APPLICATION OF ANALYTICAL HIERARCHY PROCESS (AHP) FOR CONTRACTOR EVALUATION IN PROJECT MANAGEMENT – A CASE STUDY

by

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A project work submitted to the Department of Industrial and Production Engineering, Bangladesh University of Engineering and Technology in partial fulfillment of the requirements for the degree of Master of Advanced Engineering Management

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CERTIFICATION OF APPROVAL

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It is hereby declared that this project work or any part of it has not been submitted elsewhere for the award of any degree of diploma.

Rahman

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DEDICATION

To My Mother

Monowara Begum

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ABSTRACT

At present, in Bangladesh, most of the companies are using two step evaluation methods for awarding contracts to contractors for large construction projects. In the first step of this method, screenings of contractors are done on simple pass fail basis. They must go through this step to be eligible for the second phase. A simple kind of weighted sum model (WSM) is used here for this decision making. The choice of selection criteria and their weights are dependent on the subjective judgment of the project owner. A thresh-hold value is fixed by the owner and a simple pass-fail method is used. Those contractors crossing this threshold value are qualified for going into the second phase. This first step is also known as prequalification evaluation of contractors and it ensures that only firms with adequate experience, resources, qualifications and expertise are selected to tender. The problem with this method is deciding the weight of the respective criteria, something for which AHP does provide a better solution. In the second step, pre qualified contractors from the first step are assessed of their capacity in more detail. This assessment is performed to ensure adequate, experience; resources, qualifications and expertise available exist in the selected firm. Then the lowest qualified bidder is awarded with the contract.

The new challenge in the field of Project Management may be considered like dealing with the number of alternatives that have grown dramatically over the last few decades. Managers have to deal more with conflicting goals now a days. In case of construction projects, selecting the best contractor among many contractors may be considered as one of this particular type. Analytical Hierarchy Process (AHP) is an efficient tool for dealing with these types of multi-criteria decision making problems. AHP is famous for its ability to incorporate both the quantitative and qualitative factors simultaneously. In this presented paper, a case study about sub-contractor prequalification evaluation (an evaluation problem) has been performed using the traditional approach and the Analytical Hierarchy Process (AHP). Later, sensitivity analysis was carried out by changing the comparison matrix to show the greater capability and flexibility of AHP over traditional approach.

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Chapter One

INTRODUCTION

1.1 Introduction

Decision making in Projects has become more complex due to reasons related to: the alternatives, the goals, the environment in which Project decisions are made. Nowadays, the single contractor concept is almost impossible, there are numerous alternatives. The number and the nature of the goals, criteria or constraints, is changing day by day. User departments are also involved in making their own project decisions and have added their own goals. Some goals are conflicting; many are not well defined and hardly measurable. Moreover the complexity is also increased because project budgets are being cut constantly.

Every decision is made within a decision environment, which is defined as the collection of information, alternatives, values, and preferences available at the time of the decision. An ideal decision environment would include all possible information, all of it accurate, and every possible alternative. Since decisions must be made within this constrained environment, the major challenge of decision making is uncertainty, and a major goal of decision analysis is to reduce uncertainty. It is quiet impossible to find all the information needed to make a decision with certainty, so most decisions involve an undeniable amount of risk.

Decision analysis can be used to determine an optimal strategy when a decision maker faced with several decision alternatives and an uncertain or risk filled pattern of future events [1]. The goodness of a selected alternative depends on the quality of the data used in describing the decision situation.

Decision-making involving multiple, sometimes conflicting, objectives and/or criteria is called Multi Criteria Decision-Making, MCDM. Often the criteria include not only quantitative factors but also qualitative factors. One of the MCDM methods to which recently much attention is being paid is Analytical Hierarchy Process (AHP).

The analytical hierarchy process (AHP) is a decision aiding method developed by satty [2]. It aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision maker, and stresses the importance of the intuitive judgments of a decision maker as well as the consistency of the comparison of alternatives in the decision making process [3].

Since a decision-maker bases judgments on knowledge and experience, then makes decisions accordingly, the AHP approach agrees well with the behaviour of a decision-maker. By breaking a problem down in a logical fashion from the large, descending in gradual steps, to the smaller and smaller, one is able to connect, through simple paired comparison judgments, the small to the large.

The main advantage of this method is that it can handle a complex problem by preparing a hierarchy of choices explaining the reasons of such choices through decomposition and synthesis. It can compare different alternatives and attributes using a scale of relative importance [4].

Contractor prequalification evaluation can be used as an example of using AHP in project management. Prequalification (an evaluation problem) is defined by Moore [5] and Stephen [6] as the screening of contractors by project owners and their representatives according to a predefined set of criteria deemed necessary for successful project performance, in order to determine the contractor's competence of ability to participate in the project bid. Another formal definition by clough [7] is that prequalification means that the contracting firm wishing to bid on a project needs to be qualified before it can be issued bidding documents or before it can submit proposal.

A number of studies have focused on contractor prequalification. Lower [8] reviewed the guidelines for prequalification process in different states in the US. He also discussed how prequalification can provide the owner with appropriate facilities representing an effective and efficient expenditure of money.

Russel and skibniewski [9] mentioned that the actual process of contractor evaluation had received little attention in the past. They tried to describe the contractor evaluation process along with the decision making strategies and the factors that influence the process. They reported five methods that they found in use for contractor evaluation: Dimensional weighting method, two step prequalification, Dimension wise strategy, Prequalification formulae, and Subjective judgment [10].

In this paper I will try to incorporate Analytical Hierarchy Process (AHP) with traditional weighted sum model (WSM) to support Project manager's for decision making like prequalification evaluation of subcontractors along with its strengths and weaknesses with respect to decision making.

1.2 Problem Identification

Project managers are faced with decision environments and problems in projects that are complex. The elements of the problems are numerous, and the interrelationships among the elements are extremely complicated. Relationships between elements of a problem may be highly nonlinear; changes in the elements may not be related by simple proportionality. Furthermore, human value judgment systems are integral elements of project problems [11]. Therefore, the ability to make sound decisions is very important to the success of a project. In fact, Schuyler [12] makes it a skill that is certainly near the top of the list of project management skills, and notices that few of us have had formal training in decision making.

Before the implementation of the Public procurement regulations in Bangladesh, the public infrastructure construction projects were used to be awarded to the lowest bidder without judging its capability of performing the project. This on the other hand resulted in lower performance quality and schedule delays.

At present, in Bangladesh, most of the companies are using two step evaluation methods for awarding contracts to contractors for large construction projects.

In the 1^{st} step of this method, screenings of contractors are done on simple pass fail basis. They must go through this step to be eligible for the 2^{nd} phase. A simple kind of weighted sum model (WSM) is used here for decision making. The choice of selection criteria and their weights are dependent on the subjective judgment of the project owner. A thresh-hold value is fixed by the owner and the simple pass-fail method is used. Those contractors crossing this threshold value are qualified for going into the 2^{nd} phase. This 1^{st} step is also known as prequalification evaluation of contractor's. This 1^{st} step ensures that only firms with adequate experience, resources, qualifications and expertise are selected to tender. The problem with this method is deciding the weight of the respective criteria, something for which AHP does provide a better solution.

In the 2^{nd} step, pre qualified contractors from the 1^{st} step are assessed of their capacity in more detail. This assessment is performed to ensure adequate, experience; resources, qualifications and expertise available exist in the selected firm. Then the lowest qualified bidder is awarded with the contract.

In practical situation there are multi-experts each of them having sufficient relevant knowledge about the project. In the initial step of decision making process, all the experts sit together and determine the following things:

- The available alternatives (list of contractors), which are the possibilities one has to choose from.
- Importance of each criterion, quantifier for each criteria and desire of each criterion against the final objective which is successful completion of the project.
- The thresh-hold value for pass-fail selection.

1.3 Objective

The objectives of this study are:

1. To analyze the existing decision making procedures.
2. To incorporate Analytical Hierarchy Process (AHP) with project management for contractor evaluation.

The possible outcome of the proposed study is the improvement in methodology for evaluating contractor's strengths for accomplishing any particular project.

1.4 Methodology

1. Study of the "Analytical Hierarchy Process (AHP)"
2. Examination of contractor evaluation procedures developed by different agencies for different projects. (Evaluation documents prepared by World Bank, Asian Development Bank, Central Procurement Technical Unit - GOB).
3. Application of AHP for evaluating the contractor's information.
4. Checking consistency of the outcome to validate the proposed method.

Chapter Two

LITERATURE REVIEW

Decision making based on scientific methodologies is the main goal of organizational managers. So, a realistic decision making is the key to success for a business organization. Because of this people are much aware about their decision making process. Decision making process needs to consider multiple criteria, which are often qualitative and conflicting as well in nature. All these impose a pressure upon the manager to implement an appropriate tool which enables one to take realistic decisions faster.

The growing trends in decision science increasingly utilizing applications of more than one technique and involve individuals from other disciplines. A creative thinking must look in detail at how from those disciplines outside of Decision Science can come to work in the organizations on multi-disciplinary studies.

2.1 Multi-Criterion Decision Making (MCDM)

In a traditional Multi Criteria Decision Making (MCDM), each criterion is weighted by a fixed value and the decision maker uses the values to calculate a decision value for each alternative and prioritizes the alternatives based on the calculated decision values, normally in descending order [13].

Choo, Schoner and Wedley (1999) proposed Multi Criteria Decision Making models are characterized by the need to evaluate a finite set of alternatives with respect to multiple criteria. The criteria weights in different aggregation rules have different interpretations and implications which have been misunderstood and neglected by many decision makers and researchers. By analyzing the aggregation rules, identifying partial values, specifying explicit measurement units and explicating direct statements of pair wise comparisons of preferences, we identify several plausible interpretations of criteria weights and their appropriate roles in different multi criteria decision making models. The underlying issues of scale validity, commensurability, criteria importance and rank consistency are examined [14].

2.2 Analytical Hierarchy Process (AHP)

2.2.1 Traditional AHP

Decision making process needs to consider multiple criteria, which are often qualitative and conflicting as well i.e., fuzzy in nature. This requires multiple criteria evaluation using Analytical Hierarchical Process (AHP) technique developed by satty [15].

Since a decision-maker bases judgments on knowledge and experience, then makes decisions accordingly, the AHP approach agrees well with the behaviour of a decision-maker. By breaking a problem down in a logical fashion from the large, descending in gradual steps, to the smaller and smaller, one is able to connect, through simple paired comparison judgments, the small to the large.

The main advantage of this method is that it can handle a complex problem by preparing a hierarchy of choices explaining the reasons of such choices through decomposition and synthesis. It can compare different alternatives and attributes using a scale of relative importance [4].

2.2.2 Revised AHP

The revised AHP is a variant of the original AHP and was proposed by Belton and Gear [4]. They observed that the AHP may reverse the ranking of the alternatives when an alternative identical to one of the already existing alternatives in introduced.

Deng (1999) articulated that AHP is not the panacea for real world decision making problems. As mentioned above, AHP is being criticized for its unbalanced measurement scale, and its inability to deal with uncertainty and imprecision of the decision makers perceptions [16]

2.2.3 AHP Application

Poh and Ang (1999) carried out a comprehensive study of alternative study of alternative fuels for land transportation in Singapore. It is a multiple attribute analysis and is used to identify a number of fuel options for possible future use. An AHP analysis is performed to evaluate four possible plans or scenarios [17].

Madu, Kuei and Chen (1995) described a decision support system (DSS) which is designed to predict the system availability level for equipment maintenance float problems. The DSS is developed by using the Analytical Hierarchy Process (AHP) to prioritize the improvements made in the maintenance management practice through the adoption of Total Quality Management (TQM) [18].

Wang and Raz (1991) developed to assist one in the processes of selecting the best system configuration for implementing a computer-based system. Based on the Data Flow Diagram produced in System Analysis and System Design, an Alternative Evaluation Hierarchy is generated. System design criteria and characteristics of the system configuration alternatives are associated with the subsystems and the basic components in the system. The Analytical Hierarchy Process (AHP) is applied to identify the best system configuration [19].

Chapter Three

MCDM TECHNIQUES

3.1 Weighted Sum Model (WSM)

The weighted sum model (WSM) is probably the most commonly used approach, especially in single dimensional problems. If there are M alternatives and N Criteria then, then the best alternative is the one that satisfies (in the maximization case) the following expression [20]

$$A^*_{WSM} = \max_i \sum_{j=1}^{N} a_{ij} w_j, \quad for \quad i = 1, 2, 3, ..., M. \tag{3.1}$$

Where A_{WSM}* is the WSM score of the best alternative, N is the number of decision criteria, a_{ij} is the actual value of the i-th alternative in terms of j-th criterion, and W_j is the weight of importance of the j-th criterion.

The assumption that governs this model is the additive utility assumption. That is, the total value of each alternative is equal to the sum of products given as the above formulae. In single dimensional cases, in which all the units are the same (e.g. dollars, feet, seconds), the WSM can be used without difficulty. Difficulty with this method emerges when it is applied to multi-dimensional decision-making problems. Then in combining different dimensions, and consequently different units, the additive utility assumption is violated and the result is equivalent to "adding apples and oranges".

3.2 Weighted Product Model (WPM)

The weighted product model (WPM) is very similar to the WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criteria. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. In general, in order to compare the alternatives A_K and A_L, the following product Bridgman [21] and Miller and Starr [22] has to be calculated

$$R(A_K/A_L) = \prod_{j=1}^{N} (a_{Kj}/a_{Lj})^{w_j}, \tag{3.2}$$

Where N is the number of criteria, a_{ij} is the actual value of the i-th alternative in terms of the j-th criterion, and W_j is the weight of importance of the j-th criterion.

If the term R (A_K/ A_L) is greater than one, then alternative A_k is more desire able than alternative A_L (in the maximization case). The best alternative is the one that is better than or at least equal to all the other alternatives.

The WPM is sometimes called dimensional analysis because its structure eliminates anytime any units of measure. Thus, the WPM can be used in single and multi-dimensional decision making problems. An advantage of this method is that instead of the actual values it can use relative ones. This is true because

$$\frac{a_{Kj}}{a_{Lj}} = \frac{a_{Kj} / \sum_{i=1}^{N} a_{Ki}}{a_{Lj} / \sum_{i=1}^{N} a_{Li}} = \frac{a'_{Kj}}{a'_{Lj}}. \tag{3.3}$$

A relative value a'_{kj} is calculated by using the formula

$$a'_{Kj} = a_{Kj} / \sum_{i=1}^{N} a_{Ki} \tag{3.4}$$

where a_{kj} are the actual values.

3.3 Multi Attribute Value (MAV) Method

Multi-attribute value (MAV) may also be used for multiple criteria decision making approaches. This method is also pretty widely used in practice. But the greatest weakness of the MAV method is its failure to incorporate systematic checks on the consistency of judgments. Multi-Attribute value theory is an evaluation scheme which is very popular by consumer organisations for evaluating products.

According to MAV theory the overall evaluation v(x) of an object x is defined as a weighted addition of its evaluation with respect to its relevant value dimensions [23]. The common denominator of all these dimensions is the utility for the evaluator.

For example, a digital camera can be evaluated on the value dimensions quality of image, flash, viewfinder, operation time, and handling. The overall evaluation is defined by the following overall value function

$$v(x) = \sum_{i=1}^{n} w_i v_i(x) \tag{3.5}$$

Here, $v_i(x)$ is the evaluation of the object on the i-th value dimension d_i and w_i the weight determining the impact of the i-th value dimension on the overall evaluation (also called the relative importance of a dimension), n is the number of different value dimensions, and

$$\sum_{i=1}^{n} w_i = 1 . \tag{3.6}$$

3.4 Analytical Hierarchy Process (AHP)

Since a decision maker bases judgments on the knowledge and experience, then makes decisions accordingly, the AHP approach agrees well with the behavior of the decision maker. The strength of this approach is that it organizes tangible and intangible factors in a systematic way, and provides a structure yet relatively simple solution to the decision making problem.

Decision making process needs to consider multiple criteria, which are often qualitative and conflicting as well in nature. This requires multi-criteria evaluation using Analytical Hierarchy Process (AHP) technique developed by Satty [15]. Analytical Hierarchy Process (AHP) presents a different approach for the situations in which ideas, feelings & emotions are quantified to provide a numeric scale for prioritizing decision alternatives. Figure 3.1 shows the process flow of AHP technique for contractor evaluation.

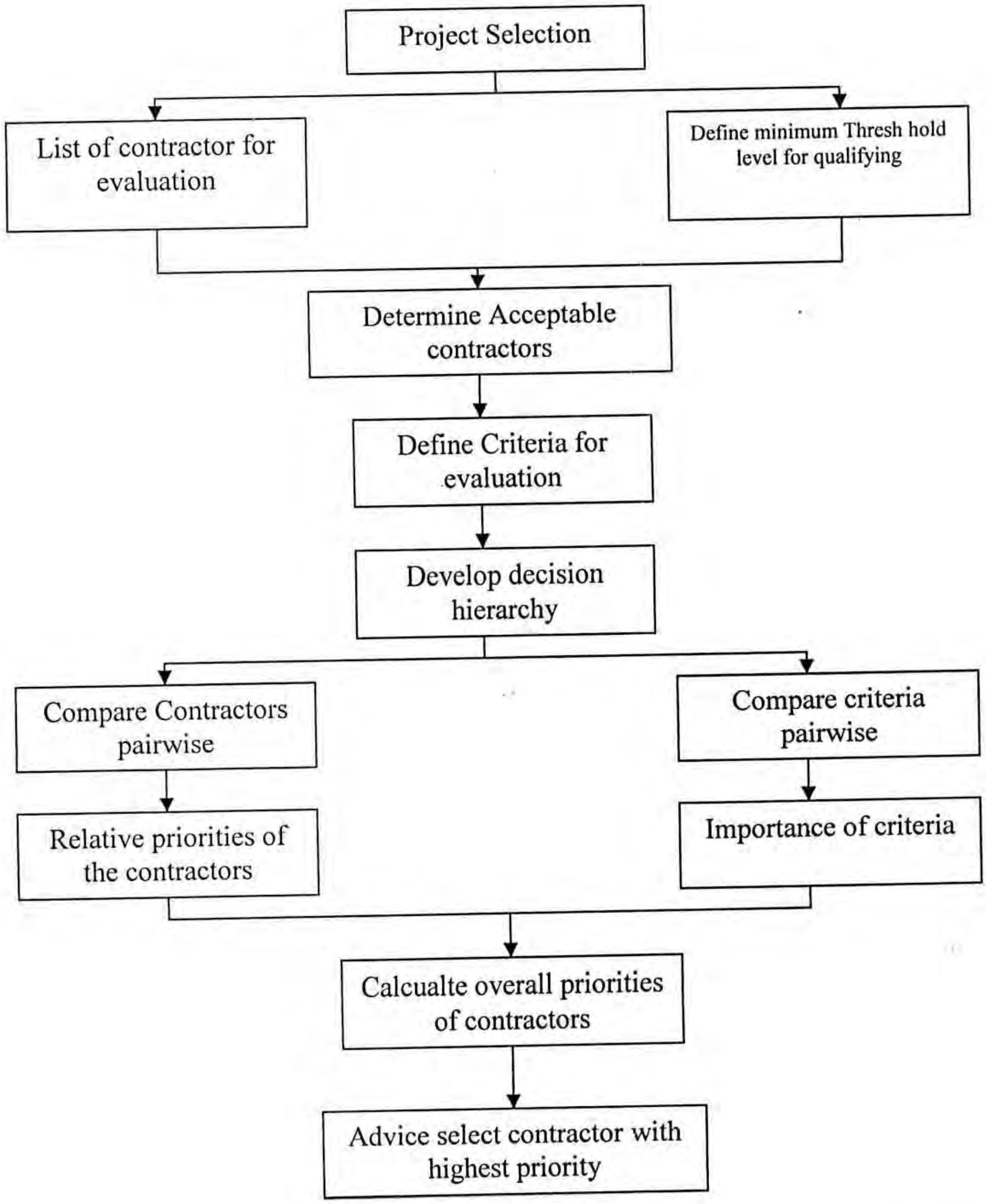

Figure 3.1 Flow Diagram of AHP process for contractor evaluation

Satty [4] developed the following steps for applying the AHP –

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the objectives from a decision makers' viewpoint) through the intermediate levels (criteria on which subsequent levels depend) to the lowest level which usually contains the list of alternatives.
3. Construct a set of pair wise comparison matrices (size n X n) for each of the lower levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in table - 01 below. The pair wise comparison are done in terms of which elements dominates the other.
4. There are n(n-1)/Judgments required to develop the set of matrices in step-3. Reciprocals are automatically assigned in each pair wise comparison.
5. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
6. Having made all the pair wise comparisons, the consistency is determined by using the eigen value, λ_{max}, to calculate the consistency index, CI as follows $CI = (\lambda_{max} - n)/(n-1)$, where n is the matrix size. Judgment consistency can be checked by taking the consistency ratio (CR) of CI with the appropriate value in Table – 3.2. The CR is acceptable if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.
7. Step 3 – 6 are performed for all levels in the hierarchy.

Table 3.1 below represents the pair wise comparison scale for AHP preferences proposed by satty. And table 3.2 represents the average values for the random consistency.

Table 3.1 Pair wise comparison scale for AHP preferences

Judgments of preferences	Numerical Ratings
Extremely Preferred	9
Very Strongly to extremely	8
Very strongly preferred	7
Strongly to very strongly	6
Strongly preferred	5
Moderately to strongly	4
Moderately preferred	3
Equally to moderately	2
Equally preferred	1

Tabie 3.2 Average Random Consistency Index (RI)

Average random consistency (RI)										
Size of the matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Chapter Four

CONTRACTOR EVALUATION TECHNIQUES

4.1 Commonly Used Techniques

Prequalification of contractors means aiming at the elimination of incompetent contractors from the bidding process. Evaluation can aid the private and public in achieving successful and efficient use of their funds by ensuring that it will be a qualified contractor who will work in the project. Furthermore, because of the skill, capability and efficiency of a contractor, completion of a project within the estimated cost and time is more probable. Nguyen [24] argued that the evaluation process remains largely an art where subjective judgment, based on individual experience, becomes an essential part of the process.

Russel and skibniewski [25] mentioned that the actual process of contractor evaluation had received little attention in the past. Russel and skibniewski [25] tried to describe the contractor evaluation process along with the decision making strategies and the factors that influence the process. They reported five methods that they found in use for contractor evaluation

1. Dimensional Weighting.
2. Two Step Prequalification.
3. Dimension Wise Strategy.
4. Prequalification Formulae.
5. Subjective Judgment.

4.1.1 Dimensional Weighting

In the dimensional weighting method, the choice of selection criteria and their weights are dependent on the owner. All contractors are ranked on the basis of the criteria. A contractor is calculated by summing their ranks multiplied by their weight of the respective criteria. Then, contractors are ranked on the basis of the criteria. Then the contractors are ranked on the basis of their total scores, and this rank order of the contractors is used for evaluation. The problem with this method is deciding the weight of the respective criteria, something for which the AHP does provide a methodology.

4.1.2 The Two-Step Prequalification Method

The Two-Step prequalification method is a modification of the dimensional weighting method. In the first step, screening of contractors is done on preliminary factors. They must get through this step to be eligible for the second phase of evaluation. In the second step, the dimensional weighting technique is used for more specialized factors. This method is useful for quick removal of ineligible candidates.

4.1.3 Dimension Wise Strategy Method

In this method a list of the most important evaluation criteria is developed in descending order depending on how important the criteria is. Contractors are then evaluated on these factors. If a candidate fails to meet any of the criteria, the candidate is removed from the evaluation process. The method continues until contractors are measured on all criteria.

4.1.4 Prequalification Formula Method

The prequalification formulae method evaluates contractors on the basis of a formula that calculate the maximum capability of a contractor. The maximum capability is defined as the maximum amount of uncompleted work in progress that the contractor can have at any one of time. In this method, the contractor's prequalification is dependent on the contractor's maximum capability, current uncompleted work and the size of the project under consideration. If the difference between the contractor's capability and current uncompleted work is less than the project works, then the contractor is removed from the bidding process.

4.1.5 Subjective Judgment Method

In some instances, owners may base their contractor selection decision on subjective judgment and not on a structured approach. The judgment may be influenced by owner biases, such as previous experience with the contractor or how well the contractor's field state operates.

4.2 Contractor Prequalification Evaluation by ADB

The purpose of this literature review here is to provide an idea on how a prequalification is performed based on ADB [26] Standard Procurement Document for the prequalification of Bidders (SPQD) and how the application of the tenderer's are evaluated.

The SPQD is based on the Master Procurement Document entitled "Prequalification Documents for Procurement of Works", prepared by multilateral development banks and other public international financial institutions, and has the structure and the provisions of the master procurement document, except where ADB specific considerations have required a change.

The SPQD has been prepared to facilitate prequalification of bidders for large and complex civil works contracts, turnkey contracts, and contracts for the fabrication of expensive and technically complex plant and equipment. This is to ensure that only firms with appropriate experience, a proven track record, and necessary annual turnover, which are free of any major pending litigation, will be invited to submit bids. The SPQD is to be used for the prequalification process for contracts to be procured through International Competitive Bidding. An important feature of this SPQD is that it can be used with minimum changes, as it does not contain explanations, footnotes or examples.

ADB's Guidelines for Procurement require prequalification of bidders for most civil works contracts, turnkey contracts, and contracts for the supply of expensive and technically complex equipment. Prequalification is followed by a closed competitive bidding procedure in which only those firms meeting specified prequalification criteria are invited to submit a bid. Prequalification should not be used for limiting competition to a predetermined number of potential bidders. All applicants meeting the specified criteria shall be allowed to bid.

ADB requires bidders to be pre qualified by meeting predefined, precise minimum requirements. The method entails setting pass-fail criteria which, if not met by the applicant, result in disqualification. Figure 4.1 represents the flow diagram of ADB's contractor prequalification process.

The criteria adopted must relate to characteristics that are essential to ensure satisfactory execution of the contract, and must be stated in unambiguous terms. In essence, the criteria must be chosen so that only contractors who are well qualified to carry out the contract are permitted to bid. The criteria must also be set so that they neither inhibit competition nor set a predetermined number of firms to be pre qualified. All firms that meet the criteria should be invited to bid. Figure 4.2 represents the flow diagram of ADB's contractors post qualification evaluation.

An applicant's capabilities to perform the contracts satisfactorily are established in respect of

- Eligibility
- Pending Litigation
- Financial Situation
- Experience.

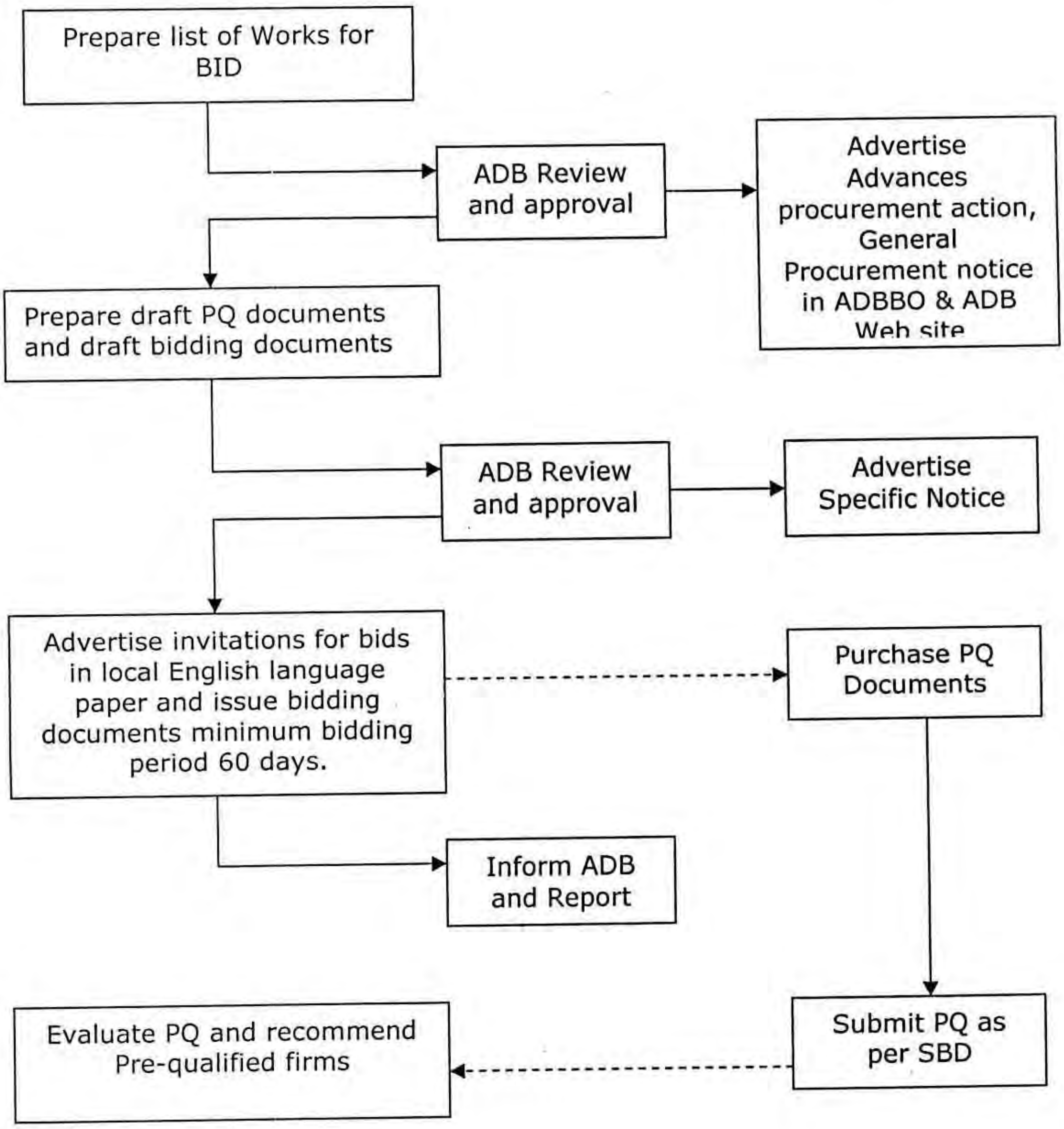

Figure 4.1 ADB Contractor pre-qualification evaluation process

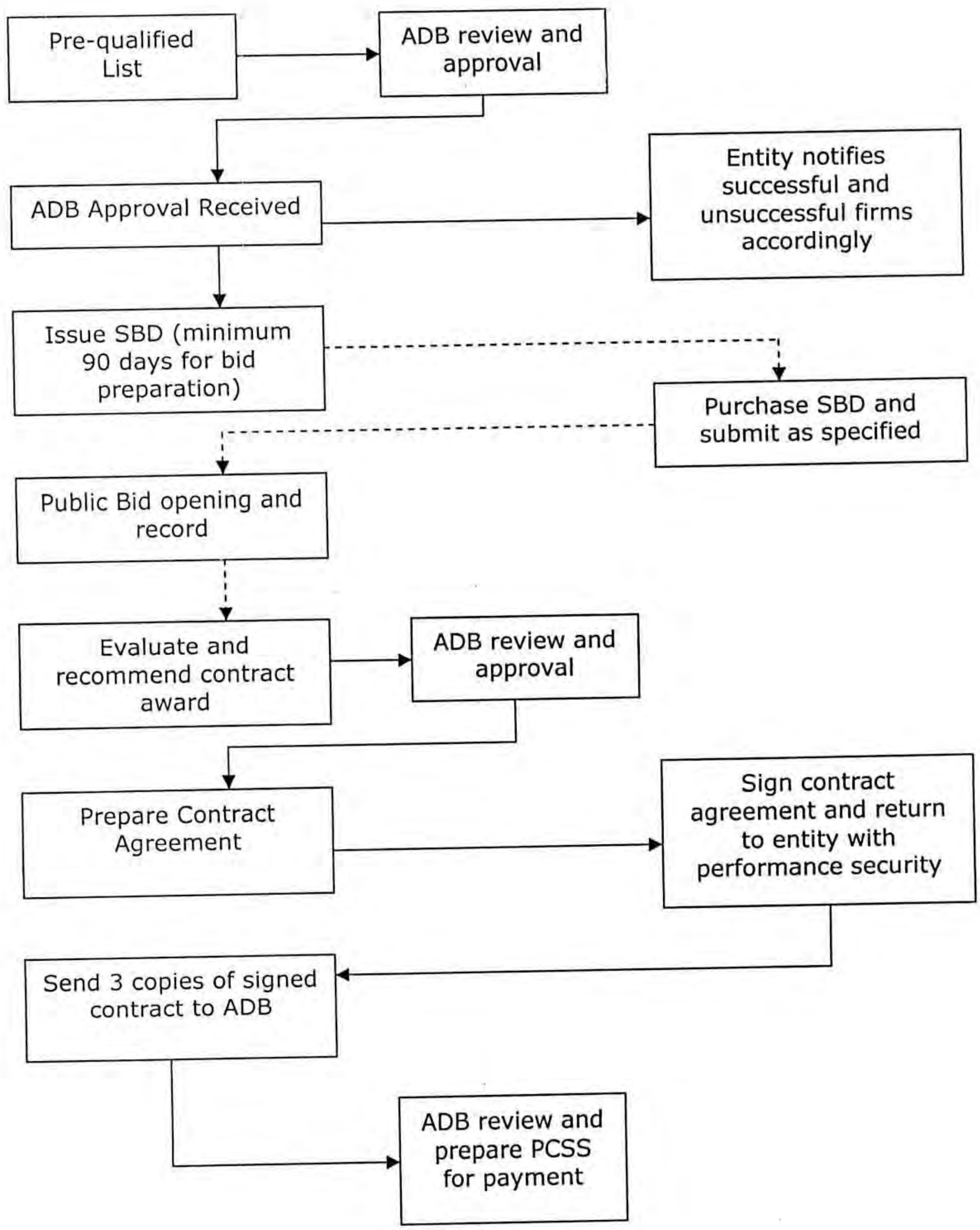

Figure 4.2 ADB Contractor post qualification evaluation process

4.3 Contractor Prequalification Evaluation by World Bank

Standard Procurement Document "Prequalification Document for Procurement of Works and User's Guide" has been prepared by the World Bank [27] and is based on the Master Procurement Document "Prequalification Document for Procurement of Works and User's Guide" prepared by the multilateral development banks and international financing institutions.

This document reflects the majority view of these institutions and is to be used when a prequalification process takes place prior to the bidding process for procurement of works through International Competitive Bidding (ICB) in projects that are financed in whole or in part by the World Bank.

This document is organized into two (2) main components

- The Prequalification Document for Procurement of Works; and
- A User's Guide for the Prequalification Document for Procurement of Works.

Qualification Criteria and Requirements are to specify the criteria and corresponding requirements that the employer shall use to evaluate the applications and pre qualify the applicants. The Employer shall specify the "Qualification Criteria and Requirements" in the Standard Tabular Form. The four main qualification criteria are

1. Eligibility
2. Historical Contract Non-Performance
3. Financial Situation
4. Experience

The Bank's policy on prequalification is that all potential bidders that meet predefined minimum requirements regarding general construction experience; particular or specialized experience; financial capabilities; personnel capabilities, and equipment availability should be invited to bid.

The procedure requires the implementing agency (employer) to set pass/fail criteria which, if all are not met substantially by the applicants, would cause them to be disqualified. The criteria adopted must relate to characteristics that are essential to ensure satisfactory execution of the subject contract (or each contract with slice and package bidding), and they must be precisely stated. Basically, the criteria must be chosen so that only applicants that are qualified to carry out the work are permitted to bid. The criteria must also be set so that they neither inhibit competition nor limit the number of eligible firms to be pre qualified. All applicants that meet the criteria should be invited to bid.

Post Qualification Evaluation like the verification of availability of resource (liquid assets or line of credit, key personnel and equipment) should be made at the time of contract award, rather than at the qualification stage. Therefore, such criteria have not been included in the SPD (Standard prequalification Document).

4.4 Standard Contractor Evaluation Procedures – CPTU (GOB)

Bangladesh constitution had no direct provision on public procurement nor did any nationally applicable procurement law existed to regulate approximately US$ 3 billion per year of government procurement. Nationally applicable procurement rules in the public sector in Bangladesh were yet to be established. Each department and public sector entity had its individual manuals and procedures. Inadequate procurement expertise, complex bureaucratic decision-making processes, lack of transparency, allegations of corruption in the procurement of goods, works and services had contributed considerably to slow down project implementation.

Project implementation was also hampered by the poor selection criteria for key personnel including project directors who are not fully familiar with project management concepts and procurement procedures. Hence the need for improved governance in public sector procurement was inevitable. It was felt that in order to achieve this, a permanent unit should be established to provide technical advice to all agencies of the government including ministries. The CPTU (Central Procurement and Technical Unit) of the IMED (Implementation Monitoring and Evaluation Division) [28] was that permanent unit.

The purpose of this literature review here, is to provide an idea on how Contractors are being evaluated for procurement of construction works. This evaluation is based on Standard Tender Document (STD) developed by Central Procurement Technical Unit (CPTU) of the Implementation Monitoring and Evaluation Division (IMED), Ministry of Planning, Bangladesh.

4.4.1 Pre Qualification

- The preferred practice for large or complex works.
- To ensure only firms with adequate experience, resources, qualifications and expertise are selected to tender.

4.4.2 Post Qualification

- The post-evaluation check to assess capacity.
- To ensure adequate, experience, resources, qualifications and expertise available exist in the selected firm

4.4.3 Prequalification Process

- Employer drafts pre-qualification advertisement and prepares standard pre-qualification form for responses.
- Advertisement placed in accordance with Regulation.
- Responses submitted in accordance with deadline and document requirements (28 days minimum period)
- Submissions received, evaluated and summary prepared (no public opening). Late submissions returned unopened.
- Applicants notified and qualified firms invited to submit tenders
- Updated information provided as part of Standard Tender Document (STD)
- Post-qualification check prior to Contract Award

Table A1 and Table A2 represent sample invitation forms for contractor prequalification evaluation.

4.4.4 Criteria for Evaluation

Evaluation Pre-set Pass or Fail Basis

- Legal Detail Registration, trading status, ownership
- Financial Detail Liquidity, current work load, capacity and potential
- Litigation Detail History, current disputes, pending cases
- Resources Detail Levels and qualifications of key staff, equipment capacity, workshops, location, deployment of specialist sub-contractors
- Experience Detail Range of work, management capacity, general construction experience, relevant specialist work.

Chapter Five

USING AHP IN CONTRACTOR EVALUATION

For applying the Analytical Hierarchy Process (AHP) in selecting the best pre-qualifying contractor for accomplishing a project, a real time case study is presented here. Using this case study the output results of AHP are compared with the output results of the traditional approach (kind of Weighted Sum Model).

This case study is involved to sub-contractor prequalification evaluation problem of Navana Construction Limited, a fully-fledged construction wing of Navana Group. Sub-contractor prequalification problem is chosen because in any large construction company selection of competent sub-contractor is very important. Appropriate sub-contractor evaluation is a systematic approach, which can save not only a huge amount of money in construction projects, but also can work toward joint continual improvement for mutual benefit in the background linkage ensuring due time completion of the construction projects.

Navana Construction Ltd. (NCL), a fully-fledged construction wing of Navana Group came into physical existence in 1996 under the Chairmanship of Mr. Shafiul Islam Kamal, the Ex-Vice Chairman and the very Key Person of Islam Group was responsible for procurement & the execution of the construction jobs of Bengal Development Corporation (BDC), the construction company of the Islam Group.

NCL comprises of highly experienced and skilled Engineers and Technical Persons of BDC who switched over to Navana after the formation of this company. The Engineers and the Technical Personnel do have the working experience in big construction works in Bangladesh. To name a few of the projects are - Embankment and River Dredging projects under Water Development Board, Road Construction under Roads & Highways Department and other Govt. and private construction as well as some projects in abroad like Road & Pre-Casted Housing Project in UAE, Housing Project in YEMEN and IRAQ.

Within a short span of time since its inception it has been famed and widely entrusted as one of the leading Construction Company in Bangladesh already having working experience with various Govt., non-Govt. and private construction. The reputation of NCL has reflected in awarding of contracts from various Embassies and foreign organizations working in Bangladesh.

NCL is enlisted with various Govt., non-Govt. Organizations such as Public Works Deportment (PWD), Bangladesh Water Development Board (BWDB), Housing & Settlement Department (H&SD), Military Engineering Services (MES), Dhaka City Corporation and Roads & Highways Department (RHD).

This case study involved four very senior engineers from the construction department of Navana Constructions Limited nominated by the chief engineer, who often had to deal with the sub-contractor evaluation for construction projects, supervise the ongoing projects and had sufficient knowledge in project management field.

5.1 Traditional Sub-Contractor Prequalification Evaluation Approach

Navana Glory is a six-storied apartment project, for which the sub-contractors prequalification evaluation is illustrated below. The factors used in this project for prequalification are

1. Annual Turnover. (ATR)
2. Availability of Liquid assets. (ALS)
3. Key Personnel. (KP)
4. Plant and Equipments. (PE)
5. Experience with similar works. (ESW)
6. Experience with other works. (EOW)
7. Contract Execution Capacity. (CEC)

Table A3, Table A4 and Table A5 represent the Evaluation Criteria for Prequalification of Sub-Contractors in Navana Constructions Ltd.

The above mentioned criterions are used by the Navana Constructions Limited for contractor prequalification evaluation. Table 5.1 below represents the information of the subcontractors A, B, C, D, E & F for the project for which sub contractors wish to pre qualify. And furthermore table 5.2 depicts the scores on each criterion of the evaluation for the sub contractors.

Table 5.1 Information of the Pre-qualifying Sub-Contractors

Subcontractor	A	B	C	D	E	F
Annual Turnover	Between 25-30 million	Between 20 - 25 million	More than 30 million	Between 20-25 million	Between 25-30 million	Less than 20 million
Availability of Liquid Assets	Between 15-20 million	Between 10-15 million	Between 15-20 million	More than 20 million	More than 20 million	Between 15-20 million
Key Personnel	Average competency	High competency	High Competency	Average competency	High competency	Average competency
Plants and Equipments	Owned for long term leased	Majority leased for work	Sufficient for contract	Sufficient for contract	Sufficient for contract	Owned for long term leased
Experience with similar works	Between 55-65 million	Between 55-65 million	Between 65-75 million	Between 55-65 million	Between 45-55 million	Between 45-55 million
Experience with other works	Between 25-30 million	Between 20-25 million	More than 30 million	Between 25-30 million	More than 30 million	Between 20-25 million
Contract Execution capacity	Condition not Met	Condition met	Condition not met	Condition met	Condition not met	Condition met

Table 5.2 Scores of the Pre-qualifying Sub-Contractors

Subcontractors	A	B	C	D	E	F
Annual Turnover(20)	16	12	20	12	16	8
Availability of Liquid Assets(10)	8	6	8	10	10	8
Key Personnel(7)	6	7	7	6	7	6
Plants and Equipments(5)	3	2	5	5	5	3
Experience with similar works(30)	20	20	25	20	15	15
Experience with other works(18)	17	16	18	17	18	16
Contract Execution capacity(10)	0	10	0	10	0	10
Total Score	70	73	83	80	71	66

For the traditional approach subcontractor C is selected as the best pre qualifying subcontractor for performing the project having the highest score of 83.

5.2 Sub-Contractor Prequalification Evaluation with AHP

Analytical Hierarchy Process (AHP) for evaluation of the subcontractors for the same project is illustrated below. At first the decision-makers have to indicate preferences or priority for each decision alternative in terms of how it contributes to each criterion. The pair wise comparison matrices are formed by collecting the data from interviewing the related personnel.

Then the following need to be done manually

1. Synthesizing the pair-wise comparison matrix.
2. Calculating the priority vector for each criterion.
3. Calculating the consistency ratio;
4. Calculating λ_{max} ;
5. Calculating the consistency index, CI;
6. Selecting appropriate value of the random consistency ratio from Table 3.2; and
7. Checking the consistency of the pair-wise comparison matrix to check whether the decision-maker's comparisons were consistent or not.

5.2.1 Pair-wise Comparison for Annual Turnover

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.3 for pair wise comparison of the sub contractors based on the criterion "Annual Turnover".

Table 5.3 Pair wise Comparison Matrix for Annual Turnover

Annual Turnover	A	B	C	D	E	F
A	1	4/3	4/5	4/3	9/10	2
B	3/4	1	3/5	9/10	3/4	3/2
C	5/4	5/3	1	5/3	5/4	5/2
D	3/4	10/9	3/5	1	3/4	3/2
E	10/9	4/3	4/5	4/3	1	2
F	1/2	2/3	2/5	2/3	1/2	1
Column Total	5.36	7.11	4.2	6.9	5.15	10.5

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.4 represents the synthesized matrix table for "Annual Turnover". The priority vector is obtained by finding the row averages.

Table 5.4 Synthesized matrix for Annual Turnover

Annual Turnover	**A**	**B**	**C**	**D**	**E**	**F**	**Priority Vector**
A	0.187	0.188	0.190	0.193	0.175	0.190	0.187
B	0.140	0.141	0.143	0.130	0.146	0.193	0.141
C	0.233	0.234	0.238	0.242	0.243	0.238	0.238
D	0.140	0.156	0.143	0.145	0.146	0.143	0.146
E	0.207	0.188	0.190	0.193	0.194	0.190	0.194
F	0.093	0.094	0.095	0.097	0.097	0.095	0.095

Now calculating the weighted sum matrix, we get the values 1.125, 0.843, 1.430, 0.874, 1.165 & 0.572 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, we obtain λ_{max}

$$\lambda_{max} = 6.01$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.002$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows

$$CR = CI/RI = 0.0016$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.2 Pair wise Comparison for Availability of Liquid Assets

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.5 for pair wise comparison of the sub contractors based on the criterion "Availability of Liquid Assets".

Table 5.5 Pair wise Comparison Matrix for Availability of Liquid Assets

Availability of liquid assets	A	B	C	D	E	F
A	1	4/3	10/9	4/5	4/5	2
B	3/4	1	3/4	3/5	3/5	3/4
C	9/10	4/3	1	4/5	4/5	11/9
D	5/4	5/3	5/4	1	10/9	5/4
E	5/4	5/3	5/4	9/10	1	5/4
F	1/2	4/3	9/11	4/5	4/5	1
Column Total	5.65	8.33	6.18	4.9	5.11	7.47

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.6 represents the synthesized matrix table for "Availability of Liquid Assets". The priority vector is obtained by finding the row averages.

Table 5.6 Synthesized Matrix for Availability of Liquid Assets

Availability of Liquid Assets	A	B	C	D	E	F	Priority Vector
A	0.177	0.160	0.180	0.163	0.157	0.268	0.184
B	0.133	0.120	0.121	0.122	0.117	0.100	0.119
C	0.159	0.160	0.162	0.163	0.157	0.163	0.161
D	0.221	0.200	0.202	0.204	0.217	0.167	0.202
E	0.221	0.200	0.202	0.184	0.196	0.167	0.195
F	0.088	0.098	0.132	0.163	0.157	0.134	0.129

Now calculating the weighted sum matrix, we get the values 1.097, 0.713, 0.961, 1.210, 1.168 & 0.829 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 6.055$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.011$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows

$$CR = CI/RI = 0.009$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.3 Pair wise Comparison for Key Personnel

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.7 for pair wise comparison of the sub contractors based on the criterion "Key Personnel".

Table 5.7 Pair wise Comparison Matrix for Key Personnel

Key Personnel	**A**	**B**	**C**	**D**	**E**	**F**
A	1	6/7	6/7	4/3	6/7	5/3
B	7/6	1	8/7	7/6	8/7	7/6
C	7/6	7/8	1	7/6	10/7	7/6
D	3/4	6/7	6/7	1	6/7	4/3
E	7/6	7/8	7/10	7/6	1	7/6
F	3/5	6/7	6/7	3/4	6/7	1
Column Total	5.85	5.32	5.41	6.58	6.14	7.5

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.8 represents the synthesized matrix table for "Key Personnel". The priority vector is obtained by finding the row averages.

Table 5.8 Synthesized Matrix for Key Personnel

Key Personnel	A	B	C	D	E	F	Priority Vector
A	0.171	0.161	0.158	0.203	0.140	0.222	0.176
B	0.199	0.188	0.211	0.177	0.186	0.155	0.186
C	0.199	0.164	0.185	0.177	0.233	0.155	0.186
D	0.128	0.161	0.158	0.152	0.140	0.177	0.153
E	0.199	0.164	0.129	0.177	0.163	0.155	0.165
F	0.103	0.161	0.158	0.114	0.140	0.133	0.135

Now calculating the weighted sum matrix, we get the values 1.065, 1.128, 1.126, 0.925, 0.999 & 0.816 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 6.05$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.01$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows

$$CR = CI/RI = 0.008$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.4 Pair wise Comparison for Plant and Equipments

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.9 for pair wise comparison of the sub contractors based on the criterion "Plant and Equipment".

Table 5.9 Pair wise Comparison Matrix for Plant and Equipments

Plant & Equipments	A	B	C	D	E	F
A	1	3/2	3/5	3/5	3/5	4/3
B	2/3	1	2/5	2/5	2/5	2/3
C	5/3	5/2	1	6/5	7/5	5/3
D	5/3	5/2	5/6	1	6/5	5/3
E	5/3	5/2	5/7	5/6	1	5/3
F	3/4	3/2	3/5	3/5	3/5	1
Column Total	7.42	11.5	4.15	4.63	5.2	8.00

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.10 represents the synthesized matrix table for "Plant and Equipment". The priority vector is obtained by finding the row averages.

Table 5.10 Synthesized Matrix for Plant and Equipments

Plant & Equipments	A	B	C	D	E	F	Priority Vector
A	0.135	0.130	0.145	0.130	0.115	0.166	0.137
B	0.090	0.087	0.096	0.086	0.077	0.083	0.087
C	0.225	0.217	0.241	0.259	0.270	0.208	0.237
D	0.225	0.217	0.201	0.216	0.231	0.208	0.216
E	0.225	0.217	0.172	0.180	0.192	0.208	0.199
F	0.101	0.130	0.145	0.130	0.115	0.125	0.124

Now calculating the weighted sum matrix, we get the values 0.824, 0.522, 1.427, 1.305, 1.201 & 0.748 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 6.02$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.004$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows

$$CR = CI/RI = 0.003$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.5 Pair wise Comparison for Experience with Similar Works

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.11 for pair wise comparison of the sub contractors based on the criterion "Experience with Similar Works".

Table 5.11 Pair wise Comparison Matrix for Experience with Similar Works

Exp with similar works	A	B	C	D	E	F
A	1	3/4	4/5	3/5	4/3	10/7
B	4/3	1	4/5	5/6	4/3	10/7
C	5/4	5/4	1	5/4	5/3	5/3
D	5/3	6/5	4/5	1	4/3	4/3
E	3/4	3/4	3/5	3/4	1	4/3
F	7/10	7/10	3/5	3/4	3/4	1
Column Total	6.7	5.65	4.6	5.18	7.42	8.19

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.12 represents the synthesized matrix table for "Experience with Similar Works". The priority vector is obtained by finding the row averages.

Table 5.12 Synthesized Matrix for Experience with similar works

Exp with similar works	A	B	C	D	E	F	Priority Vector
A	0.149	0.133	0.174	0.116	0.180	0.174	0.154
B	0.199	0.177	0.174	0.161	0.180	0.174	0.178
C	0.187	0.221	0.217	0.241	0.225	0.204	0.216
D	0.249	0.212	0.174	0.193	0.180	0.163	0.195
E	0.112	0.133	0.130	0.145	0.135	0.163	0.136
F	0.104	0.124	0.130	0.145	0.101	0.122	0.121

Now calculating the weighted sum matrix, we get the values 0.931, 1.073, 1.303, 1.181, 0.822 & 0.731 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 6.04$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.008$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows

$$CR = CI/RI = 0.006$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.6 Pair wise Comparison for Experience with Other Works

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.13 for pair wise comparison of the sub contractors based on the criterion "Experience with Other Works".

Table 5.13 Pair wise Comparison Matrix for Experience with Other Works

Exp with other works	A	B	C	D	E	F
A	1	9/8	9/10	7/8	4/3	5/3
B	8/9	1	8/9	4/5	8/9	4/3
C	10/9	9/8	1	9/8	5/3	9/8
D	8/7	5/4	8/9	1	7/8	9/8
E	3/4	9/8	3/5	3/7	1	10/9
F	3/5	3/4	8/9	8/9	9/10	1
Column Total	5.49	6.38	5.17	5.83	6.66	7.36

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.14 represents the synthesized matrix table for "Experience with Other Works". The priority vector is obtained by finding the row averages.

Table 5.14 Synthesized Matrix for Experience with other works

Exp with other works	A	B	C	D	E	F	Priority Vector
A	0.182	0.176	0.174	0.150	0.200	0.226	0.185
B	0.162	0.157	0.172	0.137	0.133	0.181	0.157
C	0.202	0.176	0.193	0.193	0.250	0.153	0.195
D	0.208	0.196	0.172	0.172	0.131	0.153	0.172
E	0.137	0.176	0.116	0.196	0.150	0.151	0.154
F	0.109	0.118	0.172	0.152	0.135	0.136	0.137

Now calculating the weighted sum matrix, we get the values 1.121, 0.952, 1.181, 1.042, 0.935 & 0.831 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 6.06$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.012$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows.

$$CR = CI/RI = 0.010$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.7 Pair wise Comparison for Contract Execution Capacity

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.15 for pair wise comparison of the sub contractors based on the criterion "Contract Execution Capacity".

Table 5.15 Pair wise Comparison Matrix for Contract Execution Capacity

Contract Execution Capacity	A	B	C	D	E	F
A	1	5/6	5/7	5/6	3/4	5/4
B	6/5	1	6/7	3/4	6/5	3/2
C	7/5	7/6	1	7/8	7/5	7/4
D	6/5	4/3	8/7	1	6/5	3/2
E	4/3	5/6	5/7	5/6	1	5/4
F	4/5	2/3	4/7	2/3	4/5	1
Column Total	6.93	5.83	5.00	4.96	6.35	8.25

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.16 represents the synthesized matrix table for "Contract Execution Capacity". The priority vector is obtained by finding the row averages.

Table 5.16 Synthesized Matrix for Contract Execution Capacity

Contract Execution Capacity	A	B	C	D	E	F	Priority Vector
A	0.144	0.143	0.143	0.168	0.118	0.152	0.145
B	0.173	0.172	0.171	0.151	0.189	0.182	0.173
C	0.202	0.200	0.200	0.176	0.220	0.212	0.202
D	0.173	0.229	0.229	0.202	0.189	0.182	0.201
E	0.192	0.143	0.143	0.168	0.157	0.152	0.159
F	0.115	0.114	0.114	0.134	0.126	0.121	0.121

Now calculating the weighted sum matrix, we get the values 0.871, 1.043, 1.217, 1.209, 0.960 & 0.729 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 6.02$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.004$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of six using table 3.2, we find RI=1.24. We then calculate the consistency ratio, CR, as follows

$$CR = CI/RI = 0.003$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.8 Pair wise Comparison of the 7 Criteria

By interviewing four senior engineers of Navana Construction Ltd. we form the table 5.17 for pair wise comparison of the sub contractors based on the Seven Criterion.

Table 5.17 Pair wise Comparison Matrix for the 7 Criteria

Criteria	ATR	ALS	KP	PE	ESW	EOW	CEC
ATR	1	2	3	4	2/3	10/9	2
ALS	1/2	1	10/7	2	1/3	5/9	4/3
KP	1/3	7/10	1	7/5	1/4	7/18	7/10
PE	1/4	1/2	5/7	1	1/6	1/4	1/2
ESW	3/2	3	4	6	1	5/3	3
EOW	9/10	9/5	18/7	4	3/5	1	9/5
CEC	1/2	3/4	10/7	2	1/3	5/9	1
Column Total	4.98	9.75	14.14	20.4	3.35	5.53	10.33

Synthesizing the pair wise comparison matrix & this is performed by dividing each element of the matrix by its column total. Table 5.18 represents the synthesized matrix table for "Seven Criterion". The priority vector is obtained by finding the row averages.

Table 5.18 Synthesized Matrix for the 7 Criteria

Criteria	ATR	ALS	KP	PE	ESW	EOW	CEC	PRIORITY VECTOR
ATR	0.201	0.205	0.212	0.196	0.199	0.201	0.194	0.201
ALS	0.100	0.103	0.101	0.098	0.099	0.100	0.129	0.104
KP	0.067	0.072	0.071	0.069	0.075	0.070	0.068	0.070
PE	0.050	0.051	0.051	0.049	0.050	0.045	0.048	0.049
ESW	0.301	0.308	0.283	0.294	0.299	0.301	0.290	0.297
EOW	0.181	0.185	0.182	0.196	0.179	0.181	0.174	0.183
CEC	0.100	0.077	0.101	0.098	0.099	0.100	0.097	0.096

Now calculating the weighted sum matrix, we get the values 1.048, 0.731, 0.491, 0.345, 2.078, 1.278 & 0.673 as the values of the weighted sum matrix. Dividing all the elements of the weighted sum matrix by their respective priority vector element, We obtain λ_{max}

$$\lambda_{max} = 7.01$$

Now we find the consistency index, CI, as follows

$$CI = (\lambda_{max} - n)/(n-1) = 0.002$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of seven using table 3.2, we find RI=1.32. We then calculate the consistency ratio, CR, as follows.

$$CR = CI/RI = 0.003$$

As the value of CR is less than 0.1, the judgments are acceptable.

5.2.9 Priority matrix for contractor prequalification

Table 5.19 below represents the overall priority matrix for contractor prequalification as per calculation.

Table 5.19 Priority matrix for contractor prequalification

	ATR (0.201)	ALS (0.104)	KP (0.070)	PE (0.049)	ESW (0.297)	EOW (0.183)	CEC (0.096)	OVERALL PRIORITY VECTOR
A	0.187	0.184	0.176	0.137	0.154	0.185	0.145	0.169
B	0.141	0.119	0.186	0.087	0.178	0.157	0.173	0.156
C	0.238	0.161	0.186	0.237	0.216	0.195	0.202	0.208
D	0.146	0.202	0.153	0.216	0.195	0.172	0.201	0.180
E	0.194	0.195	0.165	0.199	0.136	0.154	0.159	0.164
F	0.095	0.129	0.135	0.124	0.121	0.137	0.121	0.121

Overall priority of contractor A = 0.187(0.201) + 0.184(0.104) + 0.176(0.070) + 0.137(0.049) + 0.154(0.297) + 0.185(0.183) + 0.145(0.096) = 0.169

Overall priority of contractor B = 0.141(0.201) + 0.119(0.104) + 0.186(0.070) + 0.087(0.049) + 0.178(0.297) + 0.157(0.183) + 0.173(0.096) = 0.156

Overall priority of contractor C = 0.238(0.201) + 0.161(0.104) + 0.186(0.070) + 0.237(0.049) + 0.216(0.297) + 0.195(0.183) + 0.202(0.096) = 0.208

Overall priority of contractor D = 0.146(0.201) + 0.202(0.104) + 0.153(0.070) + 0.216(0.049) + 0.195(0.297) + 0.172(0.183) + 0.201(0.096) = 0.180

Overall priority of contractor E = 0.194(0.201) + 0.195(0.104) + 0.165(0.070) + 0.199(0.049) + 0.136(0.297) + 0.154(0.183) + 0.159(0.096) = 0.164

Overall priority of contractor F = 0.095(0.201) + 0.129(0.104) + 0.135(0.070) + 0.124(0.049) + 0.121(0.297) + 0.137(0.183) + 0.121(0.096) = 0.121

For prequalification purposes, the contractors are now ranked according to their overall priorities, as follows C, D, A, E, B & F, indicating that C is the best qualified contractor to perform the project.

Chapter Six

RESULTS AND DISCUSSIONS

The data and information required in this study about sub contractor's evaluation were directly obtained from the firm. Survey and extensive interview were necessary to judge the data collection. For our evaluation purposes we interviewed four very senior engineers of the firm.

All necessary data and information could not be collected due to various reasons. It might be due to lack of assistance at the time of interview or it might be because of lack of information due to confidentiality. Sometimes data were approximated very close to actual data. In our case study, we focused only on the major criteria for sub contractor prequalification evaluation in order to avoid complexities in calculations.

For sub contractor pre qualification evaluation of Navana Contructions Ltd. the most commonly used criteria are annual turnover (ATR), availability of liquid assets (ALS), key personnel (KP), plants and equipments (PE), experience with similar works (ESW), experience with other works (EOW) and contract execution capacity (CEC).

For our particular case the chief engineer of Navana Constructions Ltd. first decided who should be the decision makers and how much weight each criteria should contain. For data collection and interviewing purposes he nominated four very senior engineers who were directly involved in decision concerning sub contractor evaluation.

Finally with the help of spreadsheet analysis I analyzed the collected data. The analysis is developed based on the mathematical model discussed thoroughly in the previous sections. This model can easily aid to select the best pre qualifying contractor both quantitatively and graphically. Table 6.1 below, represents the final overall priority values of each pre-qualifying subcontractor for our case study.

Table 6.1 Overall priority values for each subcontractor

	ATR (0.201)	ALS (0.104)	KP (0.070)	PE (0.049)	ESW (0.297)	EOW (0.183)	CEC (0.096)	OVERALL PRIORITY VECTOR
A	0.187	0.184	0.176	0.137	0.154	0.185	0.145	0.169
B	0.141	0.119	0.186	0.087	0.178	0.157	0.173	0.156
C	0.238	0.161	0.186	0.237	0.216	0.195	0.202	0.208
D	0.146	0.202	0.153	0.216	0.195	0.172	0.201	0.180
E	0.194	0.195	0.165	0.199	0.136	0.154	0.159	0.164
F	0.095	0.129	0.135	0.124	0.121	0.137	0.121	0.121

In figure 6.1 below, the pre qualifying contractors for our case study is represented graphically. It is associated with its quantitative portion for its easy understanding. From the bar diagram and overall priority table we find that contractor C should be selected due to its highest overall priority.

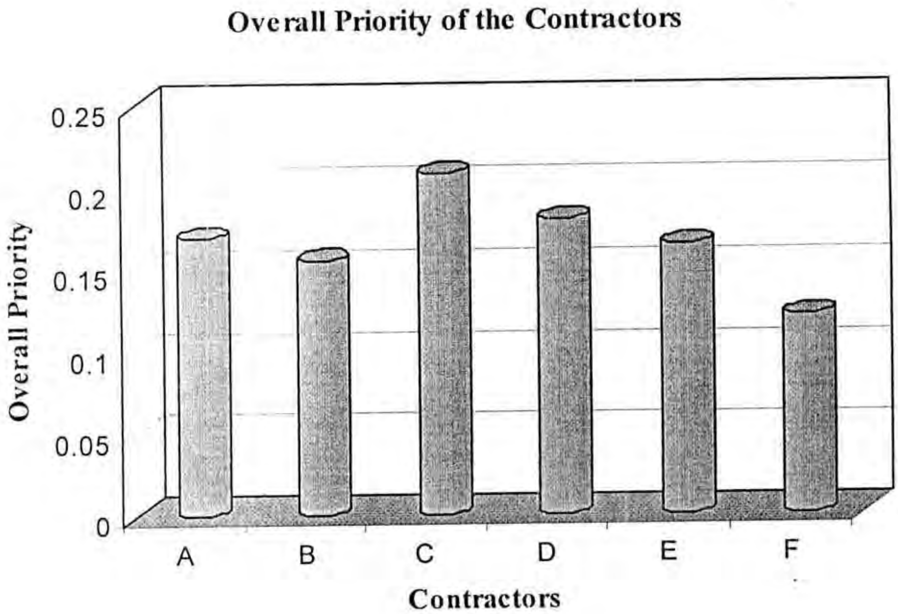

Figure 6.1 Graphical representations of the pre qualifying contractors

Spreadsheet analysis provides better scope for sensitivity analysis and what-if analysis scenarios. Sensitivity analysis can be performed to identify the more sensitive alternatives and to the greater extent this analysis can alert the project owner ahead of the situation. When a large number of criteria and alternatives are considered, the number of pair wise comparisons may increase quickly; in these types of situations spreadsheet analysis can come really handy.

For explaining the sensitivity analysis two scenarios are formed. The first scenario is formed by changing the pair wise comparisons of the contractors based on the evaluation criteria used in the case study. Table 6.2 illustrates the overall priority values for each contractor according to this first scenario and figure 6.2 represents this first scenario graphically.

Table 6.2 Overall priority values for each subcontractor (first scenario)

	ATR (0.201)	ALS (0.104)	KP (0.070)	PE (0.049)	ESW (0.297)	EOW (0.183)	CEC (0.096)	OVERALL PRIORITY VECTOR
A	0.244	0.326	0.257	0.234	0.159	0.241	0.141	0.217
B	0.122	0.102	0.185	0.071	0.204	0.138	0.152	0.152
C	0.205	0.146	0.161	0.244	0.220	0.176	0.203	0.197
D	0.164	0.165	0.134	0.170	0.191	0.183	0.209	0.178
E	0.185	0.149	0.144	0.178	0.120	0.138	0.188	0.150
F	0.080	0.112	0.120	0.102	0.107	0.1124	0.107	0.106

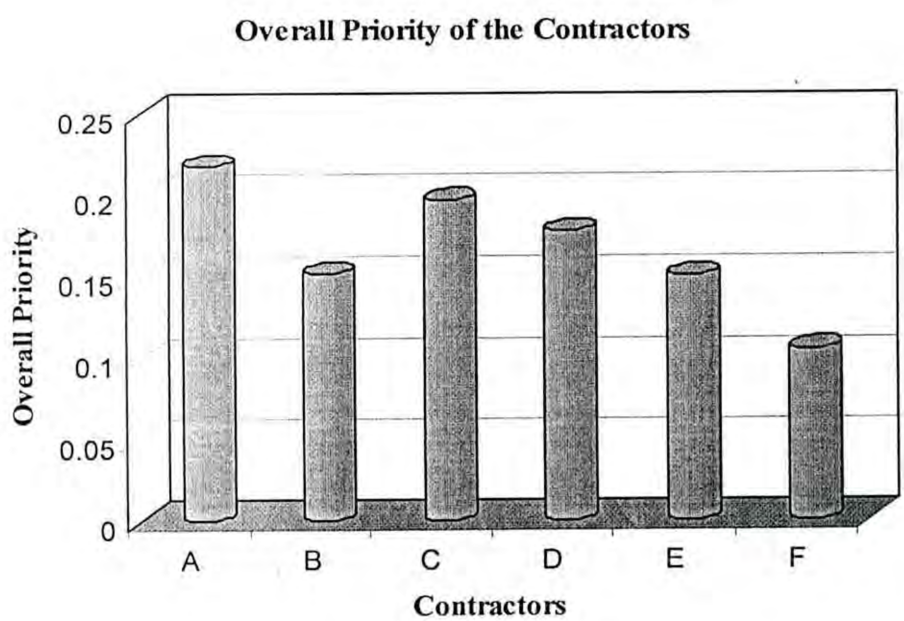

Figure 6.2 Graphical representations of the pre-qualifying contractors (first scenario)

From the bar diagram figure 6.2 and overall priority table 6.2, we find that contractor A should be selected due to its highest overall priority according to this changed first scenario.

The second scenario is formed by changing the pair wise comparisons of the contractors based on the evaluation criteria along with the comparison criteria used in the case study. Table 6.3 illustrates the overall priority values for each contractor according to this second scenario and figure 6.3 represents this second scenario graphically.

Table 6.3 Overall priority values for each subcontractor (second scenario)

	ATR (0.164)	ALS (0.126)	KP (0.069)	PE (0.048)	ESW (0.329)	EOW (0.174)	CEC (0.090)	OVERALL PRIORITY VECTOR
A	0.154	0.326	0.257	0.234	0.159	0.241	0.141	0.163
B	0.110	0.102	0.185	0.071	0.204	0.138	0.152	0.151
C	0.193	0.146	0.161	0.244	0.220	0.176	0.203	0.199
D	0.308	0.165	0.134	0.170	0.191	0.183	0.209	0.209
E	0.147	0.149	0.144	0.178	0.120	0.138	0.188	0.156
F	0.089	0.112	0.120	0.102	0.107	0.1124	0.107	0.122

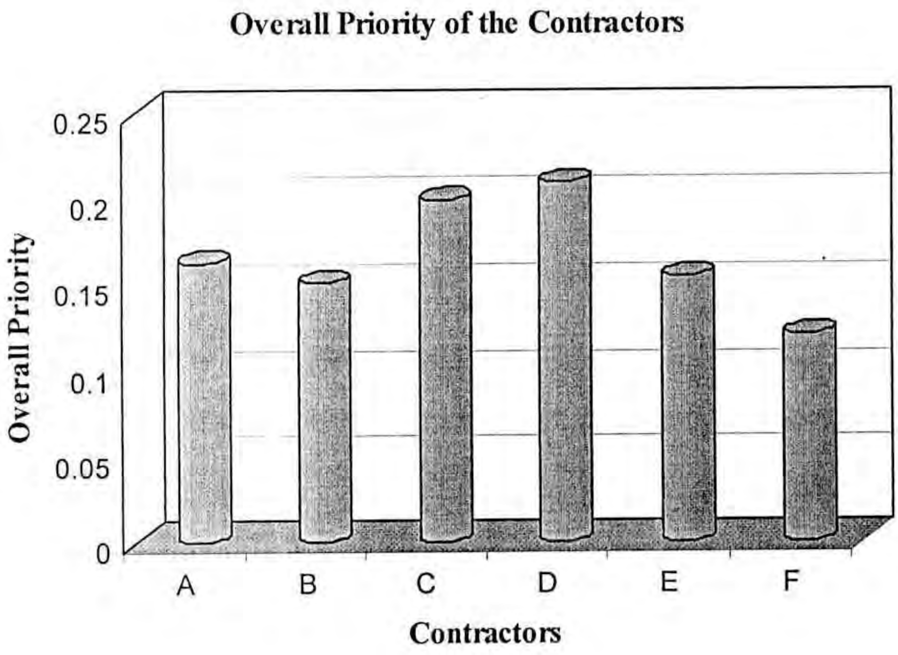

Figure 6.3 Graphical representations of the pre-qualifying contractors (second scenario)

From the bar diagram figure 6.3 and overall priority table 6.3, we find that contractor D should be selected due to its highest overall priority according to this changed second scenario.

Chapter Seven

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In recent years, projects are becoming very common phenomenon in all the organizational business units. Especially for the construction companies, every construction work they perform is an example of ideal project. The primary challenge of project management was to achieve all of the project goals and objectives while adhering to classic project constraints usually scope, quality, time and budget. The secondary and more ambitious challenge was to optimize the allocation and integration of inputs necessary to meet pre-defined objectives.

The new challenge may be considered like dealing with the number of alternatives that have grown dramatically in the field of Project Management. Managers have to deal more with conflicting goals now a days. In case of construction projects selecting the best contractor among many contractors may be considered as one of this particular type. Recently, much research effort has been devoted to the method - Analytical Hierarchy Process (AHP) for solving problems with multi-criteria decision making. An important characteristic of AHP is its ability to incorporate both quantitative and qualitative factors. It has great applicability in contractor evaluation for any project especially when the comparative judgments are made based on qualitative factors.

On the other hand, AHP has some weaknesses also. The method includes rather complex mathematical calculations, using eigenvalues and eigenvectors. However, these calculations can be performed easily when using one of the available AHP programs. The number of pair-wise comparisons a project manager has to make, may increase quickly when a large number of (sub) criteria and alternatives are considered. Finally, the assumption of independence of criteria might cause problems in practice.

In this presented paper, a case study about sub contractor prequalification evaluation is performed comparing the traditional approach (kind of Weighted Sum Model) with the Analytical Hierarchy Process (AHP). Though for this particular case study the two methods depict the same result, but the main distinguishing feature is the strength of AHP dealing with qualitative factors (subjective judgments). Only AHP can deal with such an exception not the traditional approach. Moreover consistency checking of the matrices formed for performing the calculation of AHP validates the decision maker's judgments.

Reviewing all of these aspects I would like to conclude that AHP may be a promising method in project management decision making. The appropriateness of AHP is not limited to the selection of possible best contractor only. If Project managers feel a need to improve the effectiveness and efficiency of their decision making process, AHP should be considered in case the decision problem includes multiple objectives, conflicting criteria, incommensurable units, and aims at selecting the best alternative from a set of alternatives. AHP can accommodate uncertain and subjective information and allows the application of experience, insight, intuitive in a logical manner. Perhaps another most important advantage, however, is in developing hierarchy itself. As long the scale is applied consistently by each individual, the AHP can correctly process their judgment.

7.2 Recommendations

This study analyses the sensitivity of the process considering only the certain conditions in the decision environment. For further development, to handle uncertainty level of the decision environment, algorithm can be developed. Another possible development may be, making this decision support system (DSS) more intelligent by developing suitable algorithm to identify the sensitive alternative automatically after getting initial information about the alternatives.

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APPENDIX

Table A1. Invitation for Pre-qualification
(For use when there is a single lot package)

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH				
1	Ministry/Division	< select > V		
2	Agency	< select > V		
3	Procuring Entity Name	< type in name >		
4	Procuring Entity Code	Not used at present		
5	Procuring Entity District	< select > V		
6	Invitation for	< select > V	< select > V	< select > V
7	Invitation Ref No	< type in name >		
8	Date	< select > V		
KEY INFORMATION				
9	Procurement Method	< select > V	< select > V	
FUNDING INFORMATION				
10	Budget and Source of Funds	< select > V		
11	Development Partners (if applicable)	< type in name >		
PARTICULAR INFORMATION				
12	Project / Programme Code (if applicable)	< use MOF code >		
13	Project / Programme Name (if applicable)	< use MOF name >		
14	Proposed Tender Package No.	< type in name >		
15	Proposed Tender Package Name	< type in name >		
		Date	**Time**	
18	Pre-qualification Closing Date and Time	< select > V	< select > V	
19	Name & Address of the office(s)	**Address**		
	- Selling Prequal. Document (Principal)	< type in name >		
	- Selling Prequal. Document (Others)	< type in name >		
	- Receiving Prequal. Document	< type in name >		
20	Place / Date / Time of	< type in name >		
		Date	**Time**	
	Pre-Qualification Meeting (Optional)	< select > V	< select > V	
INFORMATION FOR APPLICANT				
21	Eligibility of Applicant	< type in name >		
22	Brief Description of Goods or Works	< type in name >		
23	Brief Description of Related Services	< type in name >		
24	Price of Prequal Document (Tk)	< type in price >		
	Lot No	Identification of Lot	Location	Completion Time in Weeks / months
25	1	< type in name >	< type in name >	<type in>
PROCURING ENTITY DETAILS				
29	Name of Official Inviting Prequalification	< type in name >		
30	Designation of Official Inviting Prequal.	< type in name >		
31	Address of Official Inviting Prequal.	< type in name >		
32	Contact details of Official Inviting Prequal.	< Tel. No. >	< Fax No. >	< e-mail >
33	The procuring entity reserves the right to accept or reject all prequalifications			

Table A2. Invitation for Pre qualification
(For use when there is a multiple lot package)

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH				
1	Ministry/Division	< select > V		
2	Agency	< select > V		
3	Procuring Entity Name	< type in name >		
4	Procuring Entity Code	Not used at present		
5	Procuring Entity District	< select > V		
6	Invitation for	< select > V	< select > V	< select > V
7	Invitation Ref No	< type in name >		
8	Date	< select > V		
KEY INFORMATION				
9	Procurement Method	< select > V	< select > V	
FUNDING INFORMATION				
10	Budget and Source of Funds	< select > V		
11	Development Partners (if applicable)	< type in name >		
PARTICULAR INFORMATION				
12	Project / Programme Code (if applicable)	< use MOF code >		
13	Project / Programme Name (if applicable)	< use MOF name >		
14	Proposed Tender Package No.	< type in name >		
15	Proposed Tender Package Name	< type in name >		
		Date	**Time**	
18	Pre-qualification Closing Date and Time	< select > V	< select > V	
19	Name & Address of the office(s)	**Address**		
	- Selling Prequal. Document (Principal)	< type in name >		
	- Selling Prequal. Document (Others)	< type in name >		
	- Receiving Prequal. Document	< type in name >		
20	Place / Date / Time of Pre-Qualification Meeting (Optional)	< type in name >		
		Date	**Time**	
		< select > V	< select > V	
INFORMATION FOR APPLICANT				
21	Eligibility of Applicant	< type in name >		
22	Brief Description of Goods or Works	< type in name >		
23	Brief Description of Related Services	< type in name >		
24	Price of Prequal Document (Tk)	< type in price >		
	Lot No	Identification of Lot	Location	Completion Time in Weeks / Months
25	1	< type in name >	< type in name >	<type in>
26	2	< type in name >	< type in name >	<type in>
27	3	< type in name >	< type in name >	<type in>
28	4	< type in name >	< type in name >	<type in>
POCURING ENTITY DETAILS				
29	Name of Official Inviting Prequalification	< type in name >		
30	Designation of Official Inviting Prequal.	< type in name >		
31	Address of Official Inviting Prequal.	< type in name >		
32	Contact details of Official Inviting Prequal.	< Tel. No. >	< Fax No. >	< e-mail >
33	The procuring entity reserves the right to accept or reject all prequalifications			

Table A3. Evaluation Criteria for Prequalification of Sub-Contractors in Navana Constructions Ltd. (Financial Condition)

Marking Criteria	Capability (BDT)	Marks
Financial Condition (20+10=30)		
1. Annual Turnover (20):		
(Average annual turn over in last 5 years)	Less that 20 million	8
	Between 20-25 million	12
	Between 25-30 million	16
	More than 30 million	20
2. Availability of Liquid Asset (10):		
	Less than 10 million	4
	Between 10-15 million	6
	Between 15-20 million	8
	More than 20 million	20

Table A4. Evaluation Criteria for Prequalification of Sub-Contractors in Navana Constructions Ltd. (Technical Qualification)

Technical Qualification (7+5=12)

1. Key Personnel (07):

I. Civil Engineer (Education=3, Exp=4)= 7 points.	1 for 1 year Exp.	
II. Electrical/Mechanical Engineer (Education=2, Exp.=3)=5 Points.	1 for 1 year Exp.	
Staff Inadequate	Between 3-7 points	4
Staff Adequate/Poor Competency.	Between 7-9 points	5
Staff Adequate/Average Competency.	Between 9-11 points	6
Staff Adequate/High Competency.	12 points	7

2. Plant & Equipments (05):

I. Trucks and Other Vehicle -- 2 Points
II. Roof Crane 5-10 ton --2 points
III. Mobile Crane 15-20 ton – 2 points
IV. Mixture Machine, 3 cft. -- 1 point
V. Vibrator, 2 nos - - 1 point
VI. Shuttering (1000 sft.) - - 1 point

Inadequate availability	Between 0 to 2 points	0
Majority Leased for work	Between 2 to 4 points	2
Owned for Long Term leased	Between 4 to 8 points	3
Sufficient for contract	9 points	5

Table A5. Evaluation Criteria for Prequalification of Sub-Contractors in Navana Constructions Ltd. (Experience)

Experience of Works (30+18+10=58)		
1. With Similar Work (30):		
(Total Work executed on the last 5 years)	Between 35-45 million	10
	Between 45-55 million	15
	Between 55-65 million	20
	Between 65-75 million	25
	More than 75 million	30
2. With other Work (18):		
(Total Work executed on the last 5 years)	Less than 10 million	0
	Between 10-15 million	10
	Between 15-20 million	15
	Between 20-25 million	16
	Between 25-30 million	17
	More than 30 million	18
3. Contract Execution Capacity (10):		
One satisfactory similar work above 40 million for a single contract		10

Total : 100 Points

(70+above) to be qualified for prequalification