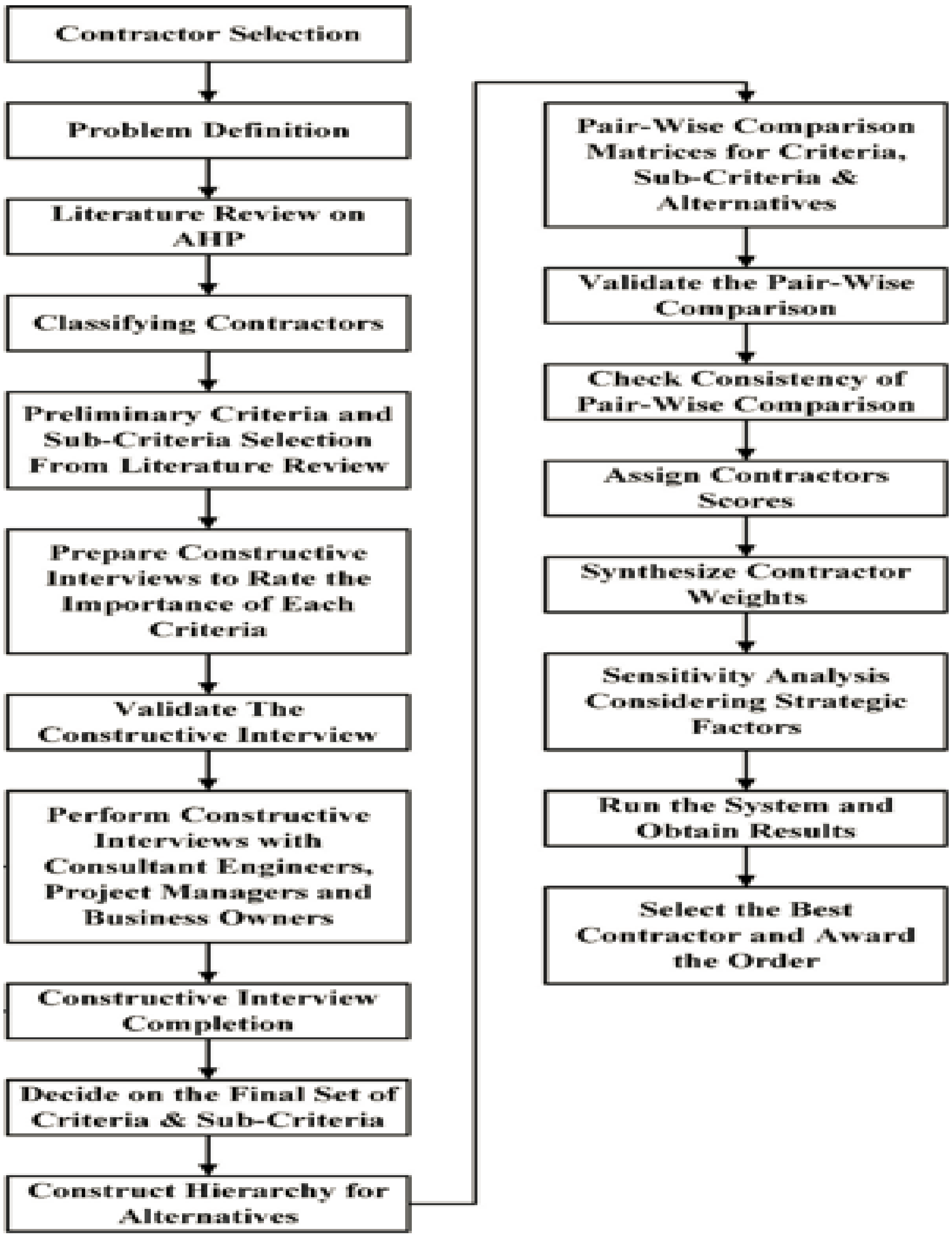
Furthermore, this section will focus on all the aspects that this research depends on. It will include identifying the problem and the process of data collection. The data gathered will depend on primary and secondary data that will be handled using the statistical evaluation techniques concerning the research purposes through the application of the SPSS method. The information collected will be used to develop a modelled hierarchy structure for the selection of contractors.

Additionally, the process for applying the AHP method will be presented along with the development of the factors for the criteria, the preparation of the questionnaire surveys (that will advise the significance of the selected factors), and the analysis of the responses gathered from the questionnaires to develop the final hierarchy of the contractor selection model.

The pair-wise comparisons will also be introduced in this section, which will allow for comparisons among the relative importance of the criteria . after the consistency of the judgments are validated. A guideline will be provided to develop the scoring system for the selected criteria and arbitrary scores will be provided for the contractors in each criterion. The scores obtained will be used to develop the pair-wise comparison matrices to determine the relative weights of all the factors under assessment. The total weight for each contractor will be integrated to acquire the final ranking of the contractors. The final phase is to conduct the sensitivity analysis, which will assist in determining the effect of altering the contractor scores or the relative importance of the criteria on the final decision. The figure below, Figure 2, illustrates the methodology structure that will be followed for this research study.

*Figure 2*

*Flowchart of the Study*



## 3.2 Problem Definition

A major problem in engineering projects is the selection of an adequate contractor, where if the contractor selected is unqualified for the job it can lead to many obstacles for the project at hand. The most commonly used approach for contractor selection is the process of awarding the contract to the lowest bidder without acknowledging other factors like quality, previous experience, safety, etc.., which result in complications such as cost overruns and time overruns. Another issue with the existing selection method is that it often depends on the skill and expertise of the decision-maker, where these aspects differ from one individual to another. There are no standards to ensure the selection process and no logical method from experienced decision-makers has been developed to help with the evaluation of the qualifications, proficiency, and working approaches of contractors to compare with the specified regulations and requirements of the specified project.

There will never be an alternative to dominate another in terms of all the decision criteria given. Hence, the decision-maker is required to conduct a trade-off using structural frameworks that permits the most fitting alternative to be chosen. This process will help in reducing the time and attempts spent throughout the evaluation process. The evaluation process also depends on personal experience, skill, and information quality that differs based on the situation. Hence, the mechanism of decision-making for identifying the most adequate contractor requires skills and proficiency, as well as a predefined and systematic method. A system should be established to assist decision-makers in identifying a suitable contractor for a project. Using the AHP method can assist in reaching an informed decision regarding contractor selection and it will have an advantage in validating the selection decision in two conditions. The first is when the final decision is received and the second is when the decision made is subject to modification or revision by other participants.

According to the literature review, it has been concluded that the AHP is widely applied in decision-making, particularly for contractor selection. Therefore, the following research is targeted at determining the influential factors on contractor selection (locally) and manipulates the factors to develop a model that can be used for contractor selection using the AHP method. This model will help decision-makers/clients to solve the selection problem they encounter when selecting the best contractor.

### 3.3 Data Collection

The data gathered and used for this thesis study are categorized under the information source as either primary or secondary data.

#### 3.3.1 Primary Data

The information gathered in this thesis helps to determine the tangible and intangible criteria that are important aspects of the case study. This is utilized to develop a constructive interview for evaluating the significance of the criteria for contractors. The information also incorporates the viewpoint of experts for evaluating the significance of the proposed criteria, as well as any suggestions for new factors. The experts' judgment on defining the relative importance of the criteria in the final hierarchy structures are also presented.

To acquire the experts' judgments, constructive interviews were carried out with local specialists in the field of contractor selection. For this study, two questionnaires were proposed and distributed. The initial questionnaire was targeted at identifying the significant factors for decision-making during the process of selecting the appropriate contractor. The second questionnaire was created to determine the relative importance of the identified criteria, which was only distributed to a specialized jury in decision-making made up of a few local experts in the field of study. This questionnaire is constructed based on the hierarchal analysis and utilizes matrices to conduct pair-wise comparisons.

The researcher and respondents' inputs are also components of the primary data gathered. The inputs are used to establish a guideline for the scoring system of the selected spate criteria. Furthermore, the inputs assist in defining the factors that are relevant to the sensitivity analysis procedure.

### 3.3.2 Secondary Data

The secondary data is gathered from previous research studies that are relevant to identifying contractor selection criteria, the application of Analytical Hierarchy Process (AHP) in contractor selection, criticism and enhancement of the AHP method, which assists in identifying the common criteria, and the most suitable variation of the AHP approach.

## 3.4 The Analytical Hierarchy Process

Thomas L. Saaty first introduced the Analytical Hierarchy Process theory during the years 1971-1975. The AHP is a general theory of relative measurement made up of absolute scales for tangible and intangible criteria that are used for decision problems. Through the utilization of the AHP, distinct and constant paired comparisons are drawn from ratio scales. The approach has been widely applied in various fields and is part of the MCDM methods group (Multi-Criteria Decision-Making) where it is used for resource and planning allocation as well as resolving problems, especially when multi-criteria decision-making is required.

The system of the AHP identifies the problem, structures the problem into a hierarchy, conducts pair-wise comparisons for each criterion, computes the priorities, and finally, evaluates the alternatives according to the priorities that were found. The AHP works at targeting complex decisions in pair-wise comparisons and reducing their complexity to achieve the best alternative. The mechanism of the approach functions by reducing the multi-dimensional problems to a one-dimensional problem. It incorporates an effective technique to study the determination of the decision-makers assessments, which assists in avoiding any bias during the decision-making process.

Structuring the problem is considered the most vital and efficient phase of the decision-making process. One simple and easy technique to continue the structure is breaking down the objective into more general and easily managed factors. Once the structure is completed, the alternatives that fulfill and combine the criteria are assembled into generic higher-level criteria until the levels are linked in a manner that permits for comparison.

An essential component of the AHP is the utilization of pair-wise comparisons. To determine the priorities of the main criteria, the criteria must be judged in pairs according to their relative importance, which results in the creation of a pair-wise comparison matrix. The decision-maker judges the criteria based on Saaty's fundamental scale, which is composed of a list of verbal judgments that are numbered from one to nine (one meaning equally preferred and nine meaning extremely preferred). There are other scales, which have been suggested by researchers such as the power scale by Harker and Vargas in 1987 and the geometric scale by Lootsma in 1989. However, the Saaty Linear Scale (1-9) is the basic scale used for pairwise comparisons. The quantity of judgments for a specific matrix is in order $n$ and the number of elements being compared are $n(n-1)/2$; (if the value is found to be reciprocal, the diagonal elements will be equal to unity). Another set of pair-wise comparison matrix are developed when the alternatives are respectively compared. The matrices are then translated using the eigenvector to achieve the priorities ranks. The final phase weighs the outcomes to determine the final priorities.

The following three principles can serve as a guideline when applying the AHP to resolve problems: (i) decomposition, (ii) comparative judgments, and (iii) synthesis of the priorities. The principle of decomposition can be obtained through the structuring of the problem from the more traditional and tentative elements down to the more precise and tangible elements. Researcher Saaty classifies the two forms of dependence for elements, which are functional and structural. Functional dependence is a more recognized context of differentiating elements from other performing elements and structural dependence is the dependency of the element's priority on the priority and quantity of the other elements. In situations where structural dependence is ignored among the elements, absolute measurement or scoring is applied, if not then the relative measurement is applied. The second principle, 'comparative judgments', is applied to perform pairwise comparisons relevant to the importance of the elements within a specific level respectively of similar criteria on the next level resulting in the establishment of the matrices that will be used. The third principle, 'synthesizing priorities', functions by multiplying the local priorities with the corresponding criterion of that priority and adding to it based on the criteria it influences, which will result in the composite or global weight of the element that is used to weigh the priorities of the elements.

### 3.4.1 Why the Analytical Hierarchy Process?

To manage the current complex decision problems, innovative logic is required to handle the numerous factors that affect the success of obtaining objectives and the consistency of the judgments to reach influential outcomes. Moreover, the logic should be acceptable, rational, and not complex so that it can be applied as a standard thinking tool and not only by intellects.

Initial studies have shown that the AHP methodology is the most suitable technique to use when resolving complex problems; J.W. Lee, S.H. Kim (2000). Using a hierarchal analysis system contributes to resolving complex problems by using a hierarchal structure composed of relevant parameters and outputs. This structure derives the judgments to establish priorities and predict the possible outcomes corresponding to the judgments provided. The results obtained are used to rank the alternatives, allocate resources, allow comparisons of utility/budgets, and practice managing of the system by evaluating the sensitivity of the results to alterations in the judgments and for anticipated and presumed future planning. The AHP offers the framework required for solving numerous problems and allows the decision-maker to make efficient decisions in complicated situations by simplifying them and encouraging natural decisions.

Essentially, the AHP is an approach that functions by breaking down any difficult and non-structural problem into its basic variables. The variables are then organized sequentially and the personal judgments are utilized to appoint numeric values so that the importance of each variable (separately) is quantified, which assists in determining which of these variables will be prioritized. Moreover, this approach presents decision-making groups with an efficient scientific structure that enforces a system and is committed to the intellectual system of the group. The necessity to establish a numerical value for each variable in the problem structure allows the decision-maker to maintain a rational conceptual model to help achieve the desired outcome. Additionally, the decision-maker's instinctive nature enhances the rationality of the decisions while improving the validity of the AHP method as a tool for decision-making.

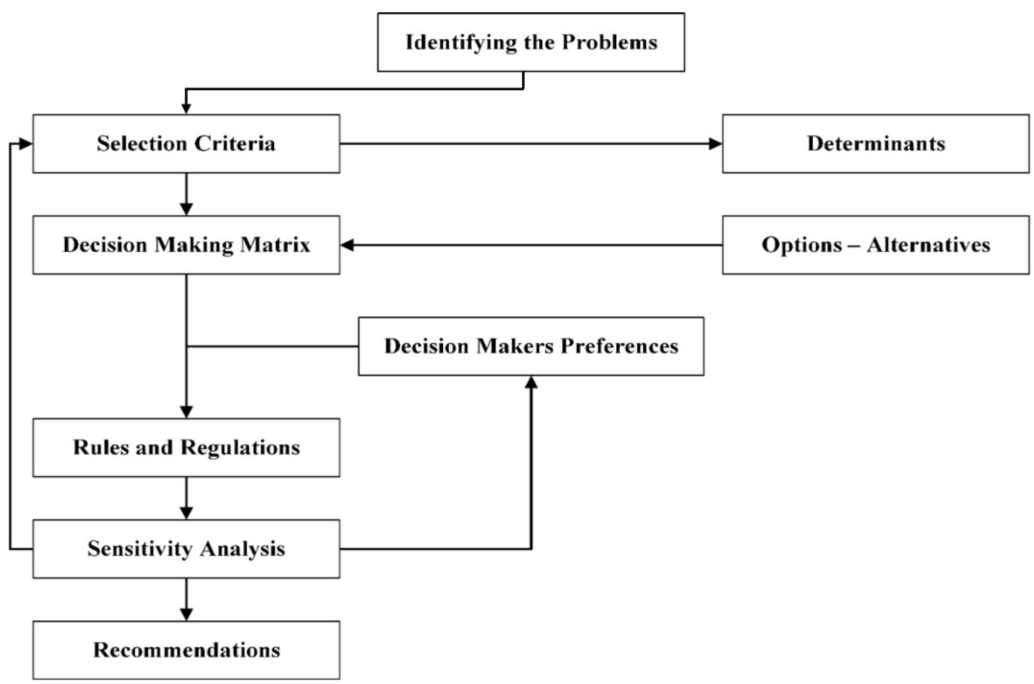
### 3.4.2 Structuring of Knowledge of Decisions

One of the most essential characteristics of the Analytical Hierarchy Process is its attentiveness to the process of the human mind in arranging the information required to make a decision. There have been two basic approaches, developed by humans for analysis, and they are the deductive approach and the systematic approach.

The AHP assists decision-makers to visualize the ongoing interaction of several elements in difficult and unorganized problems. It also helps them to identify the elements of the problem and determine the priorities based on the objective desired, the operator’s knowledge, and experience in every problem. The AHP method was founded on the concept of multi-criteria decision-making (MCDM). The following Figure 3, illustrates the concept of this theory.

***Figure 3***

***Concept Structure of AHP (Malczwski 1999)***



### 3.4.3 Analytical Hierarchy Process: An Adaptable Model for Decision-making

Given that the AHP observes human nature, analytical thinking, and quantification, it has become an efficient tool for resolving quantitative problems. Moreover, the AHP is an adaptable approach that permits individuals or groups to develop concepts, define problems by applying their suppositions to achieve the desired solutions, and test the sensitivity of the results when any data is modified.

The approach has been devised to conform to human nature rather than enforcing a rational situation, which may deviate the better judgments. This allowed the approach to be a powerful tool in solving difficult political and socio-economic conflicts. The hierarchical analysis technique rationally combines judgments and personal values from the user's thoughts, experience, and knowledge, to develop the problem. As for obtaining the judgments, the technique depends on logic, instinct, and familiarity. Once the approach is understood, the process becomes clear; how the elements of one part of the problem are linked with different parts of the problem to reach the complex output of each element. The AHP method defines, understands, and evaluates the overlaps throughout the entire system.

When utilizing the AHP to identify a complex problem and achieve good judgments, it should be repeated several times since it is complicated to expect an instant resolution for a complex situation. The AHP is a flexible method in that it enables decision-makers to revise and expand the problem elements within the hierarchy, modify their judgments, and validate the sensitivity of the outcomes to any expected alterations. Every attempt of the AHP is similar to the hypothesis and testing procedure, where the continuing revision of the hypothesis results in a better comprehension of the process. The numerous practical implementations of the AHP generate samples of the hierarchal structures that can be altered and used to develop new problems.

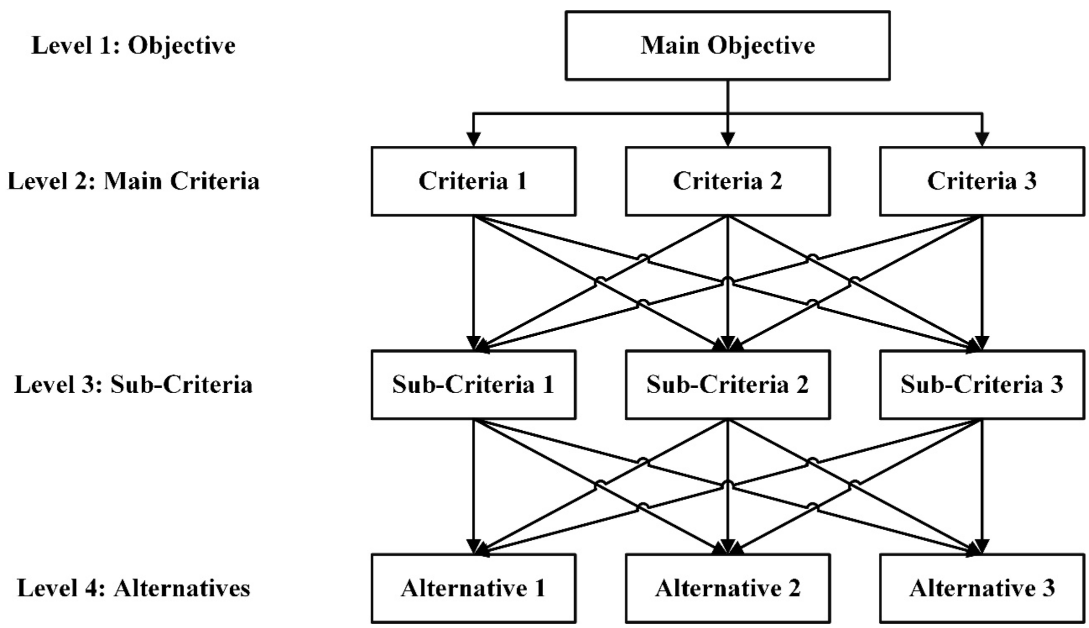
One feature of the AHP is the framework it offers for group participation for decision-making or problem-solving. The judgments provided are usually liable and may be supported or weakened depending on the evidence presented by the other decision-makers. The evaluation process of any complication utilizing the AHP necessitates the decision-maker to consider thoughts, judgments, and evidence accepted by others as essential features of the problem. Moreover, group participation adds to the validity of the outcomes even though it does not contribute to the simplicity of applying the method when the visions vary. Hence, any data can be derived scientifically or intelligently throughout the evaluation process.

The AHP is applicable in realistic situations and useful for allocating resources, planning, assessing the impact of policies, and resolving conflicts. Generally, this approach can be implemented by individuals (such as sociologists, naturalists, engineers, politicians) without any expert assistance. Only the person encountering the problem is completely aware of the full details of the situation. Presently, the AHP method is widely applied in the planning phase of large enterprises, as well as in examining the portfolios and expenditure assessment by government facilities for allocating natural resources for investment purposes.

In the following figure, Fig.4, the typical AHP model applied for the evaluation of the alternatives is illustrated.

***Figure 4***

***Typical AHP model used for Evaluation of Alternatives (Saaty 1996)***

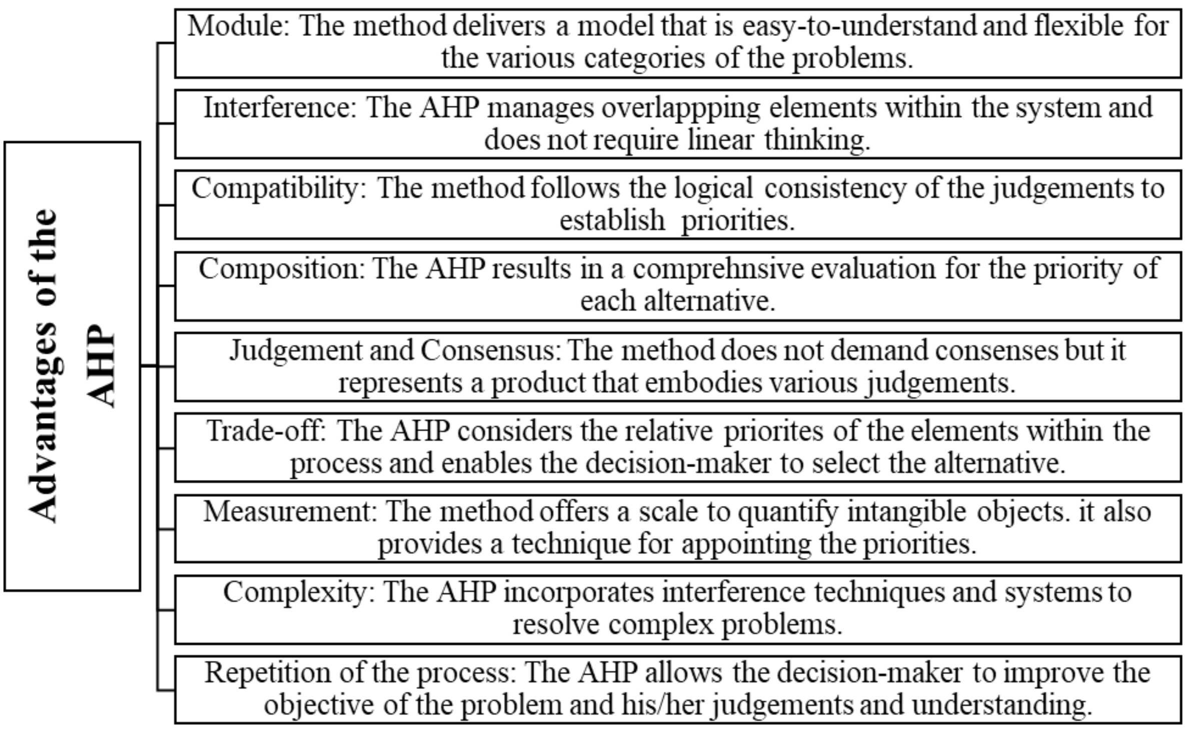


### 3.4.4 Advantages of the Analytical Hierarchy Process

The AHP has been used in various applications and helps in determining subjective and objective analysis measures. There are many advantages to this method and they have been an essential debate matter among the experts. In the figure shown, Fig. 5, the advantages of applying the AHP as an approach in decision-making and solving problems are listed.

***Figure 5***

***Advantages of the Analytical Hierarchy Process***




In the following list, the benefits of applying the AHP method are presented in accordance with how they were identified by the researcher (Warren, 2004):

- The AHP is a practical method that quantitatively handles various forms of functional relationships within a complex system.
- An influential method for incorporating anticipated and desired planning in an essential form that represents all members of the department. Either this process can result in clear

foundations for resource allocation among prevailing and new strategies, or it can satisfy a specific category of the overall objectives under alternatives of natural judgments for an organization.

- The AHP is an innovative approach that integrates clear data with substantive judgments on intangible factors, combines the judgments of various individuals to resolve the differences among them, performs sensitivity analysis and serves as an audit tool at low costs, utilizes minimal and intermediate priorities to rationalize allocation, and strengthens the management ability to make compromises clearer.
- A tool that perfects other tools such as utility, cost, priorities, and risk reduction for the selection of projects.
- It is an alternative for a range of future prediction approaches and protects against risks in the presence of uncertainty.
- Manages and guides the organization towards its objective through a set of critical goals.

### 3.4.5 Characteristics of the Decision-Making Method

The following characteristics are required in any decision-making method:

- It must be simple in structure.
- Individuals and groups can apply the method
- It should be consistent with intellect and general thinking.
- It should encourage compromise.
- It should not require exceptional specialization to master the method and connect it to others.
- The details of the systems leading to the method must be easily revised and edited.

The AHP reflects the instinctive behavior and thinking technique and handles difficult situations based on each of their interactions. It enables the individual to establish the problem as they envision it in terms of complexity and permits them to identify and organize the problem into stages. To determine complex problems, the conflict sites composition and identification must be identified and resolved into a hierarchal structure, which needs the information and judgments from various participants in the system. By using a mathematical sequence, the judgments of the participants are translated into an all-inclusive evaluation of the alternative's relative priorities. The priorities that are obtained from the AHP signify the essential units that are required in all forms of analysis methods, where they may be applied as indicators for allocating resources or probabilities for future anticipations.

### 3.4.6 Classification and Building of Hierarchal Structures

Hierarchal models are categorized into two forms: structural and functional. The structural hierarchal forms incorporate the basic parts of the complex systems in a descending manner according to their structural features (size, shape, color, or age). The structural pyramid is indistinguishably associated with the process in which the human mind breaks down complex problems by disassembling the objects that the senses recognize into larger groups then into smaller groups and so forth. The functional hierarchal forms evaluate the complex systems according to their basic associations. Such hierarchy forms assist the individuals to guide their systems towards the desired objectives like resolving differences, efficient performance, or obtaining complete satisfaction. Each group of elements in this structure occupies one level of the pyramid. The highest level is referred to as the 'focal' or 'central' level, which contains only one element and is the overall general objective. The following levels consist of several elements and usually range from five to nine elements. The elements in these levels are compared to each other according to a specific standard on the level above; hence, the elements of each level are required to be equally significant. For instance, it is impossible to make an accurate comparison between two functions, whose performance is distinctive in terms of complexity with a factor of '100', because the judgments of this situation will be subject to clear error. It is simpler to break down the factors, placing the functions in a set and comparing the functions in this group to the next most difficult and significant functions. All the outcomes are compared to acquire the actual comparison among the easy and more difficult functions. As a result, it is essential to establish these groups to avoid fatal errors. This structural method allows efficient comparisons between easy and difficult situations, which can be completed by developing several hierarchal groups of similar factors so that the transition procedure and comparison of the difficult to easy is possible.

There is no standard basis for constructing hierarchal forms. The process of structuring hierarchal models relies on the kind of decision that is to be made. If the decision requires selecting alternatives, the last level may be initiated by establishing the alternatives presented in the list. The following level will contain the criteria that will be used for judging the selected alternatives, while the higher level will contain only one element for which the decision depends on the existing criteria and the significance of their respective contributions. Take for example; an individual is required to decide on buying a sports car from five different types. These types of sports cars will form the last level in the hierarchy structure and the next level will contain the criteria used for judging them. The criteria can be financial ability, social advantages, necessary demands, satisfying other needs, and so on. The priorities of these criteria will be defined according to the decision which each criterion provides in obtaining the central level of the structure, which is selecting the best car.

The fundamental basis for structuring hierarchal forms is the capability to answer the following question; ‘Can lower-level elements be compared to some or all of the elements at the succeeding or higher level?’ There are some propositions to develop an accurate structure and include the following:

- Identifying the overall goal, the sub-goals, and the time prospects that affect the decision.
- Identifying the criteria that should be met to reach the sub-goal.
- Identifying the main criteria by using sets of numerical values or verbal concepts.
- Determining the active individuals objectives and policies.
- Determining the alternatives or outcomes.

As for decisions that require either a ‘yes’ or ‘no’ answer, compare the costs and benefits if the decision is made and conduct revenue and cost evaluations by using marginal values. The most effective method to construct a hierarchal structure is to conduct an in-depth analysis on the subject in the presence of a group of investors and then list all the elements and alternatives relevant to the situation at hand. The participants then gather the alternatives and structure them into a hierarchy to carry out the remaining process.

### 3.5 Other Methods Applied for Decision-Making

The Analytical Hierarchy Process is one of the various tools implemented for resolving selection problems. It follows the multi-criteria decision-making approach (MCDM). Some of the other quantitative approaches that are utilized for decision-making problems will be briefly explained in the following subsections.

#### 3.5.1 The Analytical Network Process

The Analytical Network Process (ANP) was proposed by T.L. Saaty in 1980, in his book 'Multicriteria Decision Making: The Analytical Hierarchy Process". The ANP is believed to be a simplification of the AHP theory. Some decision problems are incapable of being structured in a hierarchy because higher-level elements depend and interact on lower-level elements. Hence, the ANP is an approach that utilizes a network for decision-making problems without requiring the structuring of the alternatives into a hierarchy. The importance of the criteria not only decides the importance of the alternative but also the importance of the alternative decides the importance of the criteria.

Hierarchies and networks differ in that the hierarchy is a linear structure (top-down), while the network spreads in any direction composed of cycles in between clusters and loops within the same cluster. The ANP is made up of cycles that link the components of the elements with loops, which connect the components to themselves. It also contains sources and sinks. The source point is the beginning of the influence paths and is never the destination of the path. The sink node, on the other hand, is the destination of the influence path and never the beginning of the path. A network can be sink nodes, source nodes, cycle nodes, source, and cycle nodes, or sink and cycle nodes.

Some restriction of the ANP is that it demands more comparisons than the AHP and more effort due to the numerous alternatives present in the model. Unlike the AHP, the ANP requires many calculations and the establishment of additional pairwise comparison matrices. Moreover, the ANP method proved to be efficient in solving complex problems that consist of dependent factors and judgments that are evaluated based on advantages, possibilities, expenses, and risks. One benefit of the method is that it is descriptive similar to science rather than just being a normative/perspective framework. The outcomes gained from the ANP are not seen as simple but rather the best results according to the values and risks of the user's choice.

### 3.5.2 The Fuzzy Logic

The Fuzzy Logic was developed by Lotfi A. Zadeh in 1965, who was a professor at UC Berkeley and believed that computer logic is incapable of manipulating vague information. The method was introduced to assist the process of decision-making. Its main features are claimed to be the following; (i) information is considered a fuzzy constraint of variables, (ii) accurate analyzing becomes estimated analyzing, (iii) all rational processes can be fuzzified, and (iv) everything is a matter of degree.

The fuzzy approach is applied in numerous fields to resolve problems relevant to inconsistency and vagueness. It has been identified by the decision–making system as the apprehension procedure concerning the mental process targeted at selecting a single alternative. The method is capable of providing approximated solutions to problems through the processing of inadequate information.

Given that uncertainty is the main factor for developing the models applied, which increases their sufficiency resulting in a realistic and consistent decision alternative according to the evaluations. The various models that are applied in the fuzzy logic are; (i) high-risk decision, (ii) low-risk decision, and (iii) typical risk decision. Generally, the fuzzy method is characterized by the idea of an adaptive model established on approximation. This approach implements human reasoning capacity into artificial knowledge-based systems possible. The main domain employed in the fuzzy approach is dependent on the prevailing uncertainty. The method has proved to be efficient in resolving multi-criteria decision situations since it depends on the satisfaction degree between the alternative and objective. Moreover, the concept of fuzzy logic provides an arithmetical structure that works to employ vague elements, which is a typical multi-objective problem.

### 3.5.3 The Graph Theory and Matrix Method

In some of the contractor selection problems, it is assumed that the selection criteria are independent of each other. In the graph theory and matrix method, the criteria are interdependent rather than independent of each other.  The graph theory method is recognized as rational and methodical and it has proven to be suitable for modelling and evaluating various forms of systems and problems in different work fields. Once the graph becomes very complex, the matrix method is proposed.

The method helps identify the elements and depicts a more appropriate vision of the elements and their associations. It is also capable of handling any amount of quantitative and qualitative elements. Moreover, the graph and matrix method offers high distinction, demands fewer calculations, is established on axioms, and provides a more objective, simplified, homogenous decision-making method.

The graph and matrix method functions by identifying the factors depending on the determined requirements and appointing the factors as a quantitative or qualitative value. The relative association among the factors is then defined and normalized for the various alternatives. After that, the selection factors are attained and the values are normalized and analyzed. The final phase in the method organizes the results in descending order and the alternative with the highest value is selected.

### 3.5.4 The Heuristic Decision-Making Method

Heuristic decisions usually disregard parts of the given information and this does save time and effort, however, it leads to more flaws when compared to the other rational decision methods. The Heuristic decision-making method presumes that disregarding some of the data may provide outcomes that are more accurate and that it is not necessary to weight and add all the data. When the approach was proposed, researchers advocated that simple heuristics were found to be much more accurate than the standard statistical methods, which used the same data. For the first time during the 1990s, it was proven that relying on one good alternative while disregarding the others may result in a higher anticipated validity than the outcomes achieved by the other approaches.

This method is different from the analytical methods because the heuristic methods are applied to find proof rather than check proof like the analytical methods. The framework of this method can be formal heuristic models or inferences rather than preferences; inferences identify the unique criterion and the preferences define the alternatives that do not share the same criteria. The heuristic approach contains both linear and nonlinear hierarchal function models. Rather than gathering the alternatives from constructive interviews, direct quantitative-based questions aimed at the attainable values of various objectives are applied.

### 3.5.5 The Naturalistic Decision-Making Method

To explain the process of human decision-making, in reality, the Naturalistic decision-making method was introduced in 1989. Researchers wanted a better understanding of how the human mind made decisions when placed under tough circumstances such as limited time, imprecise goals, high risks, changeable conditions, and improbability. During the year 1993, nine models for this method were developed. One model was Hammond's cognitive continuum theory, which claimed that decisions fluctuate depending on the extent it depends on the initiative and analytical process. Another model was the cognitive control model by Rasmussen, which distinguished behaviors based on abilities, knowledge, and regulations. According to the outcomes gathered from numerous studies, it was evident that individuals depended on previous experience to make a decision and did not produce or compare alternatives.

## 3.6 Application Method of the Analytical Hierarchy Process

The AHP approach was developed to solve complicated problems, particularly multi-criteria decision problems. The approach depends on the human ability to make thorough judgments on small problems and influences decision-making by arranging the factors into a structure, which faces the forces that influence the effect of the result. The AHP functions by taking a set of specified probabilities and computing the priorities of every probability in the set through a rating scale, which depends on the decision maker's judgment.

Pair-wise comparisons are carried out using ratio scales to establish the relative importance of the factors at each level to the level above in the hierarchy structure. The alternatives at the lower level are then evaluated to ensure that a better decision is made between the various alternatives present.

The contractor selection process can be classified into five main phases that are (i) identifying the problem, (ii) determining the criteria, (iii) ranking and assessing the qualified contractors, (iv) conducting the sensitivity analysis, (v) selecting the best contractor. Listed below are the general steps to follow when applying the AHP method in decision-making and their relevance to solving selection problems.

### 3.6.1 Identify the Problem and Establish the Objective

The problem of this study is the process of contractor selection for any given project. The objective of this study is to rank the qualified contractors based on their success in attaining the evaluation factors and choose the contractor that will gain the award order. Unlike the conventional approaches, which depend on limited selection factors, the modern approaches are built on the deep assessment of tangible and intangible factors for the intention of ranking a set of contractors.

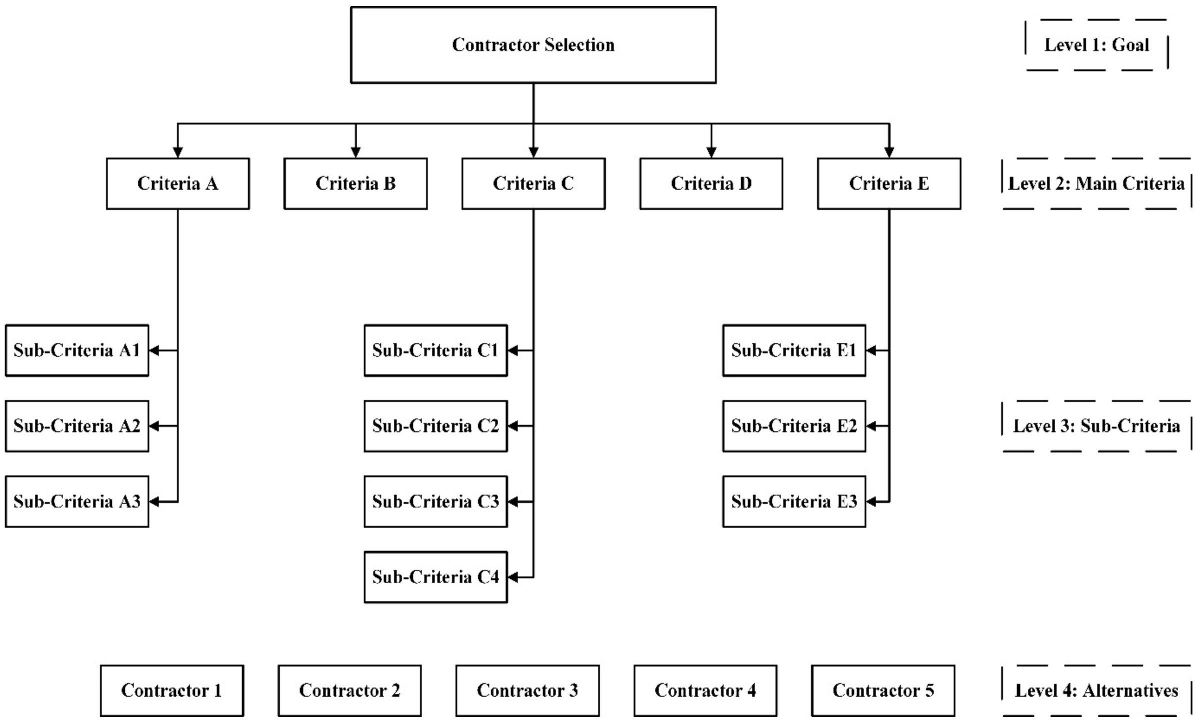
### 3.6.2 Arranging the Vital Evaluation and Decision Factors into a Hierarchy

The complicated contractor selection problem is designed into a hierarchy structure, similarly shown in Fig 5. The highest level of the structure signifies the objective; in this case, selecting the optimum contractor. The lowest level of the structure consists of the contractors competing with one another to win the award order. As for the levels in between, they are made up of the criteria that influence the selection of results. The hierarchy developed needs to contain the most influential factors that are taken into account when selecting the contractor to deliver the project at hand.

To minimize the number of comparison judgments and reduce the complexity of the structure, some of the important factors can be disregarded in the hierarchy model. However, they can be considered by employing them in the sensitivity analysis. Factors that have similar influences are grouped under a specific main criterion to minimize the quantities of comparison judgments and to enhance the quality of the outcome of the decision.

***Figure 6***

***Contractor Selection Hierarchy (Saaty 1996)***




### 3.6.3 Pair-Wise Comparison for Criteria

Given that the criteria of contractor selection are not directly related, they cannot be quantified using the same scale, therefore, pair-wise comparison matrices are applied. The decision-maker uses pair-wise comparison judgments to present his opinion of preference on one criterion over the other while taking into account the main objective required. These comparisons are conducted in terms of which element dominates the other.

To gather the decision-maker's opinion on the relative importance of the criteria, the pair-wise comparison matrix shown in Equation 1 should be produced.

$$A = [a_{ij}] = \begin{matrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}$$

***Equation 1***

$$aij = 1 \ and \ a_{ji} = 1/a_{ij} \quad i,j = 1,2,3,... \ n$$

Where C1, C2... Cn represents the set of elements (criteria), while *aij* represents a measured decision-maker judgment on the relative importance for a pair of elements Ci and Cj using the fundamental scale proposed by Saaty as shown in Table 1.

***Table 1***

***Saaty's fundamental scale***

| Intensity Preference | Definition | Explanation |
| --- | --- | --- |
| 1 | Equally preferred | Activities C1 and C2 equally contribute to the objective |
| 3 | Moderately preferred | Experience and judgment slightly prefer activity C1 over C2 |
| 5 | Strongly preferred | Experience and judgment strongly prefer activity C1 over C2 |
| 7 | Very strongly preferred | Activity C1 is very strongly preferred over C2, its dominance is shown in practice |
| 9 | Extremely preferred | The evidence preferring activity C1 over C2, as the highest possible order of affirmation |
| 2, 4, 6, & 8 | Intermediate Values | When a compromise is required. |

To compare the relative importance between the criteria of the hierarchy structure, it is important to prepare matrices similar to the one shown in Table 2. These matrices are converted into tables and sent to the respondents to gather their priority judgments by using the Saaty scale.

***Table 2***

***Pair-wise comparison matrix***

| | **J** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| **i** | Criteria | C1 | C2 | C3 | C4 | C5 |
| **1** | C1 | 1 | 1 | 9 | 1/7 | |
| **2** | C2 | 1 | 1 | | | |
| **3** | C3 | 1/9 | | 1 | | |
| **4** | C4 | 7 | | | 1 | |
| **5** | C5 | | | | | 1 |

Take for example, if criterion C1is considered as 'equally preferred' to criterion C2, the entry for the cell *c12*, should be '1'. In contrast, if criterion C4 is 'very strongly preferred' to criterion C1, then the entry for the cell *c14* will be '1/7', meaning that criterion C1 is 'very strongly less important' than criterion C4. The diagonal cells of the matrix will always hold the value of '1', given that the criteria are compared with themselves. The respondent needs to give the judgment for the cells that are above the matrix diagonal only (shaded cells) since the values for the cells under the diagonal are the reciprocals of the given judgments. In this case, criterion C1 is 'extremely important' than C3, the value given to the cell c13. The cell c31, which is the importance of criterion C3 compared to C1, is given the reciprocal of c13, i.e. 1/9. This means that criterion C3 is extremely less important than criterion C1. The total number of comparison judgments depends on the matrix size, which is computed by using the following Equation 2.

$$N_j = \frac{n(n-1)}{2} \qquad \textbf{\textit{Equation}}\ 2$$

$N_j$ represents the number of comparison judgments, while *n* is the number of compared criteria. For example, for a matrix of size *n=5*, it will require 10 expert judgments.

### 3.6.4 Pair-Wise Comparison Scales

Researchers and practitioners often use the Saaty linear scale (1-9) for the AHP pair-wise comparisons. Several other scales have been proposed by researchers and have been identified by (Ishizaka and Labib, 2011) as shown in Table 3.

***Table 3***

***Different Scales for Comparing Alternatives***

| **Type of Scale** | Definition | **Parameters** |
|---|---|---|
| Linear (T.Saaty, 1977) | $c = a \cdot x$ | $a > 0\,; x = \{1, 2, \ldots, 9\}$ |
| Power (Harker& Vargas, 1987) | $c = x^{a}$ | $a > 1\,; x = \{1, 2, \ldots, 9\}$ |
| Geometric (Lootsma, 1989) | $c = a^{x-1}$ | $a > 1\,; x = \{1, 2, \ldots, 9\}$ *or* $x = \{1, 1.5, \ldots, 4\}$ or another step |
| Logarithmic (Ishizaka, Balkenborg, & Kaplan, 2010) | $c = \log_{a}\big(x + (a-1)\big)$ | $a > 1\,; x = \{1, 2, \ldots, 9\}$ |
| Root square (Harker& Vargas, 1987) | $c = \sqrt[a]{x}$ | $a > 1\,; x = \{1, 2, \ldots, 9\}$ |
| Asymptotical (Dodd & Donegan, 1995) | $c = \tan h^{-1}\left(\frac{\sqrt{3}(x-1)}{14}\right)$ | $x = \{1, 2, \ldots, 9\}$ |
| Inverse linear (Ma & Zheng, 1991) | $c = {}^{9}\!/_{(10-x)}$ | $x = \{1, 2, \ldots, 9\}$ |
| Balanced (Salo & Hamalainen, 1997) | $c = {}^{w}\!/_{(1-w)}$ | $w = \{0.5, 0.55, 0.6, \ldots, 0.9\}$ |

The leading feature of the AHP approach is its evaluation of quantitative and qualitative criteria and alternatives based on the same preference scale. The scales can be numerical, verbal, or graphical. Since the AHP approach depends on pair-wise comparisons, ratio scales are necessary. Some criticism has been made on the manipulation of scales for expressing opinions, but most scholars prefer this approach. Table 3 lists some of the numerous techniques that have been established for judging scales, yet out of all the proposed scales, the linear scale is most commonly used.

### 3.6.5 Consistency Ratio Calculation

In certain situations, the judgments of the respondents regarding the criteria are not consistent. Hence, the AHP approach developed a technique to determine the consistency of the judgments. The consistency ratio can be used for each comparison matric by applying Equation 3.

$$CR = \frac{CI}{RI} \qquad \textbf{\textit{Equation}}\ 3$$

CR stands for the consistency ratio, CI represents the consistency index of the matrix, and RI is the random index for the same order matrix. The RI is defined as the average value of the consistency index (CI), which is achieved from 500 positive reciprocal pair-wise comparison matrices whose entries were randomly computed using the linear scale (1-9). The values of the random index are identified in Table 4 based on the matrix order *n*. The results were gathered by Saaty in 2001.

***Table*** 4
**Saaty's average random consistency index (RI)**

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.9 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.48 | 1980 |
| RI | 0 | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 | 2001 |

The consistency index CI is computed using Equation 4.

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \textbf{\textit{Equation 4}}$$

Where *CI* represents the consistency index, *n* is the matrix order and is the maximum real Eigenvalue of the matrix.

Even though the set of Eigenvalues can be determined precisely and the maximum real Eigenvalue can be generated using the matrix theory. For the positive reciprocal matrix, the maximum Eigenvalue can be approximately computed from Equation 5.

$$\lambda_{max} = Nw_{i1} * \sum_{i=1}^{n} j_1 + Nw_{i2} * \sum_{i=1}^{n} j_2 + \cdots + Nw_{in} * \sum_{i=1}^{n} j_n \qquad \textbf{\textit{Equation 5}}$$

Where $N_w$ signifies the normalized weight for row n that is calculated through equation 7 which will be presented later on.

$\sum_{i=1}^{n} j_n$ is the summation of column $j_n$ and i and j= 1 to n

According to Saaty (1996), the acceptable CR range fluctuates based on the size of the matrix. (i.e. 0.05 for a 3-by-3 matrix, 0.08 for a 4-by-4 matrix and 0.1 for all larger matrices, $n \geq 5$). If the value of CR is equal to, or lower than the indicated value, then the assessment within the matrix is acceptable and indicates a good level of consistency in the comparative judgments. Alternatively, if the CR is higher than the acceptable value, this signifies that there is an inconsistency in the matrix. Hence, the evaluation process should be reviewed, reconsidered, and enhanced.

**3.6.6 Relative Normalized Weights for Criteria and Alternatives**

Two techniques can be utilized to determine the weights for the elements. The first technique is applying the geometric mean (GM), which can be used for each row within the pair-wise matrix by implementing Equation 6, where $x_i$ is the entry in the $i_{th}$ row and $n$ is the matrix order.

$$GM = \left(\prod_{i=1}^{n} x_i\right)^{1/n}$$ ***Equation 6***

The normalized weight for each criterion is achieved by dividing the geometric mean of the row relevant to the criterion by the summation of geometric means for all rows. The relative weight for each row (criteria or alternative) will be calculated from Equation 7.

$$N_{wi} = \frac{GM_i}{\sum_{I}^{n} GM}$$ ***Equation 7***

Where $Nw_i$ is the normalized weight for row $i$ and $GM$ is the geometric mean for the $i$-$th$ row.

The geometric mean technique may be applied when the pair-wise judgments are rationally consistent; the benefit of using the geometric mean technique is saving time and effort, particularly no specific software for the AHP application is available.

### 3.6.7 Criteria Global Weights

The following equation, Equation 8, is used to determine the global weight for a certain.

$$GWji = GWi * LWj \qquad \textbf{\textit{Equation 8}}$$

Where, GWji is the global weight for criterion j for criteria i GWi is the global weight of criteria i, and LWj is the local weight of criterion j.

## 3.7 Preliminary Selection of Criteria

The preliminary set of criteria are selected from the previous research relevant to contractor selection problems. Once the factors are selected, they are evaluated by experts using constructive interviews so that they can then be structured into the contractor selection model. The factors will be utilized to begin developing the AHP hierarchy. Various factors are considered such as bid price, financial ability, firm's background, technical ability, experience, and construction ability. Most of the criteria were divided into to incorporate the significant factor and minimize the quantity of pairwise comparison numbers.

## 3.8 Constructive Interviews for Rating the Importance of the Selected Factors

A constructive interview was established to assist in determining the significance of the selected factors influencing contractor selection. The interviews were assessed by two experts and verified before the interview occurred.

The backgrounds of the respondents for this study are as follows:

1. Project Managers who are employed in contractor companies with at least 15 years of experience in construction projects, sustainable energy projects, etc.

2. Consultant Engineers including Civil, Architectural, Industrial, Electrical, and Mechanical, with 10 years of experience at least.

3. Project Owners with about 10-15 years of experience.

It should be noted that all respondents have at least a B.Sc. in any related subject.

The interviewed individuals were kindly requested to rate the importance of the criteria for contractor selection. The scale that was used is the linear scale (1-9), which was developed by Saaty. The respondents were also asked to recommend any important criteria that were not mentioned in the interview, as well as rating the importance of the newly recommended factors.

A survey was also included in a constructive interview to determine the background details of the respondents. Such details include their field of work, experience, education, and academic position. The information gathered from the interviews will be analyzed and the relative importance of the criteria will be computed.

### 3.9 Calculating Relative Importance Index for Constructive Interview Factors

Analyzing the data gathered from the constructive interviews, the relative importance index for the criteria is calculated through the Equation 9:

$$RII_k^i(\%) = \frac{n_1+2\,n_2+3n_3+4n_4+5\,n_5}{5(n_1+n_2+n_3+n_4+n_5)} * 100 \qquad \textbf{\textit{Equation 9}}$$

Where i, signifies each factor, k, each year, and n1, n2, n3, n4, n5, are the number of respondents who answered for each factor based on the Lickeret scale. Where 1 is “not important”, 2 is “moderately important”, 3 is “important”, 4 is “very important”, and 5 is “extremely important”. The values of the relative importance index for the factors must exceed a specific threshold before it can be manipulated into the contractor selection hierarchy for the AHP model.

### 3.10 Constructing Hierarchies for Contractor Selection Criteria

Based on the results obtained from the constructive interviews the hierarchy for the contractor selection model was established. The factors that achieved the higher ranking were arranged in a similar structure as the one previously illustrated in Figure 6.

### 3.11 Pair-wise Criteria Comparison Matrices

For respondents to compare the criteria, pair-wise comparison matrices were developed and distributed to them, similar to the matrix shown in Table 2. The respondents are required to provide their judgments on the relative importance of each criterion to the other. After the pair-wise comparison judgments for the criteria are collected, the consistency validation is computed by determining the consistency ratio. The calculated value should be within the acceptable range relevant to the matrix order (explained above). If the matrix is found to be inconsistent with low inconsistency levels, it should be resent to the respondent for revision. However, if the matrix is found to have high inconsistency levels based on the respondent’s judgments, the matrix will be disregarded.

### 3.12 Contractor Selection Criteria Scores

When selecting the criteria that will be used to develop the contractor selection model for projects, they must be identified in a way that tolerates the utilization of a scoring process during the evaluation phase of the contending contractors and their proposed offers. The scoring system should incorporate the process of gathering the required information that will be used to give each factor its respectable score. By applying this scoring system and comparing the outcomes, each contractor will obtain it's proper ranking position. Moreover, if a new factor was proposed in the contractor selection model, its presence will not influence the ranking of the existing factors. This implies that if a stronger alternative is rated higher than a weaker alternative, in any circumstance, it will continue to be the stronger alternative. It should also be noted that if a rank reversal complication should occur each time a new alternative is proposed to the model, it would automatically be resolved.

Every contractor in the evaluation process will receive a rating scale from 1-9 for the criteria, where 1 signifies the lowest contractor success and 9 is the highest success relevant to the analyzed criteria. As for the intangible factors, they will be taken into consideration during the sensitivity analysis, which will be conducted after the contractors are ranked.

### 3.13 Comparing Contractors According to Criteria

The contractor's scores were appointed by the user of the contractor selection model, which will be utilized to compare the selected contractors. As mentioned previously, the scores were established based on Saaty’s (1-9) linear scale. The most vital aspect is to assign the most accurate scoring based on the collected data in compliance with the scoring scale, which will help to avoid conducting any consistency tests for the contractor assessment. For each criterion, the relative weight for the contractor compared with the other will be determined by using the geometric mean method.

### 3.14 Synthesizing the Global Weights for the Contractors

Synthesizing the priorities for all the criteria, to identify the global weight for the alternatives, is the final step before conducting the sensitivity analysis. The AHP approach adapts an additive aggregation with normalization of the sum for the priorities to the unit; the global weight for each alternative will be acquired from the Equation 10.

$$GWc = \sum_{i=1}^{n} GW_i * RW_{ci} + \sum_{j=1}^{m} GWji * RW_{cj} \qquad \textbf{\textit{Equation 10}}$$

In this equation, *GWc* represents the global weight for contractor C and *GWi* represents the global weight of criterion *i*. *RWci* is the relative weight for contractor C for criteria *I*, *GWcj* is the global weight for contractor C for criteria *i*, *RWcj* is the relative weight for contractor C for criteria *j*, *n* is the number of criteria that stand alone, and *m* is the number of criterions.

It should be noted that *RWci* and *RWcj* are the contractor's normalized weights of the criteria, which are acquired from the contractor's pair-wise comparison matrices.

### 3.15 Sensitivity Analysis

The sensitivity analysis is applied by altering the scores of the alternative with the higher rating and the alternative with the second-highest ranking to see if these slight modifications will change the ranking order of the outcome. Moreover, the sensitivity analysis is verified by changing the weights for the decision variables separately to see if such an alteration will influence the ranking of the alternatives.

When the difference in ranking among the first and second alternatives is minor and the difference between the two criteria is large, the decision-maker can conduct the selection process depending on the ranking of the criteria. Hence, the sensitivity analysis can be utilized by the awarding committee to evaluate the results to acquire the final decision and award the order to the contractor with the best tradeoff among the entire considered selection factors.

# CHAPTER 4
# DATA ANALYSIS AND RESULTS

## 4.1 Introduction

The following section will discuss the mathematical computations and the theoretical approach used in this study. It will also include the procedure utilized to develop the contractor selection model. Initially, the main selection criteria will be defined according to the first questionnaire, which was distributed in the first constructive. This will set the foundation for the contractor selection model. Once the model is developed, the pair-wise comparison matrices for the criteria will be computed according to the Analytical Hierarchy Process (AHP) and the relative weights for the criteria will be obtained. This will be based on the results gathered from the second questionnaire that was developed based on the AHP, which was distributed to seven local experts. To apply the AHP, a practical example will be used. Depending on the results of the questionnaires, the two alternatives that will participate in the competition will be evaluated.

This section will also present the competition proposal that was suggested as the case study for this research project. The case study was performed to identify whom, of the two competing contractors, would win the award. The outcomes gathered will be employed through the software system recognized as the Open Decision Maker (ODM). This system concentrates on identifying the relative weights for the selected field. Finally, the outcomes required will be obtained and the alternative with the higher weight will be chosen.

## 4.2 Using the SPSS to Obtain Criteria

Observing the previous discussions, the initial questionnaire was developed to identify the primary criteria that are recognized as the most influential factors when selecting the appropriate contractor. The process involved identifying nine main criteria, which were selected following the primary data gathered from the literature reviews. From the outcomes attained in the first questionnaire, the second questionnaire will be determined. The statistical package for social sciences (SPSS) method was used to attain the outcomes for the first phase of the research, which is determining the main criteria.

### 4.2.1 Study Sample

The questionnaires developed were distributed to 250 respondents, which assisted in determining the essential criteria required in the selection process. The following table, Table 5, represents the distributing mechanism used in Questionnaire1  for the study sample.

***Table 5***

***Respondents of Questionnaire 1***

| **No.** | **Description** | **Surveys Distributed** | | | |
|---|---|---|---|---|---|
| | | **Total Amount** | **Technical Engineers** | **Project Managers** | **Project Owners** |
| **1** | The total sum of questionnaires distributed | 250 | 141 | 101 | 8 |
| **2** | Questionnaires which were collected | 248 | 140 | 100 | 8 |
| **3** | Unanswered Questionnaires | 2 | 1 | 1 | 0 |

As shown in Table 5, the number of distributed questionnaires was 250. Of the 250 that were sent out, 248 questionnaires were returned. As for the remaining two questionnaires, they were unanswered due to the lack of employees available in the workplace. Therefore, the questionnaires were not recovered.

### 4.2.2 Respondents Details

The Tables (6-8) and Figures (7-9) will illustrate the respondent's details according to the answers gathered from the questionnaire. The outcomes were obtained by utilizing the SPSS program.

***Table 6***

***Respondents Field of Work***

| **Respondents Work Field** | | | |
|---|---|---|---|
| | | Frequency | Percentage |
| ***Valid*** | Technical Engineer | 140 | 56.0% |
| | Project Manager | 100 | 40.0% |
| | Project Owner | 8 | 3.2% |
| | Total | 248 | 99.2% |
| ***Missing*** | System | 2 | 0.8% |
| ***Total*** | | 250 | 100% |

The following pie chart in Figure 7 below depicts the results in Table 6. As shown in the figure and from the table, 56.5% of the respondents work in the field of Technical Engineers, 40.3% are employed as Project Managers, and only 3.2% are Project Owners.

***Figure 7***

***Respondent's Work Field Pie Chart***

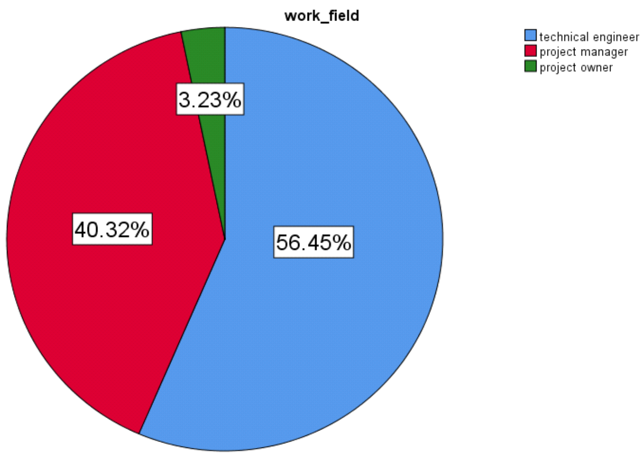



***Table 7***

***Respondents Education***

| Respondents Educational Field | | | |
|---|---|---|---|
| | | Frequency | Percentage |
| ***Valid*** | Engineering | 193 | 77.2% |
| | Business Management | 41 | 16.4% |
| | Other | 14 | 5.6% |
| | Total | 248 | 99.2% |
| ***Missing*** | System | 2 | 0.8% |
| ***Total*** | | 250 | 100% |

The following pie chart in Figure 8 below depicts the results in Table 7 As shown in the figure and from the table, 77.8% of the respondents have an academic degree in Engineering, 16.5% carry a degree in Business Management, and only 3.2% carry an academic degree in various fields.

**Figure 8**

**Respondents Education Pie Chart**

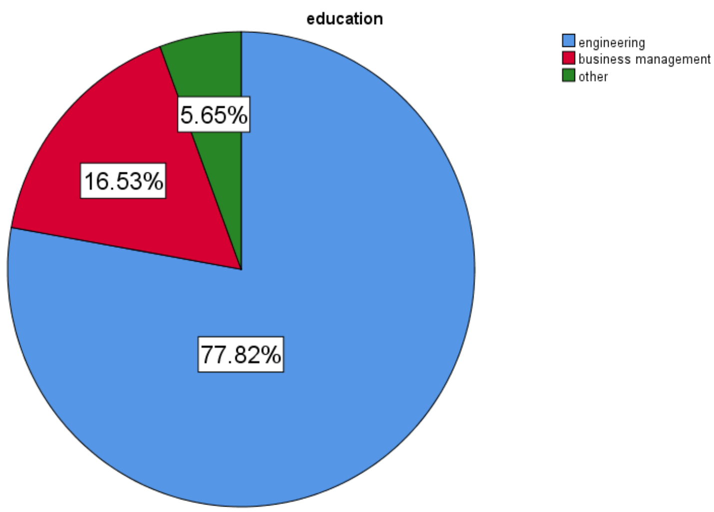



**Table 8**

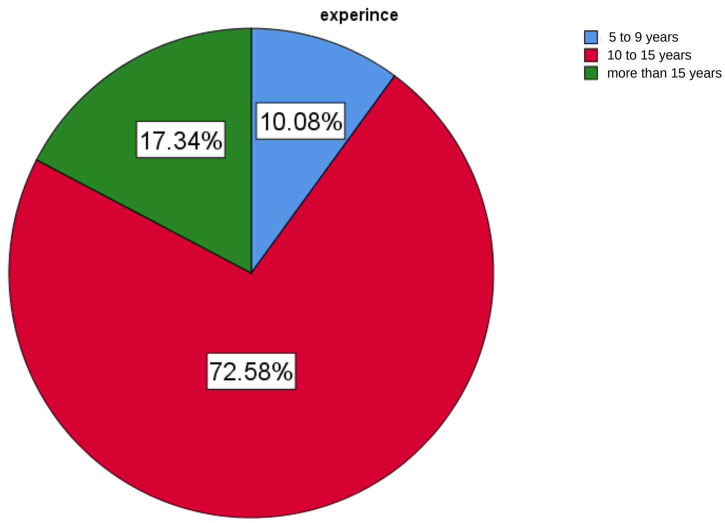
**Respondents Experience**

| **Respondents Experience** | | | |
|---|---|---|---|
| | | Frequency | Percentage |
| ***Valid*** | 5 to 9 years | 25 | 10% |
| | 10 to 15 years | 180 | 72% |
| | More than 15 years | 43 | 17.2% |
| | Total | 248 | 99.2% |
| ***Missing*** | System | 2 | 0.8% |
| ***Total*** | | 250 | 100% |

The following pie chart in Figure 9 below depicts the results in Table 8 As shown in the figure and from the table, 10.1% of the respondents have work experience of 5-9 years, 72.6% have work experience of 10-15 years, and only 17.3% have more than 15 years of working experience.

**Figure 9**

**Respondents Experience Pie Chart**




### 4.2.3 Study Utilization

The constructive interviews were manipulated into this study to collect the primary information required to complete this research. This was completed, through constructive interviews that consisted of the questionnaires, which needed to be answered.

### 4.2.4 The Reliability of the Questionnaires

To determine the reliability of the questionnaire, Cronbach Alpha was utilized. The Cronbach Alpha is applied to calculate the internal consistency and is considered the coefficient of reliability.

The alpha coefficient for the nine items is 0.81, which portrays that the reliability of the first questionnaire is highly valid and reliable.

### 4.2.5 Statistical Analysis Results for Questionnaire 1

The outcomes acquired for the following section were computed by utilizing the SPSS program. The following table, Table 9, depicts the outcomes for the criteria in accordance with the respondent's opinions. The outcomes were categorized into the mode, mean and standard deviation. As for the standard deviation, if the value is found to be less than (1), then the value of the mean is considered.

**Table 9**

**Statistical Description for the Main Criteria**

| Descriptive Statistics | | | | | |
|---|---|---|---|---|---|
| | **N** | **Minimum** | **Maximum** | **Mean** | **Std. Deviation** |
| **Price Bid** | 248 | 2.00 | 5.00 | 3.0363 | .54984 |
| **Experience Criteria** | 248 | 1.00 | 3.00 | 1.3992 | .50696 |
| **Technical Criteria** | 248 | 2.00 | 4.00 | 3.1250 | .51348 |
| **Service Criteria** | 248 | 1.00 | 3.00 | 1.3185 | .51627 |
| **Past Performance** | 248 | 3.00 | 5.00 | 4.7097 | .48079 |
| **Resources** | 248 | 1.00 | 3.00 | 1.5403 | .52314 |
| **Current Work Load** | 248 | 1.00 | 3.00 | 2.1976 | .64676 |
| **Safety Performance** | 248 | 3.00 | 5.00 | 4.5161 | .53966 |
| **Financial Criteria** | 248 | 3.00 | 5.00 | 3.6411 | .57989 |
| **Valid N (listwise)** | 248 | | | | |

From a statistical perspective, the factors that obtained a mean value of (3) and above were chosen to develop the second questionnaire. The factors that obtained a mean value of less than (3) were disregarded. According to the following outcomes, the five highlighted criteria listed in the table will be chosen to develop the second questionnaire. The criteria chosen are Price Bid (3.0363), Technical Capability (3.1250), Financial Capability (3.6411), Safety Performance (4.5161), and Past performance (4.7097).

### 4.2.6 Statistical Analysis Results for Questionnaire 2

The outcomes acquired for the following section were computed by utilizing the SPSS program. The following table, Table 10, depicts the outcomes for the respondents' judgments of the selected criteria. The results were determined following the mode of the judgments for the criteria. The results will be used for the AHP model to rely on.

**Table 10**

**Main Criteria Results According to the Mode**

| Main Criteria | N | Mode |
|---|---|---|
| **Financial Criteria - Technical Criteria** | 7 | 3 |
| **Financial Criteria - Past Performance** | 7 | 1/5 |
| **Financial Criteria - Safety Performance** | 7 | 1/3 |
| **Financial Criteria - Price Bid** | 7 | 5 |
| **Technical Criteria - Past Performance** | 7 | 1/7 |
| **Technical Criteria - Safety Performance** | 7 | 1/5 |
| **Technical Criteria - Price Bid** | 7 | 3 |
| **Past Performance - Safety Performance** | 7 | 3 |
| **Past Performance – Price Bid** | 7 | 9 |
| **Price Bid - Price Bid** | 7 | 1 |

### 4.3 Manipulating the AHP to Determine

The second questionnaire developed in this study was to allow the researcher to determine the ranking weight for the criteria selected. The second questionnaire was distributed to seven experts in the field of construction projects. According to the results obtained from the first questionnaire, the criteria were identified to establish the second questionnaire. The factors were placed in pair-wise comparison matrices to simplify the judgment process. The judging factor scale was also provided to guide the respondents. Depending on the results obtained, the contractor selection model will be established. In turn, the AHP methodology will be applied to analyze the factors and gather the results needed to complete the following study.

To test the developed AHP model, a practical example was applied after the hierarchical analysis model was developed. The relative importance of the 'criteria was calculated, to determine the best contractor from the two contractors who participated in the competition to be awarded the project. Table 11 shows the main criteria determined from the first questionnaire and their definition.

**Table 11**

**Criteria definition**

| Criteria | Definition |
|---|---|
| **Financial Capability** | Allows the client to maintain an opinion based on the overall financial capacity and position of the company. |
| **Experience criteria** | Proof of the company's building work experience |
| **Technical Capability** | Technical capability of the company that verifies it can perform/complete the work for which it is registering. |
| **Service criteria** | Allows the client to assess the company's ability to manage and deliver projects within a given time |
| **Past Performance** | A guide to check the contractor's capability to execute the works through past performance. |
| **Resources** | Sufficiency of technical equipment and materials adequate resources (human and physical resources) that the construction firm has to carry out works. |
| **Current workload** | To evaluate the contractor's current workload and determine any severe difficulties with ongoing projects. |
| **Safety performance** | Availability of safety measures on-site, health and safety information about employees/Safety health record and accident rate. |
| **Price bid** | The lowest bid price is an important aspect of awarding the contract. |

### 4.3.1 Developing Contractor Selection Model

,To establishes the contractor selection model, the equations proposed in chapter three are utilized and applied. The developed model is based on the criteria needed to evaluate the alternatives. The factors are classified according to their importance, which will be shown in Table 12.

### 4.3.2 Setting Contractor Selection Problem Hierarchy

The first step of the AHP approach is to structure the problem into a hierarchy. In this study, one hierarchal structure will be utilized, which consists of three levels. These levels are the objective (contractor selection), the criteria (evaluation factors), and the alternatives (contractors).

Based on the results obtained from the constructive interviews for rating the importance of the suggested factors, Table 12 shows a set of important criteria with their correspondent weight ranking. The weights are calculated by using Equation 7 and Equation 8 utilized in the program to obtain the results shown in Table 12.

***Table 12***

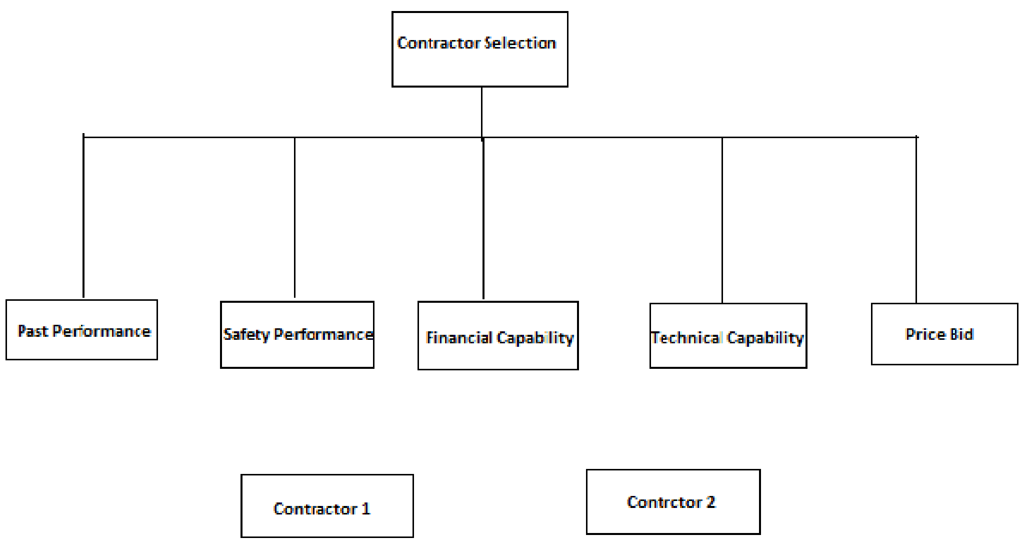
***Criteria Importance Rating***

| Criteria | Weight Value |
|---|---|
| Past Performance | 51.28% |
| Safety Performance | 26.15% |
| Financial Capability | 12.90% |
| Technical Capability | 6.34% |
| Price Bid | 3.33% |
| Total weight | 100% |

The hierarchy for the factors is shown in Figure 10

***Figure 10***

***Contractor Selection Hierarchy***




**4.3.3 Criteria Pair-Wise Comparisons**

The pair-wise comparisons depend on the linear scale that was proposed by Saaty. Each respondent will provide a value based on the scale provided, from 1-9. Their judgments will contribute to determining the relative weight of the selected criteria.. After entering the judgments into the Open Decision Maker (ODM), the program will check the consistency for the pair-wise comparison matrix.

As mentioned before, if the consistency ratio is higher than a certain value related to the order of the matrix, the judgment will be considered inconsistent. This means that either the respondent will be required to revise the pair-wise comparison judgment or the judgment will not be taken into consideration.

The original Saaty (1-9) linear scale, shown in Table 13, was applied to determine the normalized weights of the criteria. In the Saaty scale, the judgments $c_{ij}$ are directly entered into the pair-wise comparison matrices.

***Table 13***

***Saaty's scale***

| Intensity Preference | Definition | Explanation |
|---|---|---|
| 1/9 | Extremely not favored | Activities C1 is extremely not favored to activity C2 |
| 1/8 | Very strongly to extremely not favored | Compromise judgment between 1/7 and 1/9 |
| 1/7 | Strongly favored | Activity C1 is very not strongly favored to activity C2 |
| 1/6 | Strongly to very strongly not favored | Compromise judgment between 1/5 and 1/7 |
| 1/5 | Strongly not favored | Activity C1 is strongly not favored to activity C2 |
| ¼ | Moderately to strongly not favored | Compromise judgment between 1/3 and 1/5 |
| 1/3 | Moderately not favored | Activity C1 is moderately not favored to activity C2 |
| ½ | Equally to moderately not favored | Compromise judgment between 1 and 1/3 |
| 1 | Equally favored | Activities C1 and C2 equally contribute to the objective |
| 3 | Moderately favored | Experience and judgment slightly favor activity C1 over C2 |
| 5 | Strongly favored | Experience and judgment strongly favor activity C1 over C2 |
| 7 | Very strongly favored | Activity C1 is very strongly favored over C2, its dominance is demonstrated in practice |
| 9 | Extremely favored | The evidence favoring activity C1 over C2, as the highest possible order of affirmation |
| 2, 4, 6, & 8 | Intermediate Values | When a compromise is needed |

### 4.3.4 Criteria Pair-Wise Comparison Matrix Results

The following section is composed of the results gathered from the pair-wise comparison matrices for the criteria. The results depend on the scores that the respondents provided in the distributed questionnaires. The following Tables 14 & 15 will show these outcomes.

***Table 14***

***Comparison Matrix for Main Five Criterions***

| Criteria | Financial capability | Past experiences | Technical criteria | Safety performance | Price bid |
|---|---|---|---|---|---|
| **Financial capability** | 1 | 1/5 | 3 | 1/3 | 5 |
| **Past experiences** | 5 | 1 | 7 | 3 | 9 |
| **Technical criteria** | 1/3 | 1/7 | 1 | 1/5 | 3 |
| **Safety performance** | 3 | 1/3 | 5 | 1 | 7 |
| **Price bid** | 1/5 | 1/9 | 1/3 | 1/7 | 1 |

*The following judgments are in accordance with the judgments provided by the experts.

***Table 15***

***Normalization Matrix for Main Five Criterions***

| Main Criteria | Financial capability | Past experiences | Technical criteria | Safety performance | Price Bid | Weight |
|---|---|---|---|---|---|---|
| **Financial capability** | 0.10489 | 0.11119 | 0.1836 | 0.07128 | 0.2 | 0.13435 |
| **Past experiences** | 0.52447 | 0.55950 | 0.428571 | 0.64154 | 0.5625 | 0.54332 |
| **Technical criteria** | 0.03496 | 0.07992 | 0.06122 | 0.04276 | 0.12 | 0.06778 |
| **Safety performance** | 0.31468 | 0.18650 | 0.306122 | 0.213849 | 0.28 | 0.26023 |
| **Price Bid** | 0.02097 | 0.06216 | 0.02040 | 0.03054 | 0.04 | 0.03482 |

### 4.3.5 Contractor Pair-wise Comparison

After identifying the criteria weights, the next procedure is to perform the contractor's pair-wise comparisons. Each contractor should be assigned a ranking value, scores from (1-9), to represent their achievement in fulfilling the selected criteria.

According to the scores assigned for the competing contractors, each will be compared with its competitor separately. All matrices will be consistent because the judgments will depend on predetermined scores rather than a subjective judgment, which might raise inconsistency problems. It is crucial to assign the appropriate scores for the contractors concerning their actual merits after evaluating the information collected on the contractors through the submitted offers.

### 4.3.6 Contractors Global Weight

To obtain the contractor global weights, equation (3.8) will be applied, in which the weights will be determined through the Open Decision Maker (ODM) program.

## 4.4 Contractor Selection Model Structure

The proposed CSM will be manipulated through the Open Decision Maker (ODM) program. The proposed model in this study deals with data received from 248 respondents who are project managers, consulting engineers, and project owners. The number of data entered into the program is not restricted to just 248 respondents; it is unlimited. Therefore, the model is suitable to be utilized under any circumstance faced.  The following Figure briefly describes the inputs and output data Figure 11 illustrates the model pathways.

*Figure 11*

***The Inputs and Outputs for the proposed Contractor Selection Model***

| Inputs | Contractor Selection Model | Outputs |
|---|---|---|
| • The pair-wise comparsion judgments for the criteria based on the respondents judgements<br>• The respondents perspective on the signifiicant criteria<br>• The scores assigned to the Bidders by the experts<br>• Modifications that have been employed by the operator to validate sensitivity of the decision. | • Staistical Package for Social Sciences (SPSS)<br>• Open Decision Maker (ODM)<br>• Linear Scale (proposed by Saaty) | • The average matrices retrieved from the criteria pair-wise by using the SPSS.<br>• Determining the Consistency Ratio using the ODM.<br>• Using the ODM to retrieve the normalized weights for criteria<br>• Computing the Bidders weights through the ODM.<br>• Using the ODM to conduct the sensitivity analysis |

**4.5 Proposed Case Study**

The case study, which was proposed for this study, was conducted in response to Kurdistan Regional Government (KRG) in Erbil, Iraq.

The alternative bidders participating in the competition will present their technical proposal, program, and methodology to meet the Kurdistan Regional Government objectives. Each bidder will provide their proposals on the project and the documents required to be presented. The project is the construction of Erbil’s new highway (150M highway) that circles Erbil city. It is currently the largest and most modern project undergoing construction in Erbil city. The master plan for Erbil incorporates a series of ring roads — 30 Meters, 40 Meters, 60 Meters, 100 Meters, 120 Meters, and 150 Meters. The objective is to allow the commuters in Erbil's suburbs and surrounding towns to exploit the ring roads to avoid congestion around the city center. The last section, totaling 11 kilometers, stretches from the Erbil-Kirkuk Road to the Erbil-Mosul Road. In addition, the data needed to complete the ranking procedure was obtained by interviewing the staff of the company. Table 16 illustrates the comparison of the bidders for the criteria.

***Table 16***

***The Comparison Alternatives for the Criteria***

| | **Bidder 1** | **Bidder 2** |
|---|---|---|
| Price Bid | 25.00% | 75.00% |
| Past Performance | 83.33% | 16.67% |
| Safety Performance | 88.89% | 11.11% |
| Financial Capability | 20.00% | 80.00% |
| Technical Capability | 16.67% | 83.33% |

Once the bidders are identified and the data needed is gathered to determine the best alternative, the evaluation process will begin. The tables provided in the following section will illustrate the evaluation process. Each criterion will have its matrix. A brief description will be provided below each table, including the ranking results of the participants. The final ranking evaluation for the 'criteria will also be provided. Tables (17-28) show the pair-wise comparison matrices for the criteria scores for the alternatives based on the questionnaire.

**4.5.1 Criteria 1 Past Performance**

The criterion Past Performance as shown in Table 17 is considered a significant criteria when awarding the contract. The total weight for the Past Performance was 51.28%. As shown in Table 18 , Bidder 1 obtained a higher weight (83.33%) than Bidder 2 with respect to the criterion.

***Table 17***

***Past Performance***

| **Past Performance** | Bidder 1 | Bidder 2 |
|---|---|---|
| *Bidder 1* | 1 | 5 |
| *Bidder 2* | 1/5 | 1 |

Consistency ratio (0.01) Critical Consistency Ratio (0.1)

***Table 18***
***Contractor Ranking***

| **Bidder** | **Weight** |
|---|---|
| *Bidder 1* | 83.33% |
| *Bidder 2* | 16.67% |

#### 4.5.2 Criteria 2 Safety Performance

The criterion Safety Performance as shown in Table 19 allows the client to determine the availability of safety measures on-site, health and safety information about employees as well as the safety health record and accident rate for the bidder. The total weight for the Safety Performance was 51.28%. As shown in Table 20, Bidder 1 obtained a higher weight (88.89%) than Bidder 2 concerning concerning the criterion.

***Table 19***

***Safety Performance***

| **Safety Performance** | Bidder 1 | Bidder 2 |
|---|---|---|
| *Bidder 1* | 1 | 8 |
| *Bidder 2* | 1/8 | 1 |

Consistency ratio (0.01) Critical Consistency Ratio (0.1)

***Table 20***
***Contractor Ranking***

| **Bidder** | **Weight** |
|---|---|
| *Bidder 1* | 88.89% |
| *Bidder 2* | 11.11% |

#### 4.5.3 Criteria 3 Financial Capability

The criterion Financial Capability as shown in Table 21 provides evidence portraying the financial standing of the company. The total weight for the Financial Capability was 12.9%. As shown in Table 22, Bidder 1 obtained a higher weight (80%) than Bidder 2 concerning the criterion.

***Table 21***

***Financial Capability***

| **Financial Capability** | Bidder 1 | Bidder 2 |
|---|---|---|
| *Bidder 1* | 1 | 1/4 |
| *Bidder 2* | 4 | 1 |

Consistency ratio (0.01) Critical Consistency Ratio (0.1)

***Table 22***

***Contractor Ranking***

| **Bidder** | **Weight** |
|---|---|
| *Bidder 2* | 80% |
| *Bidder 1* | 20% |

### 4.5.4 Criteria 4 Technical Capability

The criterion Technical Capability as shown in Table 23 proves that the participant can perform completely the work for which it is registering. The total weight for the Technical Capability was 6.34%. According to Table 24, Bidder 2 obtained a higher weight (83.33%) than Bidder 2 concerning the criterion.

***Table 23***

***Technical Capability***

| **Technical Capability** | Bidder 1 | Bidder 2 |
|---|---|---|
| *Bidder 1* | 1 | 1/4 |
| *Bidder 2* | 4 | 1 |

Consistency ratio (0.01) Critical Consistency Ratio (0.1)

***Table 24***

***Contractor Ranking***

| **Bidder** | **Weight** |
|---|---|
| *Bidder 2* | 83.33% |
| *Bidder 1* | 16.67% |

### 4.5.5 Criteria 5 Bid Price

The lowest ranking was obtained by the criteria Bid Price as shown in Table 25 and not important to consider when selecting the appropriate bidder. The total weight for the Bid Price was 3.33%,as shown in Table 26 it is noticed that Bidder 2 obtained a higher weight (75%) than Bidder 1 concerning the criterion.

***Table 25***

***Price Bid Matrix Scores***

| **Price Bid** | Bidder 1 | Bidder 2 |
|---|---|---|
| *Bidder 1* | 1 | 3 |
| *Bidder 2* | 1/3 | 1 |

Consistency ratio (0.01) Critical Consistency Ratio (0.1)

***Table 26***

***Contractor Ranking***

| **Bidder** | **Weight** |
|---|---|
| *Bidder 2* | 75% |
| *Bidder 1* | 25% |

### 4.5.6 Criteria Matrix for the Alternatives

The final weights for all the criteria results between the 2 bidders as shown below in Table 27

***Table 27***

***Criteria Matrix for the Alternatives***

| | **Financial Capability** | **Past Performance** | **Safety Performance** | **Technical Capability** | **Price Bid** |
|---|---|---|---|---|---|
| Bidder 1 | 20% | 83.33% | 88.89% | 16.67% | 25% |
| Bidder 2 | 80% | 16.67% | 11.11% | 83.33% | 75% |

Consistency ratio (0.05) Critical Consistency Ratio (0.1)

#### 4.5.6.1 Main Criteria Ranking

From Table 28 it should be noted that the criteria that won first place in the evaluation procedure were the Past Performance Criterion with a weight of 51.28%. In the second place, the criteria Safety Performance with a weight of 26.15%.

***Table 28***

***Criteria Ranking***

| Criterion | Weight |
|---|---|
| Past Performance | 51.28% |
| Safety Performance | 26.15% |
| Financial Capability | 12.9% |
| Technical Capability | 6.34% |
| Price Bid | 3.33% |

The matrix for the criteria with the alternatives shows the final weight for each alternative concerning the criteria.

# CHAPTER 5
# CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK

## 5.1 Introduction

The following study was carried out to determine the factors that affect contractor selection and ensure the project's success. The Analytical Hierarchy Process was applied as a mechanism to develop a contractor selection model to be regularly used for construction projects locally. The outcomes gathered from the constructive interviews showed that the criteria Price Bid- is not the only criteria that clients depend on when selecting the competent contractor. Several other factors affect the selection decision for the competent contractor. This requires considering all factors when analyzing the contractor's offers and their aspects to grant the award to the appropriate candidate. Therefore, the contractor selection model proposed in this research is aimed at improving the awarding phase, which will positively influence the outcome of the project. By applying the proposed model, it ensures that the decision made with the support of the model will be better than the decision made when applying the traditional contractor selection techniques.

## 5.2 Conclusions

According to the analysis of the literature review, the results gathered from the constructive interviews and the pair-wise comparison judgments, the following conclusions were attained:

- Through endless research analysis of the local techniques and literature reviews, the important criteria required for the selection process were identified. The criteria that are taken into consideration for local projects were determined from the constructive interviews, which were distributed to 250 respondents, and the final criteria selected were based on the judgments of experts in the field.
- The traditional methods applied must be redeveloped to accommodate the local conditions, hence the reason behind establishing the proposed model in this study.
- The average weights for the determined criteria were computed using the Saaty scale and they are; Past Performance (51.28%), Safety Performance (26.15%),

Financial Capability (12.9%), Technical Capability (6.34%), and Price Bid (3.33%).

- The criteria that achieved the highest weight was Past Performance with the value 51.28% when compared to the factor that is most commonly relied on in local projects, which is Price Bid at 3.33%.
- Based on the study conducted, the contractor who won the award concerning the AHP method was Bidder 2. If the traditional selection approach was applied, the contractor who would win the award would be Bidder 1.
- By applying the AHP approach, decision-makers can organize their alternative and determine the competent contractor promptly and with high precision especially after finalizing the pair-wise comparison matrices

### 5.3 Recommendations for Future Work

The following section will contain a list of recommendations based on the results gathered from the study conducted.

- The researcher recommends that the criteria applied in the proposed selection model of this research should be applied as a foundation for the selection process of contractors, in which the same criteria are considered when selecting the competent contractor by the local authorities and rely on the local context.
- The selection criteria need to set specific parameters to be measured. These determinants can be set by the owners, concerning the nature of the particular project at hand.
- Local institutions should reconsider adopting modern quantitative methods in decision making, such as the Analytical Hierarchy Process, to assist in resolving endless situations that may be faced. They also should provide training programs for the managers and employees to guide them on the application of such methods to ensure that the entire workforce is capable of making decisions based on scientific methods. This will result in a higher performance level for the institution.
- To apply the proposed selection model in this study, the operator must be familiar with the AHP approach and the implementation of the Open Decision Maker (ODM) program.

The researcher hopes that a training program will be established to train employees on the manipulation and application of the ODM in the future training programs of institutions.

## 5.4 Future Works

In this section, a list of probable future works is provided.

- To conduct a study on the application and impact of traditional methods and modern quantitative approaches in decision making on the performance and efficiency levels in government and private organizations.
- To research the probability of applying different quantitative methods other than the Analytical Hierarchy Process in contractor selection, which will strengthen the approach by merging other methods with the AHP to enhance the outcomes achieved.

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# APPENDEX A

**Respondents Detail**

**Please fill in the following circles:**

1. **Field of Work:**

☐Consultant Engineer ☐ Business Owner ☐Project Manager

2. **Experience:**

☐ 1-4 years ☐5-10 years ☐ more than 10 years

3. **Education:**

☐ Engineering ☐Business Administration ☐Others

4. **Academic Degree:**

☐B.Sc. ☐M.Sc. ☐ Ph.D.

## Criteria and Sub-Criteria Rating

**Requested response:**

Kindly provide ratings that represent the significance of the factors towards selecting the best contractor for delivering a successful project. The factors will be listed in the following table; Table number 1.

If there are any criterions or sub criterion factors that are considered to be important in contractor selection and are not mentioned herein, kindly write down the new suggested factors in Tables number 2, 3, and 4.

| **Importance Rating Scale** | | | | |
|---|---|---|---|---|
| Not Important | Moderately Important | Important | Very Important | Extremely Important |
| 1 | 2 | 3 | 4 | 5 |

| **Table 1 Criteria Rating** | | | | | | |
|---|---|---|---|---|---|---|
| **Criteria** | **Definition** | 1 | 2 | 3 | 4 | 5 |
| Bid Price | The lowest bid price is the important aspect in awarding the contract. | | | | | |
| Work Experience | Proof of the company's building work experience . | | | | | |
| Financial Capability | Allows the client to maintain an opinion based on the overall financial capacity and position of the | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | company.<br><br>. | | | | | |
| Technical Capability | Technical capability of the company that proves it can perform/complete the work for which it is registering. | | | | | |
| Service criteria | Allows the client to assess the company's ability to manage and deliver projects within a given time | | | | | |
| Past Performance | A guide to check the contractor's capability to execute the works through past performance.. | | | | | |
| Resources | Sufficiency of technical equipment and materials adequate resources (human and physical resources) that the construction firm has to carry out works. | | | | | |
| Current workload | To evaluate the contractor's current workload and determine any severe difficulties with ongoing projects. | | | | | |
| Safety performance | Availability of safety measures on-site, health and safety information about employees/Safety health record and accident rate. | | | | | |

If there are criteria or sub-criteria factors that are considered important in contractor selection, but were not mentioned in this questionnaire, kindly write down the new suggested factors in table numbers (2, 3, and 4).

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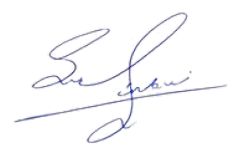

Assoc. Prof. Dr. Shaban Ismael Albrka

## ETHICS LETTER

### TO THE INSTITUTE OF GRADUATE STUDIES

**REFERENCE: DLVEEN ALI HUSSEIN MOHAMMED (21084584)**

I would like to inform you that the above candidate in one of our postgraduate students in Civil Engineering department. He was taking thesis under my supervision, the thesis entailed *" MULTI-CRITERIA MAKING FOR CONTRACTOR SELECTION USING ANALYTICAL HIERARCHY PROCESS (AHP): A CASE STUDY IN ARBIL*". The data used in this study was our own data obtained from a questionnaire that we have developed from the literature review.

Please do not hesitate to contact me if you have any further queries or questions.

Thank you very much indeed.

Best regards,

***Assoc. Prof. Dr. Shaban Ismael Albrka***
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