EFFICACY OF CONTRACTOR PREQUALIFICATION MODELS

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CONSTRUCTION ENGINEERING AND MANAGEMENT

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بسم الله الرحمن الرحيم

In the Name of Allah, Most Gracious, Most Merciful.

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This thesis, written by MIR FAROOQ ALI under the direction of his thesis advisor and approved by his thesis committee, has been presented to and accepted by Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE**.

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Dedicated to my Mother & Father for their
innumerable prayers and encouragement

"O Lord, bestow on them thy Mercy even as they cherished me in childhood." (The Holy Quran 17: 24)

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THESIS ABSTRACT

FULL NAME OF STUDENT : MIR FAROOQ ALI

TITLE OF THE STUDY : EFFICACY OF CONTRACTOR PREQUALIFICATION MODELS

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Contractor prequalification models and prequalification criteria (PQC) were studied through extensive literature review to determine their respective working methodologies. These prequalification models were segregated into two groups namely “Practical” and “Theoretical” groups. Further attention was devoted to the former group and the prequalification models comprising of the first group were further analyzed to determine the different levels of methodology sophistication and complexity. Then three prequalification models were selected representing the different levels of complexity. These models were then subjected to a comparison analysis which comprised not only of the quantitative comparison but also of the qualitative aspect. Conclusions were drawn on the basis of this comparison analysis. One of the important conclusions drawn was that agreement between the various prequalification models was based more on the extent of objectivity used in making decisions rather than in the inherent methodologies of the models. The difference in the models is the ease with which decisions were elicited from the user.

MASTER OF SCIENCE DEGREE

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خلاصـة الرسـالـة

الاسم الكـامل الطالب:	مير فاروق علي
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طرق تأهيل المقاولين ومتطلبات التأهيل قد تمت دراستها من خلال دراسة وتحليل عدة أبحاث وتقارير, واستخلاص جوهرها لمعرفة كيفية عمل كل طريقة على حدة. هذه الطريقة التأهيلية قد تما توزيعها إلى مجموعتين: المجموعة النظرية والمجموعة العملية. وتم تسليط الضوء على المجموعة العملية, وتم تحليل طرق التأهيل التابعة لها لمعرفة المستويات المختلفة من حيث الصعوبة والتقيد لكل خطة. ثم تم اختيار ثلاثة طرق تأهيلية ذات خواص تعقيد مختلفة وقورنت هذه الطرق من ناحية تحليلية والتي تضمنت ليس فقط مقارنة اجابات رقمية, بل أيضاً مقارنة جودة النتائج. جوهر البحث تم الحصول عليه من هذه المقارنة التحليلية. وأحد أهم هذه النتائج المستخلصة هو أن مقدار التوافق بين هذه الطرق كان بالاعتماد على الموضوعية في اتخاذ قرار معين أكثر من اعتماده على الطريقة في حد ذاتها. والفرق بين هذه الطرق هو مستويات السهولة للمستخدم لاتخاذ قرار.

درجة الماجستير في العلوم

جامعة الملك فهد للبترول والمعادن

الظهران، المملكة العربية السعودية

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The construction industry is not only exclusive in many ways but also has enormous scope with several wide-ranging fields of interest with these areas also being highly specialized. In spite of these diversities in the construction industry, the overall objectives of the project unite a diverse collection of project participants. Most of the owners recognize the role of the contractor in the overall success and final cost of the project. So construction owners as such, have developed many different ways of selecting contractors who will be responsible for the execution of the project. These different ways of selecting contractors have been based on several factors ranging from the circumstances of the prospective owners to the extent of advice or guidance supplied by the project consultants. The public owners for instance award contracts to the lowest responsible bidder in order to fulfill the requirements of the law that protect public interest and funds, prevent fraud, collusion, and favoritism, and obtain quality construction at reasonable and fair prices. Determination of the lowest bidder is easy and direct, while on the other hand determining whether the contractor is responsible or not is not as easy.

Selection of contractors based on the lowest bid price has been criticized by a section of the construction industry itself. It has long been a source of frustration to those involved with competitive-bid construction projects that owners often treat low-quality construction work no differently from high-quality construction work. Both owners and contractors have acknowledged this problem. In a study carried out for AASHTO by Minchin Jr. and Smith, 2001, it was observed that contractors who were confident in their ability to produce high-quality work expressed their perceptions that public owners actually reward poor workmanship, at least indirectly. According to the contractors, they do this by not penalizing poor workmanship, thus giving a bidding edge to those contractors who take advantage of the owners' reluctance to penalize them. The contractors performing high quality work are discouraged about the prospect of continuing to bid for construction work against contractors who consistently submit low bids and produce low quality products. In many cases, it was expressed that these same low bidding contractors consistently submit change orders for extras even when the claimed work was part of the original design. No evidence was provided, however, to support these claims.

Contractor prequalification is one of the processes among many others that are used to ensure that the right contractor is chosen for the right job. Briefly, contractor prequalification can be defined as a decision making process by which an owner evaluates the competence of a candidate contractor to perform the requirements associated with a given project even before the final bidding process is set in motion. Contractor prequalification will be described in greater detail in the subsequent chapter.

One or any combination of the following may be considered for prequalification:

- Contractors.
- Subcontractors.

- Suppliers.
- Products.
- Services, including professional services.

Prequalification of contractors, subcontractors, suppliers, products and services for publicly funded projects is problematic and the potential for criticism by the private sector, particularly by those parties who are not qualified, is always present. Thus making it obvious for everyone that the prequalification process is not be taken lightly and also that its application is a function of a project's complexity and magnitude.

Several multi criteria decision making models for contractor prequalification are available for use in the industry and research field. These decision making models encompass a wide range of methodologies beginning with the simple Point Allocation (PA) methodology and ending up with complex models such as models based on genetic algorithms, neural networks and stochastic probabilities. Each method has its own unique group of users. Users have based their choice of prequalification models on varying factors such as user sophistication, cost of application of method, appropriateness of application of method to the particular project etc. This proliferation of prequalification models is both a boon and a bane for an educated owner since it gives the owner a wide range of models to choose from while at the same time it creates doubt in the owner's mind regarding the best possible method or model for prequalifying contractors for a particular project.

The models that are on the high end level of the methodology ladder are too sophisticated to be easily understood and appreciated by an average owner thus leaving the owner with no choice but to choose a model from the existing simpler ones being used in the industry. The advantage of using models implemented in industry is that they are simpler and easily understandable by everyone in the construction industry. This type of models can be labeled as "Practical" prequalification models. Within the "Practical" models the level of sophistication varies from the simple to the highly complex. The issue of concern is to determine how efficient these contractor prequalification models really are. Which contractor prequalification model gives the best result when each prequalification model is supplied with the same set of contractor information? This issue can be best addressed by a comparative analysis of prequalification models. This analysis would include both quantitative as well as qualitative analysis in order to arrive at a proper conclusion regarding the efficacy of the prequalification models.

1.2 OBJECTIVES

The objectives of this research are as follows:

1. To determine the different prequalification criteria used in the various prequalification models and their respective application mechanisms.
2. To conduct a comparative analysis of specific number of prequalification models which are representative of their varying sophistication levels.
3. To assess the efficacy of the above given models of contractors' prequalification by comparing computational effort to the quality of the prequalification outcome.
4. Based on the above, make conclusions and recommendations on the method(s) most suited for pre-qualifying contractors in the Kingdom.

1.3 SCOPE AND LIMITATIONS

The following limitations were applicable to this study:

1. This research has been restricted to those prequalification models which are generally used in the construction industry as identified by literature review and comprise of a much lesser level of sophistication than those required by some other ones. The models included were limited to those widely used by the industry. Other models such as genetic algorithms, neural networks, cluster analysis, stochastic probabilities were excluded because they were not used widely in the industry.
2. The set of prequalification models used in the industry is still too substantial to be put through simulation analysis because of it being prohibitively time consuming and cumbersome. Hence the research was restricted to analyzing only a specific number of models selected from the set of models used by the industry. These models represented different levels of sophistication in their working and methodologies.

1.4 SIGNIFICANCE OF THE STUDY

1. This research would provide an educated owner/architect with the necessary information that is needed to decide upon a prequalification model that is best suited to the characteristics of a particular project for which prequalification needs to be performed.

2. This research has been carried out on the “Practical” models thus making it more relevant to the construction industry. If project owners were to know which prequalification models are best suited for their needs then it would make them more confident of their decisions and decision making capabilities.

CHAPTER TWO

RESEARCH METHODOLOGY

2.1 INTRODUCTION

The objectives of this research have been stated earlier and comprise the following:

1. Determine the different prequalification criteria used in the various prequalification models and their respective application mechanisms.
2. Conduct a comparative analysis of specific number of prequalification models which are representative of their varying sophistication level.
3. Assess the efficiency of the above given models of contractors' prequalification by comparing computational effort to the quality of the prequalification outcome.
4. Based on the above assessment, make conclusions and recommendations on the method(s) most suited for pre-qualifying contractors in the Kingdom.

In order to achieve these objectives the research methodology utilized is as explained in detail. Initially the various elements that are not only used in this research but also may have an effect on the outcome of the research are identified. Identification of prequalification models, development of a list of models used in the construction industry, identification of representative prequalification models etc was carried out. The first objective was achieved at this stage. After identifying various elements, the representative prequalification models were then compared quantitatively through the process of simulation. This was followed by comparing the representative models based on certain qualitative criteria. The second and third objectives were achieved after both these types of analysis. Finally, conclusions and recommendations were made based on the results of the earlier analysis.

The research methodology is displayed in the following flow chart (Figure 2.1).

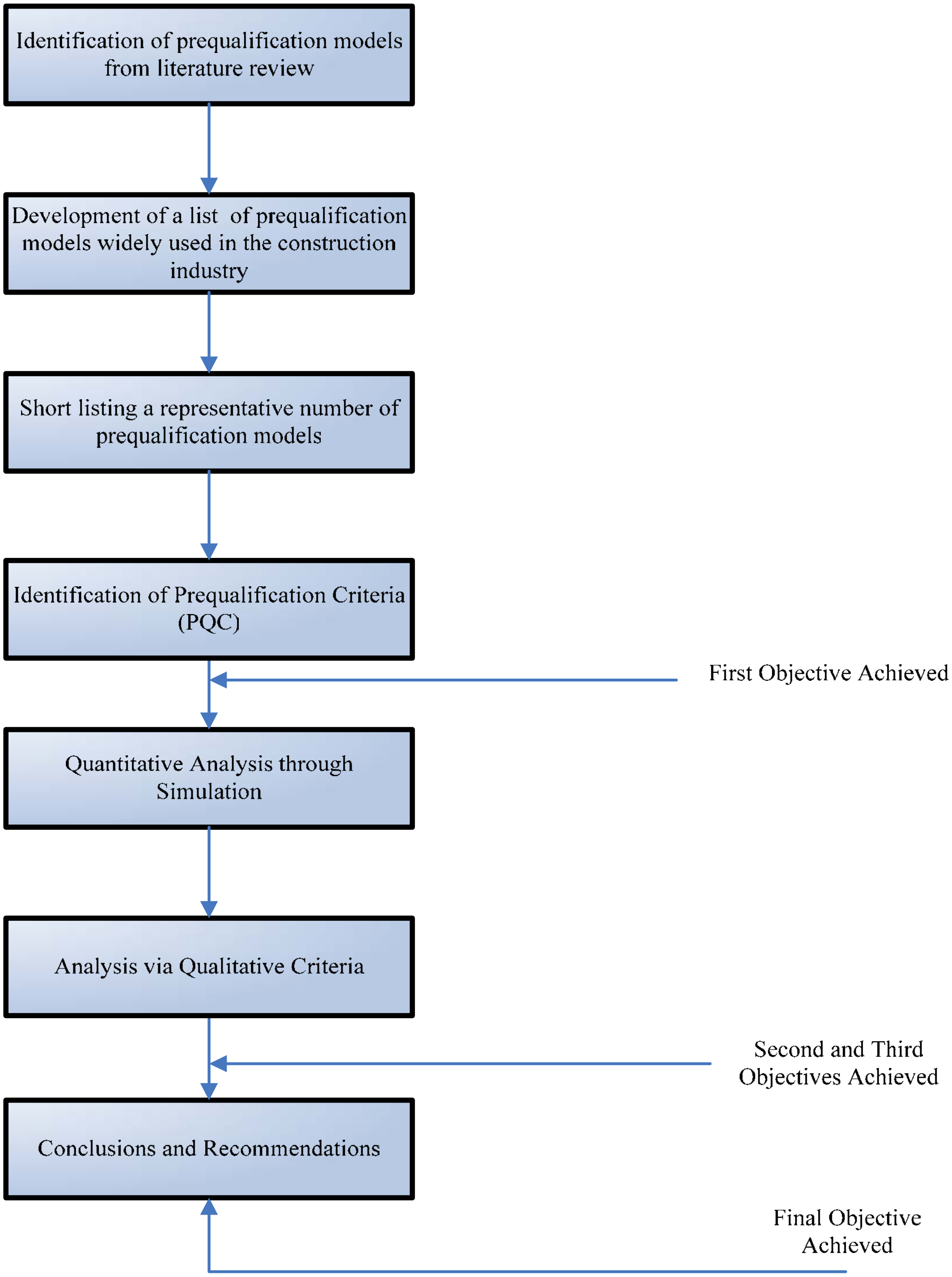


Fig. 2.1: Research Methodology Flow Chart

2.2 EXPLANATION OF EACH SEGMENT OF THE RESEARCH METHODOLOGY

A more elaborate explanation of each segment of the research methodology is as follows:

1. Contractor prequalification models were identified through the means of extensive literature review. The prequalification models gleaned from literature encompass a wide range of variations among themselves. The primary aspect of variation being the working methodology of each model. This range of methodologies begins with the most rudimentary end with subjective analysis being a representative of that end while neural networks being representative of the most advanced methodologies on the extreme opposite end of the scale. These advanced methodologies are more of interest to researchers rather than to the construction professionals.
2. The prequalification models identified earlier were then segregated into two groups. The first group comprising of those models that are commonly used among the construction industry professionals. The representative models for this group are Point Allocation Method, Dimensional Weighting, Two – Step Prequalification Model etc. These models are labeled for lack of a better word as “Practical Models”. The distinguishing feature of these models is that they are easy to understand and have a pretty simple method of application. The second group comprises those models that were developed through research

but haven't found wide acceptance in the construction industry. These models have been labeled as "Theoretical Models".

3. The list of "Practical" models developed was pretty comprehensive. It was observed that even this curtailed list still contained prequalification models with differing working methodologies. The range of working methodologies even though restricted still comprises of methodologies differing from each other on the basis of their complexity. To analyze all the models in this "Practical" list would be time consuming and cumbersome. For this reason, a representative number of models were selected from the list with each model representing the varying degrees of working methodology complexity.
4. After short listing a representative number of prequalification models, the Prequalification Criteria (PQC) most commonly used by owners or A/E's for the purpose of prequalification were identified. Care was taken during this process to accommodate all important and pertinent PQC. The success of any prequalifying effort depends largely on the selection of relevant PQC because the exclusion of any pertinent PQC would mean that the effect of that particular PQC on the decision making process has not been taken into account. The probability of the failure of such a decision would thus be substantially increased.
5. After identifying all the necessary elements needed simulation analysis was carried out on the prequalification models short listed and a predefined list of PQC is used for the purpose. For the defined set of PQC and their respective weights, contractor profiles were generated so that each contractor profile had

its own unique set of values or points for the respective PQC. These contractor profiles were essentially hypothetical data. The reasons behind using such sort of data are:

- The number of real contractor profiles to be used to compare the methods can become quite large and practically impossible to obtain from existing contractors.
- To achieve the main objectives of this research (the comparisons of the methods) would require the use of all possible contractor profiles. This is best achieved through hypothetical construction of data. Real data will fall short of mapping all possible contractor profiles.

6. The comparison process had to be exhaustive, meaning that no possible contractor profile was left unconsidered. The number of combinations of contractor profiles that can be determined mathematically depends on the number of criteria used and the number of possible values for the scores. As an example, consider the situation where only three criteria are used for prequalification with three possible score values for each: high, medium, and low. This situation will generate twenty seven possible contractor profiles, (high-high-high, high-high-medium, high-high-low, and so on.) In general,

   Possible contractor profiles = m^k, where:

   k = Number of criteria.

   m = Number of possible score values.

7. After analyzing the contractor profiles for each prequalification model, three sets of ranks were obtained. These three sets of ranks were correlated with

each other to understand the degree of agreement between the models. For this purpose of correlation, the Spearman's rank correlation coefficient was used. The significance of the difference between the correlations was then tested for a significance level of 0.01.

8. The results of the simulation analysis would be in the form of numbers and thus these prequalification models were analyzed qualitatively before any concrete conclusions and recommendations could be put suggested.
9. Finally conclusions were deduced from the earlier quantitative and qualitative analysis of the prequalification models. From these conclusions, further recommendations were developed as the base for further research in the context of contractor prequalification in the construction industry of Saudi Arabia.

CHAPTER THREE

LITERATURE REVIEW

3.1 CONTRACTOR PREQUALIFICATION

Prequalification has not been defined consistently and different views of what the process should include are evident in the literature. Nettleton (1948) describes prequalification as the determination of the responsibility of each contractor to satisfactorily undertake and complete a certain construction project before the issuing of plans, specifications, and proposals. Others (Russell, 1996; Thomas et al., 1985) focus on a more deterministic process for evaluating the competence and responsibility of contractors before submitting bids. Clough and Sears (1994) state that Contractor prequalification involves the screening of prospective contractors by the owner of a project or his representatives in accordance with some predetermined set of criteria found to be the necessary ingredients for ensuring quality performance, in order to determine their capabilities to perform the required work, if awarded the construction contract. The purpose served is to eliminate the incompetent, overextended, under-financed and inexperienced contractors from consideration.

After screening so many varied definitions of prequalification, one can safely state that contractor prequalification is a process by which an owner evaluates the competence of a candidate contractor to perform the requirements associated with a given project with prequalification being the first step taken by owners to ensure the successful execution of field construction.

Palaneeswaran and Kumaraswamy (2001) in their study have expostulated that a general (non-project specific) prequalification system is performed to identify `eligible' contractors from a group of `interested' applicants and to classify them according to their technical and financial capacity, organizational and managerial expertise, and track records in terms of past performance, occupational health and safety, environmental concerns and even at times on their attitudes towards claims.

They also have stated that the prequalification system aims to facilitate and not to replace tender assessment and some objectives of prequalification are as follows:

- To eliminate contractors who are not responsive, responsible and competent.
- To enhance and/or assure bidding opportunities for `eligible' contractors.
- To encourage healthy competition among `eligible' contractors.
- To avoid/minimize risks of contractor failure and improve client satisfaction.
- To optimize the contractor selection in terms of achieving a better balance between price and performance parameters.

Moving on further Palaneeswaran and Kumaraswamy (2001) state that even though owners are always eager to secure the lowest prices possible for their projects; selecting bidders who are responsive, responsible and competent is not lost on them. `Responsiveness' is reflected in the prompt delivery of correct information required by the prequalification questionnaire. The responsiveness may be checked on a `pass/fail' binary decision exercise and/or scored/measured on the scales of realism and completeness. `Responsibility' can be attributed according to the contractor's track record and compliance with other mandatory/desirable requirements such as quality system, registration with societies/organizations, safety policy, conformance with bylaws, standards and regulations, and experience in/ attitude to partnering. The responsibility of the bidders can thus be evaluated on the basis of past performance records and reports. The `competency' of the bidders is their capability to undertake contracts of the type usually awarded by the given organization (or a specific contract) with respect to their resources and capacities such as financial capacity, technical capacity, plant and equipment, human resources, organizational and management capabilities. The competency of the bidders can be evaluated on the basis of available resources, track record, and current workload.

An alternative perspective of the responsible bidder would be for the bidder to prove possession of satisfactory skill, knowledge, integrity, plant, equipment, personnel, and finances to undertake the work. A responsive bidder merely submits the appropriate bid information as requested by the DOT. Thomas et al. (1985) extended the concept of responsibility to include:

- Financial strength and resources of the contractor.
- Documented skill of the contractor and subcontractors on previous contracts.
- Judgment which is extended to financial and construction management.
- Overall experience in the construction industry, as well as experience of the key personnel who execute the work.
- Integrity of the officers to ensure they have not been involved in previous wrongdoing or contract crimes.
- Previous performance, which evaluates the contractor's quality of construction and ability to complete the project within the goals of time and cost.

- Ownership of equipment or the ability to rent or lease equipment needed to perform the project.
- Ability to perform in accordance with the contract.
- Ability to acquire bonding from an established and reputable surety.
- Conformity to the goals and objectives of affirmative action plans.

Palaneeswaran and Kumaraswamy (2001) state that prequalification of bidders is performed either on a project-by-project basis or on a periodic basis (normally annually) also called `registration'. The project-by-project prequalification is dynamic in nature and has the advantage of considering project specific requirements; whereas, the periodic prequalification (`registration') is static in nature (over the registration/ prequalification period). However it may classify eligible contractors into different range of work capacity levels, depending on their perceived capabilities. Of course, shortlists could also be derived from the `registered' lists, for specific projects based on updated in- formation on the registered contractors, as well as any particular project requirements. This point of view is concurred by Manitung and Emsley(2002). The following sections describe a sample of some of the more structured contractor prequalification approaches practiced around the globe

In terms of prequalifying contractors prior to their procuring construction contracts, contractors can be evaluated in several ways. Drew and Skitmore (1993) suggest that contractors be qualified solely on the basis of their historical record of being competitive with their bids; thus, they view the objective of prequalification as obtaining the lowest bid at the minimum bidding cost to the owner. Holt, et. al. (1994) suggest past performance and quality as measures of client satisfaction for the objective of prequalification. Hauf (1976) focuses on disqualifying incompetent, overextended, and under-financed contractors. Diekmann (1981) identifies the four objectives of prequalification as limiting cost exposure, evaluating company stability, ensuring quality in the finished product, and evaluating management capability. Thomas et al. (1985) identifies three functions: minimizing adverse consequences of contractor default by carefully screening out financially and technically weak contractors maximizing the benefits of overall competitive bidding, and improving the quality of public construction work. No authoritative study was found that validated the use of qualification systems efficacy in meeting these criteria.

Interestingly Holt et al. (1995) have the opinion that an effective selection approach should integrate prequalification as part of any selection exercise, introduce a standard secondary investigative procedure for evaluation of contractors, combine the latter with the total tender cost to generate a final combined score, and thus recommend the most eligible (compromised) bidder.

Hence it can be concluded from the above that the prequalification process is used to accommodate risks. While high risk would normally be the main criterion, there may be circumstances when, for program, project or policy reasons, other criteria provide the justification for prequalification.

3.2 ADVANTAGES AND DISADVANTAGES OF PREQUALIFICATION

The prequalification system has advantages and disadvantages that have been identified in previous work (Lower, 1982; Hauf, 1976; Nettleton,1948, Russell, 1996). A summary of these advantages and disadvantages follows:

ADVANTAGES:

- Reduces subjectivity in selecting bidders.
- Avoids selection of unqualified bidders.
- Ensures competent, successful parties.
- Eliminates unqualified parties, even though they can be bonded.
- Controls the number of bidders.
- Reduces the cost of bid solicitation.
- Significantly hastens evaluation and award process.
- Provides structure and discipline to the process.
- Protects contractors from being awarded work they are incapable of doing.
- Facilitates bidding by quality contractors who might have been inhibited from submitting a bid because of competition from unqualified bidders.
- Improves ability to react quickly.
- Allows more time for investigation of the contractors.
- Removes low cost bias.
- Reveals contractors who may be unable to perform due to backlogs.

DISADVANTAGES:

- Factual determination of responsibility is difficult.
- Additional screening is a burden on the contractor and creates workload for the owner.
- Qualified contractors may choose not to participate.

- Developing, implementing, and evaluating objective criteria are costly.
- Difficult to formalize decision process without introducing subjective judgment and biases.
- Potential for biased or erroneous denial of admission into bidding process.
- Limits contractors' ability to expand into new areas in which there is no prior experience.

Of these factors, the most problematic would be the use of subjective data that is used in the determination of the contractor's eligibility, particularly if it results in an erroneous denial of admission into the bidding process.

3.3 APPLICATIONS OF PREQUALIFICATION

Alberta Infrastructure Master Specification's Prequalification Guidelines (1999) states that prequalification as such should be undertaken only if high priority is to be given to the quality of the work done. i.e.

- Quality assurance, including the meeting of contractual requirements and performance in practice or use, should be the principal concern in prequalification considerations. If there is no extraordinary concern in this respect, there should be no need for prequalification.
- Quality assurance considerations are influenced by two major factors: risk and information.
- Risk: The importance of a requirement is determined by considering the consequences of a failure or a shortfall, e.g.:

    - The direct consequences for users, contents, property, public.
    - Economic consequences of remedying the failure or shortfall, eg. Minor repair to complete replacement.
- Information:
    - Since information is a basic input to management decision making and project specification, a lack thereof increases uncertainty, and risk.
    - In principle, risk diminishes in proportion to the amount of information available, however the quality and accuracy of the information is critical to accurate evaluation.
    - It is helpful to relate information to risk:
        - Low Risk: A well defined set of requirements with all necessary information known and available, and with a high degree of certainty that objectives will be met.
        - Medium Risk: A reasonably well defined set of requirements with most information known and available, but further input and refinement is needed.
        - High Risk: A poorly defined set of requirements with little information available, and a high degree of uncertainty that objectives will be met.
- Evaluation should include the use of experiential information (personal and organizational experience), as well as other "external" information.

3.4 “PRACTICAL” PREQUALIFICATION MODELS

After extensive literature review, prequalification models were identified and from these, those models are short listed which are widely used in the construction industry. These models have been labeled as “Practical” prequalification models for easier reference.

A brief description of the models listed in the first list follows:

- **Point Allocation Method:**

  Point Allocation (PA) method is a simple and commonly used in multi-criteria decision making process. But its basis isn’t well thought out or explained. This method consists of assigning a hypothetical number of points, e.g. 3, 5 or 10 to decision criteria and/or alternatives. This allocation is strictly at the discretion of the decision maker. Then the decision maker evaluates the alternatives on how good they are and assigns them points out of the assigned maximum points. The redeeming feature of PA is its simplicity. PA is ignored by researchers because of its lack of theoretical foundation. It is more likely to be seen in "popular" literature or in basic management texts as an example of a simple method for decision aiding (Zeleny 1982). This process has been implemented in the commercially available software GroupSystems V and VisionQuest. It is reported that the United States Army Corps of Engineers uses a variant of this technique under the name ‘merit point system’ (MPS) in determining qualified bidders (World Bank Manual, 1992). MPS is based on weighted criteria such as experience on similar projects, equipment and manpower availability, time and quality dimensions, but the method further establishes a relationship between the total score of the criteria and the bid price. The contract is awarded to the bid that receives the lowest price per merit point. But this method is more relevant in the evaluation of bids than prequalification.

- **Dimensional Weighting Method:**

  Under this method, each criterion or decision parameter and its weight of importance are determined based on the Owner/Consultant's (decision maker's) requirements. The contractors are rated on a scale of 1-10 (1 – "Unsatisfactory", 10 – Excellent"), subjectively, with respect to these criteria based on the total score, which is calculated as a weighted sum of ratings over all the criteria using the percentages specified by the Owner/Consultant. All the aggregate scores are then ranked. This selection process is compensatory since a high score in one dimension can compensate a low score in another dimension.

  In order to make a decision, this strategy utilizes a decision rule such as: if the candidate contractor's aggregate score is less than or equal to a certain minimum score, then the prequalification decision is "no" and hence the contractor is rejected. Only the qualified contractors will be permitted to submit their proposals. Alternatively, a subjective judgment may be used such as: select the three highest scores to participate in the bidding process (Russell and Skibniewski 1988).

- **Dimension Wide Strategy:**

  A dimension wide strategy has been used by owners in which the most prominent dimension is selected and all contractors are evaluated with respect to it. Then the contractors are moved on for evaluation to the next most prominent dimension. At each evaluation step, the contractor is judged for that dimension only. If the contractor fails at any particular evaluation step then he is discarded from the contractor list and not considered for subsequent evaluation steps. This process of elimination is carried on till all the evaluation steps are exhausted and a qualified contractor list is arrived at. Evidence of this approach has been observed by Russell and Skibniewski (1988).

  The methodology used in this method can be referred to as the Bespoke Approach, where every criterion has just two outcomes either a Yes or a No. It is a logical and effective process of reducing a large set of contractors with ease. But the risk is ever present that a good contractor may be wrongly eliminated in the initial proceedings. (Jennings & Holt, 1998).

- **Two-step Prequalification Method:**

  The first step under this method entails the employment of a dimension-ordering strategy. In other words, contractors are either qualified for the second part or disqualified from further participation depending upon how well they satisfy a number of preliminary screening dimensions such as whether or not the contractor has:

  - Performed work of similar size and type.

- Strong financial stability.
- Work load of similar project type.

The second step utilizes the dimensional weighting strategy using more specific criteria to determine the competitiveness of any contractor as a bidder as previously described (Russell and Skibniewski 1988). This method allows rapid elimination of unwanted contractors such that the owner can focus his attention on the remaining contractors. However, this method may eliminate some contractors possessing excellent characteristics in areas not considered in the evaluation (Al-Alawi 1991).

- **Prequalification Formula Method:**

  There are formulae used in the prequalification selection of contractors by some public owners, especially in the United States. The formulae are used to calculate the maximum capabilities of contractors. The purpose of the formulae is to provide some objectivity in the decision-making by the owner, by reducing his over-dependence on subjective judgment. Maximum capacity refers to the maximum amount of uncompleted work in progress, which the contractor can have at any one time. However, if the project cost exceeds the difference between any contractor's maximum capacity and the amount of current uncompleted work, such a contractor will not be allowed to bid while using the formula method (Russell and Skibniewski 1988).

  The formula is based on the information given in the contractor's balance sheets and income statements. For example, the Ohio State Department of Transportation employs the contractor's net current asset (obtained from the most current financial statement) multiplied by 10 in order to determine the maximum allowable work volume for a given contractor. Then the final ratings are determined by modification of the net current asset by using the following factors: for organization and key personnel 20%; for planning and equipment 20%; for construction experience 20%; for credit 15%; and for past performance 25%.

Similarly, the Iowa State Department of Transportation determines the financial capacity of a candidate contractor by obtaining the difference between total net current asset and total net current liabilities and adding to one-half of the difference between non-current assets and non-current liabilities. The formula is represented mathematically as;

Financial capacity = (Net current assets – Net current liabilities) + ½ (Non-current assets – Non-current liabilities).

This rating is then multiplied by an "ability factor" to determine the final ratings using the following factors: for attitude and cooperation 10%; for equipment 20%; for organization 20%; and for work performance 50%.

Much of the financial analysis is based on examination of ratios between figures on the balance sheets and on the income statements. The ratio also can be compared with those of similar firms and with industry average at a given time to evaluate the relative performance of the company.

- **Subjective Judgment:**

  Russell and Skibniewski (1988) have expostulated that in some instances, individuals perform prequalification based on their subjective judgment and not on a structured approach. This judgment is influenced by many factors with previous experience of the decision maker with the contractor being one of them. This approach can lead to incorrect decisions because it lacks a rational approach.

- **Weighted Evaluation Method:**

  This technique was originated by Donald Parker after studying evaluation techniques developed by other researcher such as Miles, Mudge & Fallon etc (1977). It is a formally organized process for selecting optimum solutions in circumstances involving several criteria. In evaluating alternatives, these criteria are assigned different weight values depending on their potential impact on the project under consideration, or the importance placed upon them by the decision maker. The system is divided into two processes; criteria weighting process (paired comparison) and matrix analysis.

  The system used in determining the weights of importance to be assigned to each criterion is called "paired comparison" (Parker, 1977). Initially the criteria are compared with each other and their relative importance to the evaluator is calculated. The evaluator then assigns the alternatives points out of a maximum for each particular criterion. These points are then multiplied with the respective criterion importance and the subtotals are added up to arrive at a score for the alternative in the same manner as that for the dimensional weighting method.

Al-Alawi (1991) and Assaf and Jannadi (1994) applied the weighted evaluation to contractor prequalification in Bahrain and Saudi Arabia respectively. Other application includes Russell and Skibniewski (1988).

- **The Analytic Hierarchy Process**

  The Analytic Hierarchy Process (AHP), introduced in the early 1970s by Thomas L. Saaty is used for dealing with complex technological, economic and socio-political problems. This is done by simplifying and expediting the natural decision making process (Saaty, 1980). The method utilizes pair wise comparison by breaking a complex unstructured situation into its component parts, arranges those parts into a hierarchy, assign numerical values to subjective judgments regarding relative importance (or preference), and synthesize those values to determine which variable has the highest priority and should be acted upon to influence the outcome of the situation.

  The distinguishing feature of AHP technique from the other MCDM techniques is that it does not necessarily require a tangible numerical scale of ratio and can thus be applied to the measurement of intangible criteria. The fundamental synthesis technique is additive. It also has a consistency check for encouraging enforcement of judgment transitivity. The analytic hierarchy process has been well researched and has been applied in hundreds of areas. The process has been implemented in the commercial software HIPRE, Criterion, and Expert Choice. An application of AHP to contractor prequalification was carried out by Munaif (1995) and Fong et. al. (2000).

3.5 LISTING OUT PREQUALIFICATION CRITERIA GENERALLY USED

The criteria used in the prequalification process to select a suitable contractor for a given project empower the owner or his representative to determine whether the contractor is capable or competent enough to perform the work within budget, on schedule and at the required safety and quality standards. Selecting the proper prequalification criteria is essential especially to a private owner whose objectives almost always comprise of maximizing profit, market share, goodwill and future growth. Birrell (1978 and 1985) studied the factors and criteria, which top quality subcontractors' use in evaluating the managerial performance of general contractors. These criteria can be seen as the intrinsic managerial cost and time-sensitive factors by which general contractors, or any manager of construction, could improve performance, competitiveness and profitability. The criteria found in the literature (Al-Alawi 1991, Munaif 1995, Al-Gobali 1994, Birrell 1985, Russell 1990, Russell et. al. 1990, Clough and Sears 1994 etc.) include the following:

- **Financial Stability**

  Financial stability is a factor that makes its appearance in almost every prequalifying team's list. Basically this criterion involves evaluating the financial condition of each candidate contractor. This indicates the capacity of the candidate contractor to fully meet financial commitments. Russell (1990) indicated the importance of contractor's credit rating, banking arrangements and financial statement to measure the solvency (or liquidity), efficiency and profitability of a contractor, in assessing his financial capability.

- **Experience**

  This criteria has been used in regular use for prequalification but has been called by different names like past project performed, past performance, experience etc. This involves evaluating the candidate contractor's project records to determine whether or not he has handled jobs of similar scope and complexity in the past or currently. Birrell (1985) indicated that possessing experience in projects similar to the proposed in terms of type, size and complexity should be an important evaluation criterion. This can be determined from satisfaction expressed by past clients/customers. This can also include investigating the performance history of the contractor in terms of completion on schedule and within budget, effectiveness of quality and cost control, and the quality of finished products.

- **Current Work Load (Capacity)**

  This criterion also sometimes called as current projects on hand involves the evaluation of the candidate contractor's manpower, equipment and financial resources vis-à-vis his ongoing work projects to determine if his current commitment can impact his performance on the project for which he is being currently prequalified.

- **Management and Manpower Qualification**

  Also known as experience of key personnel, it is concerned with the qualification and skill of the management (administrative staff and engineering professionals) and labor crew (craftsmen and trades). This is important as Clough and Sears (1994) remarked that the financial success of a construction enterprise depends almost entirely on the quality of its management. Russell (1991) contended that 8 out of 14 projects studied failed because of lack experience of the management and technical staff.

- **Contractor Organization**

  This seeks to evaluate the effectiveness of flow of information and decision making process among the different levels of the company. The importance of company organization was stressed by Birrell (1985) and Al-Gobali (1994).

- **Location of Head Office**

  This is concerned with the geographical location of the contractor's head office, the idea being that closer the office is to the proposed building site the better would be the backup support provided by the office. This is important because of the numerous support services rendered to the site personnel by the head office and the need for prompt feedback. These services include project financing, recruitment, staffing, ticketing, passports, visas, housing, catering, material procurement, expediting of materials, renting or leasing equipment, evaluation of design changes and contract modification, negotiations and approval of change orders and resolution of technical disputes. This calls for the availability of transportation and communication facilities to facilitate the decision-making requirements.

- **Knowledge of Geographic Location of Project**

  The lack of knowledge about the geographic location, environment and local conditions of a project can be a reason for contractor's failure (Russell 1991) and project delay (Hazmi 1987). Lack of knowledge about the location increases the contractor's risk exposure and the probability of disputes arising.

- **Equipment Resources**

  Availability of equipment and their maintenance program are major factors affecting contractor performance. In this criterion the available resources in terms of personnel, plant and equipment are evaluated (Al-Gobali 1994). Equipment shortage and low productivity may cause project delay (Hazmi 1987) and equipment cost control (maintenance, repair and replacement) is an important element of contractor's failure (Russell 1990).

- **Procurement and Material Management**

  With material cost ranging between 30 to 60% of total building project cost, procurement and material management are evidently essential to project success. Ubaid (1991) found that material delay is a major cause of project delay. Contractor's Procurement expertise and material management skills will result in on-time delivery avoiding delay as well as the additional cost for storage and double handling of early material delivery. Al-Gobali (1994) also lists procurement as one of the organizational factors that make or break the chances of the success of the project.

- **Safety Record**

  Accidents at construction sites may not only result in a loss of life but also result in increased insurance premium rates on the subsequent projects by the same contractor. It also results in a loss of goodwill. The selection of a contractor with a good safety record can minimize construction accidents and thereby save construction costs (Al-Gobali 1994). Ubaid (1991) ranked this criterion as number 8 out of 14 factors affecting project performance.

- **Claim Attitudes**

  This is a measure of trust and cordiality in the relationship between the owner and contractor. Cooperation and coordination between the parties will lead to reduced interface problems, delays and consequently cost. Past experience of contractors can indicate their tendency towards litigation. Owners should avoid contractor's who are inclined to litigation as a way of making profit. Consequently past record of claims and disputes are asked for. (Al-Gobali 1994).

- **Quality Program**

  A quality program in place always increases the chances of a better finished project. Hence Russell and Skibniewski (1988) have included the existence of a quality program as a criterion in the prequalification process.

- **Past Owner Contractor Experience**

  Earlier interaction between the owner and the contractor plays a vital role in selecting a contractor as the owner prefers to work again with a contractor that has produced the earlier project at the required cost, time and quality benchmarks.

- **Other Criteria**

  Other criteria that have taken into consideration for the prequalification process include scheduling (Al-Gobali 1994), staff available, substance abuse policy (Russell et al. 1990) and company reputation (Jennings and Holt, 1998).

Table 3.1: List of prequalification criteria from previous research

S.No	Prequalification Criteria	Authors						
		Al-Alawi	Munaif	Al-Gobali	Birrell	Russell and Skibniewski	Clough and Sears	Holt
1	Financial Stability	*	*	*	*	*	*	*
2	Experience	*	*	*	*	*	*	*
3	Current work load	*		*		*	*	*
4	Management & manpower qualification	*	*	*	*	*	*	*
5	Contractor organization	*		*				
6	Location of head office	*		*	*	*		*
7	Knowledge of geographic location of project	*				*		
8	Equipment resources	*	*	*	*	*	*	*
9	Procurement and material management	*		*				
10	Safety Record		*	*				*
11	Claims attitudes			*		*		*
12	Quality program	*		*		*		*
13	Past owner contractor experience		*	*	*	*		
14	Past performance	*	*	*	*	*	*	*
15	Other criteria	*	*	*				

3.6 GENERAL PREQUALIFICATION PRACTICES AROUND THE WORLD

Subsequent to the preceding sections, it would be beneficial if a brief overview of general contractor selection and prequalification practices that are being applied around the world is undertaken. It would be beneficial not only because of the emphasis on the global acceptance of prequalification but would also illustrate the differences that exist among the prequalification practices. These differences are not based on concrete proof of any method being right or wrong but are rather dependent on what local owners feel works in their environment.

Topcu (2004) has conducted an extensive research on global contract selection and prequalification practices. He states in his findings that one of the most frequently used procedures for selecting contractors is competitive bidding, where the lowest bidder is awarded the contract. And there are some modifications to this single objective decision-making procedure based on lowest bid price. For instance, in France, bid prices that are considered abnormally low by the project owner are excluded. In some countries such as Italy, Portugal, Peru, and Korea the highest and the lowest bid prices are excluded; the closest bid price to the average of the remaining ones is then selected. In Denmark, on the other hand, a similar procedure is used but with the two highest and the two lowest bid prices excluded. The point here is that modifications for selecting a qualified contractor should be clearly defined.

In their study, Palaneeswaran and Kumaraswamy (2001) examined prequalification practices in different countries such as US, Hong Kong, and Australia. Many project owners in the US public sector use various prequalification ratings providing a basis for a more structured and dynamic approach in order to define bidding boundaries for contractors. In some states, departments of transportation use prequalification ratings such as aggregate rating, current bid capacity, maximum rating, project rating, maximum capacity rating, work class rating, and performance rating. Briefly, these ratings can be used to define parameters such as the maximum monetary amount of work that can be allowed to a contractor or the maximum value of a work that a contractor can bid for a particular project.

The Department of Public Works Bureau in Hong Kong prepare approved lists according to relevant expertise, financial status, and technical and managerial capabilities of contractors as well as their completion of other contracts. Only contractors on the corresponding list can apply for contracts. Hong Kong Housing Authority maintains a comprehensive Performance Assessment Scoring System to review the registered contractors' performance levels of their contracting works in the ongoing projects. Scores of contractors are calculated and a comparative score league is formed. Contractors who fall in the upper section of this league are invited for bidding in the upcoming projects. The Mass Transit Railway Corporation in Hong Kong, on the other hand, uses a set of prequalification criteria for the evaluation of contractors. These criteria are corporate structure (management and relations), experience (performance on corporation's contracts, construction performance in similar projects, work experience in Hong Kong), resources and facilities (staffing, labor, construction plant, planning/programming, design, manufacturing/fabrication, subcontractors), workload (current, future), and support functions (safety, quality management). Members of a committee score candidate contractors with respect to these criteria and sub-criteria and then use the scores for recommendation of prequalified contractors.

In Australia, the Australian Procurement & Construction Council (APCC) which was founded in 1967 develops nationally consistent approaches to broader procurement policies, processes and practices, with an increasing emphasis on:

- Electronic commerce for government procurement;
- Public sector infrastructure needs;
- Competitive tendering and contracting; and
- Improving access to government markets for small to medium enterprises. (http://www.apcc.gov.au/default.asp?PageID=31)

In their report titled "National Prequalification Criteria Framework" (1998), the APCC stresses involvement with the process to manage the risks associated with doing business with private contractors. The development of a nationally consistent prequalification framework has been a focus of the APCC for the last few years. The assessment of industry participants through prequalification was a key component of the agreed ' National Action on Security of Payment in the Construction Industry' endorsed by Commonwealth, State and Territory Ministers responsible for construction in late 1996. In addition the National Code of Practice for the Construction Industry, 1997, requires a best practice commitment of contractors which will be assessed through the use of prequalification and other selection processes. The Agency has prescribed mandatory criteria to screen out ineligible or unsuitable applicants as well as additional and reserved criteria to further describe and/or evaluate the applicants' skills and philosophy in order to discriminate them properly. Mandatory prequalification criteria are technical capacity, financial capacity, quality assurance, timely performance, occupational health and safety, human resources management, and skill formation.

Claims performance, compliance with legislative requirements, and management for continuous improvement are prescribed as additional criteria while research and development facilities and export development are prescribed as reserved criteria. The prequalification system of the Department of Public Works and Housing in Queensland, Australia uses technical capacity, management approach, people involvement, business relations, and financial capacity as the prequalification criteria. By evaluating applicants with respect to these criteria, contractors are prequalified for 2 years and are placed at a predefined level. When tendering process begins, by using the first four criteria as assessment criteria the level required for the project is determined. The aim of the system is to ensure proper matching between the size and the complexity of the projects and the abilities of the contractors.

Palaneeswaran and Kumaraswamy (2001) propose a universal model for contractor prequalification. They developed this model on the basis of contractor selection practices of various public project owners in the countries mentioned above and in different countries such as Canada, Singapore, and Sri Lanka. They develop prequalification criteria which are classified in three groups: responsiveness (promptness, realism, and completeness), responsibility (conformity, performance, quality, safety, environment, partnering), and competency (resources, experience, constraints, management and organization). Initially, the applicants would be checked for these "pass/fail" criteria. At the next step, the characteristics of those contractors who meet the mandatory requirements to pass through are scored. Then, the characteristics of applicant contractors are checked against appropriate project-specific benchmarks and those applicants who have failed to meet the minimal benchmarks standards are screened out.

At the last step, prequalification ratings for workload filter proposed by authors are determined. The applicants having excessive workloads are screened out in order to eliminate the risk of contractor failure during the project. The remaining applicants are the prequalified contractors.

Another invaluable study is by Ng and Skitmore (1999) who determined 35 prequalification criteria as a result of their previous study and knowledge acquired from professionals in UK construction industry. By conducting a postal questionnaire survey with project owners and consultants, they assessed the importance of the prequalification criteria. According to the results of the survey, the top 10 prequalification criteria stated by the governmental authorities are as follows with managerial capability criterion that is found important by other respondent groups is not included in this top 10 list:

- Financial stability
- Performance
- Fraudulent action
- Contract failure
- Corporate stability
- Progress of work
- Health and safety
- Previous debarment
- Competitiveness
- Quality standard.

Contractor prequalification in the UK construction industry can be categorized into two types, that is, periodic prequalification for developing a standing list of contractors and project prequalification for developing a project or ad-hoc list of contractors (Mangitung and Emsley, 2002).

The main difference between both types is the timing of evaluation and the detailed level of contractors' data obtained (Mangitung and Emsley, 2002). Periodic prequalification, which can be used by a client for short listing or invitation to bid, is performed for certain periodic time frame. Hatush (1996) and Ng (1996) found that standing lists of contractors in the UK were reassessed annually, or every 2, 3 or 5 years. Moreover, around two thirds of contractors in the UK were re-qualified annually through periodic prequalification (Jennings and Holt, 1998). Periodic prequalification domains are mostly associated with public and utility clients and characterized by small and medium sized projects. The qualification process is based on overall suitability of contractors rather than their ability to meet the specified requirements of a particular project (Hatush, 1996, Jennings and Holt, 1998, Ng, 1996). Furthermore, the data required in the periodic prequalification are relevant to historical data rather than current data (Mangitung and Emsley, 2002). This means periodic prequalification is more concerned with contractors' capability in terms of their financial and technical experience and performance in certain periods of time (Ng, 1996).

On the other hand, project prequalification is performed to develop a list for a particular project, on a project by project basis, before invitation to bid, which is related to a certain level of contractor capacity and to meet project specific requirements or objectives. In other words, project prequalification is more concerned with contractors' current data in respect of workload, financial position and remaining resources (Mangitung and Emsley, 2002).

States and municipalities in the United States have adopted a variety of measures for ensuring that the companies chosen to perform the construction work, produce goods, or provide services under contracts with the city or state are responsible, qualified, law-abiding, and trustworthy.

Often these laws are in the shape of "responsible contractor" and related requirements. These laws can help ensure that questionable companies (the companies that routinely break, misclassify workers as independent contractors, or fail to hire and retain a skilled workforce) do not win lucrative government contracts over responsible, capable, law abiding companies with skilled, trained workforce.

Examples of U.S Government Contracting Laws are:

(http://www.aflcio.org/issuespolitics/stateissues/fiscal/state_fa_scfs.cfm)

- **"Responsible Contractor" Laws:** Many states and localities like Oregon and California have "responsible contractor" laws that require contractors to meet minimum standards for quality, capability, and ethics and integrity, including compliance with the law.
- **Disclosure:** States like Ohio have laws that expressly require the bidder to disclose to the city or state officials information relevant to the responsibility determination, including disclosure of any violations of OSHA, environmental, prevailing wage, workers compensation, and other laws.
- **Prequalification:** Some states have established a system for "prequalification" of contractors. The state of California has adopted a law under which a model prequalification questionnaire and standard evaluation system were developed by the state for use by cities and counties wishing to adopt them.

- **Contractual "Warranties":** Another approach is to mandate that contracts include warranties obligating contractors to properly classify workers as employees as opposed to independent contractors for wage and tax purposes, to comply with applicable laws during the course of the contract, and similar measures, subject to cancellation of the contract if a contractor fails to comply with these contractual provisions. For example, Danbury, Connecticut has such an ordinance.
- **Best Value Contracting:** Delaware and New Jersey are examples of two states that recently adopted "best value contracting" to replace the more traditional "lowest responsible bidder" approach on construction contracts. Delaware subjects contractors to pre-qualification or pre-award scrutiny of their past performance, including any civil judgments and criminal history, and a review of the adequacy of their supply of "craft labor."
- **Living Wage and/or Prevailing Wage Requirements:** Dozens of municipalities have enacted living wage laws requiring recipients of city funds to pay employees at least a pre-determined living wage, together with benefits or a wage premium if benefits are not offered.
- **Industry-Specific Procurement Ordinances:** The New York City Council recently adopted an ordinance requiring the city to buy apparel and textile goods only from responsible contractors that comply with workplace and environmental laws and that pay a non-poverty wage. Civil penalties may be assessed against companies that make false claims under the law.

Whether it makes sense to pursue one or more of these initiatives in any given state will depend on a number of factors, including the particulars of a state's overall contracting system, political realities in the state, legal constraints, and other considerations. In addition, it is important to bear in mind that the ultimate effectiveness of any of these provisions depends on the state and local contracting officials who will apply the laws.

As stated above, prequalifying contractors in the United States is one of the contracting methods used by the state governments with each state using its own set of laws and regulations for it. Taking the case of the state of California we know that the state enacted a law in 1999 that allows many public agencies to require licensed contractors that wish to bid for public works jobs to "pre-qualify" for the right to bid on a specific public works project, or on public works project undertaken by a public agency during a specified period of time. The law applies to all cities, counties, and special districts but does not apply to K-12 school districts. The law does not require any public agency to adopt a pre-qualification system. Instead, it authorizes every public agency to adopt a prequalification system, and describes certain requirements that must be met (described below), if a public agency chooses to adopt such a system. In fact, the 1999 law allows a public agency to establish two different kinds of prequalification procedures for public works projects. The law allows a public agency to establish a prequalification procedure linked to a single project. Or, the public agency may adopt a procedure by which a contractor may qualify to bid on projects which are put out for bid by that agency for a period of one year after the date of initial prequalification.

The law requires every public agency that creates either kind of prequalification procedure to:

- Use a "standardized questionnaire and financial statement in a form specified by the public entity"
- Adopt and apply a uniform system of rating bidders on objective criteria, on the basis of the completed questionnaires and financial statements
- Create an appeal procedure, by which a contractor that is denied prequalification may seek a reversal of that determination.

The acceptance of the prequalification system in Saudi Arabia was not common as is evident from a study conducted by Al-Gobali (1994) in which he states that the acceptance of prequalification exercises among most private firms has been recent in Saudi Arabia. But still, there are some private companies and semi-government companies that do not apply contractor prequalification procedures in their contracting system. While the classification certificate issued by the Ministry of Public Works and Housing (MPWH) to contractors is based on criteria that focus on the risk of the contractor's failure and the contractor's ability to cover losses. Thus the analysis performed by the MPWH is more financially oriented and less emphasis is places on specific project factors. This situation has changed for the better in recent years with large private firms using prequalification to increase the chances for the successful completion of their projects.

3.7 SUMMARY OF THE LITERATURE REVIEW

The following were some of the points of interest observed from the literature review:

1. Contractor prequalification was defined as a process by which an owner evaluates the competence of a candidate contractor to perform the requirements associated with a given project with prequalification being the first step taken by owners to ensure the successful execution of field construction.
2. Some objectives of prequalification were identified which include:
   a. To eliminate contractors who are not responsive, responsible and competent.
   b. To enhance and/or assure bidding opportunities for `eligible' contractors.
   c. To encourage healthy competition among `eligible' contractors.
   d. To avoid/minimize risks of contractor failure and improve client satisfaction.
   e. To optimize the contractor selection in terms of achieving a better balance between price and performance parameters.
3. A number of advantages and disadvantages of the prequalification system were observed.
4. A large number of both prequalification models and prequalification criteria were identified.
5. A brief overview of the prequalification practices worldwide was taken to illustrate the different systems of prequalification being used.

CHAPTER FOUR

IDENTIFICATION OF PREQUALIFICATION MODELS

4.1 INTRODUCTION

This chapter presents a comprehensive list of contractor prequalification models elicited after extensive literature review and then states the reasons behind segregating these models into two distinctive groups. A few representative models are then selected from a group and subjected to analysis which will be dealt with in the subsequent chapter.

4.2 IDENTIFICATION OF PREQUALIFICATION MODELS FROM LITERATURE REVIEW

Extensive literature review was carried out and contractor prequalification models were identified. Adequate attention was devoted to this aspect so that a comprehensive overview of prequalifying models is attained. As a result of such an extensive literature review, an exceedingly varied range of prequalification models is observed.

The following is the list of contractor prequalification models derived from the literature review.

- Statistical Decision Methods – Fillipone (1976), Cooper (1978).
- Point Allocation Method – Zeleny (1982).
- Dimensional Weighting – Russell and Skibniewski (1988).

- Dimension-wide Strategy – Russell and Skibniewski (1988).
- Two – step Prequalification – Russell and Skibniewski (1988).
- Prequalification Formulas – Russell and Skibniewski (1988).
- Subjective Judgment – Russell and Skibniewski (1988).
- Stochastic Decision Model – Russell et. al (1990).
- Weighted Evaluation Method – Assaf and Jannadi (1994).
- Multi-attribute Analysis Technique – Holt et. al (1994).
- Cluster Analysis – Holt (1996).
- Fuzzy Set Theory – Holt (1997).
- PERT approach – Hatush and Skitmore (1997).
- Heuristic Model – Park et. al (1998).
- Analytic Hierarchy Process – Al-Harbi (2001).
- Neural Networks – Park et. al (1998), Lam et. al (2001).

4.3 DEVELOPMENT OF A LIST OF "PRACTICAL" PREQUALIFICATION MODELS

After the identification of prequalification models, an analysis of the literature review enabled the segregation of the list into two groups. One of which consisted of "Practical" models and the other group of essentially "Theoretical" models. The major point of difference between these two lists is that the former list consists of models that are much simpler to comprehend and are much more practical in nature to implement in the industry. This is based on the fact that the implementation and understanding of the latter set of models is still in infancy as far as the construction industry is concerned. Another criterion for classifying the models was from the literature review. The "Practical" models list is as follows:

- Point Allocation Method
- Dimensional Weighting
- Dimension-wide Strategy
- Two – step Prequalification
- Prequalification Formulas
- Subjective Judgment
- Weighted Score Method
- Statistical Decision Methods
- Analytic Hierarchy Process

While the "Theoretical" models list consists of the following:

- Stochastic Decision Model
- Multi-attribute Analysis Technique
- Cluster Analysis
- Fuzzy Set Theory
- PERT approach
- Heuristic Model
- Neural Networks

4.4 AN ANALYSIS OF THE PREQUALIFICATION MODELS INCLUDED IN THE "PRACTICAL" LIST

The models comprising of the "Practical" list can generally be divided into four groups with each group having such type of features that make it distinctive from the other groups. The first group is the one consisting of the Dimensional Weighting method, Weighted Score method, the Prequalification Formulas and the Two – step Prequalification method. These three models are variations of each other with the Weighted Score method being the most general form. The coefficients of the variables in the Prequalification Formulas can be visualized as the weights assigned to that particular variable which in Dimensional Weighting is represented by criteria. The Weighted Score method is also pretty similar to these two in this matter but the concept of determining the weights of each criterion is more closely related to that used in the Analytic Hierarchy Process. The Two – step Prequalification method is a combination of two methods, namely the Dimensional Weighting and the Dimension-Wide Strategy. In the first step the Dimension-Wide Strategy is used while in the next stage, contractors are evaluated using the Dimensional Weighting method. The commonality between the Weighted Score and the Dimensional Weighting method is the freedom to decide on the number and type of criteria to be used in them which is a feature absent from the Prequalification Formulas.

The Point Allocation method is a representative of the second group. It is a very basic method, both in its structure and methodology. It does not place any restriction on the number or type of criteria that can be used. The determination of weights for each criterion is more or less a subjective decision based on experience rather than any structured methodology.

The third group comprises of the Dimension-wide strategy. In this approach, the decision for every question is either yes or no i.e. the number of options for any question is two thus the name of it. There is no restriction on the number of criteria that can be used in this method but the structure of the model is such that the prequalification result would be based not on numbers but rather on the Yes and No answers to the questions in it.

The final group is represented by the Analytic Hierarchy Process. This is the model that is most evolved among the others in the "Practical" list. The determination of weights for each criterion is done on the basis of pair wise comparison which definitely is a much more structured approach than that used in the Point Allocation method. Its structure is also very different from the other prequalification models because of its hierarchical structure which is distinctively different from the matrix structure of Point Allocation method and Prequalification Formulas

4.5 SHORT LISTING A REPRSENTATIVE NUMBER OF PREQUALIFICATION MODELS

A specific number of prequalification models were then selected from the list of "Practical" models that was developed earlier. The reason behind selecting only a few prequalification models was that the selected prequalification models were representative of the different levels of working methodologies used by the models in the "Practical" models list.

The methods short listed after analysis were:

- Point Allocation Method
- Weighted Score Method
- Analytic Hierarchy Process

The reasons behind short listing these models from the list are as follows:

- A large number of contractors prequalification methods exist in the industry as well as in literature thus it would cumbersome and time consuming to run the comparative analysis on all the methods.
- These three methods are representative of different levels of sophistication and methodology. The Point Allocation Method is the simplest of the three with the AHP on the other extreme of the scale while the Weighted Score Method being between the other two methods as a representative of average sophistication. This selection was based on the earlier analysis performed on the model's working methodology and complexity of implementation.
- Prequalification models can be divided generally into two groups irrespective of their working methodologies and implementation procedures. The models in the first group utilize not only a fixed number of prequalification criteria but also have fixed level of importance or weight for these criteria leaving the user no room to modify these models for his/her requirements which naturally are unique for every user. This set of models can be termed as rigid in nature. The other set of models not only lets the user edit the prequalification criteria

used in the model according to his/her requirements but also lets the user specify the level of importance or weight of the prequalification criteria being used in the model. This set of models can be termed as flexible in nature. Models which are flexible in their nature of incorporating prequalification criteria were highlighted for selection. Some models are rigid in their structure as in they use a fixed number of prequalification criteria as well as use only specific criteria. Thus the models which do not specify the number or type of prequalification criteria thus letting the user decide the prequalification criteria pertinent to his needs and requirements were selected.

- The above reason made the selection of these three models an obvious choice since the prequalification criteria used in making the decision would be common for all the three models selected thus providing a common basis of comparison.

A comparative analysis of these three methods would provide a better understanding of the efficiency of the contractor prequalification methods.

4.6 DESCRIPTION OF THE SHORT LISTED PREQUALIFICATION MODELS

The short listed prequalification methods are described in this section in terms of their working methodology in order to arrive at a clearer understanding of them. The description is as given under:

- Point Allocation Method:

    - A maximum possible score for each criterion is assigned which adds up to a total of 100.
    - Sub criteria under a particular criterion are also assigned a maximum score which adds up to the maximum possible score of the criterion.
    - Evaluators are asked to rate contractors for each of these criteria keeping in mind the maximum possible score for the criterion.
    - Then these points are added up to arrive at the total score for each contractor.
    - Then the contractors are ranked on the basis of their total score.
- Weighted Score Method:
    - The weights or importance for criterion are determined based on comparing them in pairs or in other words using pair wise comparison.
    - Each criterion is assigned a particular weight, the summation of which is equal to 100.
    - If sub criteria are present in a criterion then their weights are also assigned, the summation of which is equal to the weight of that particular criterion.
    - Evaluators are asked to rate each of the contractors on a scale of 1 to 10.
    - The ratings for each criterion are multiplied by the respective weights of the criteria and then added up to arrive at a total score for a contractor.
    - Then the contractors are ranked on the basis of their total score.

- Analytic Hierarchy Process (AHP):
    - The criteria are compared in pairs to elicit preferences of the evaluator for one criterion over the other on a scale of 1 to 9. From these preferences, priorities for each criterion are derived.
    - The contractors are also compared in pairs for each criterion and evaluators specify their preferences of one contractor over the other for a particular criterion. These preferences are specified on a scale of 1 to 9.
    - These preferences are then used to compute the priorities of each contractor with respect to a particular criterion.
    - For each contractor, its priority for a criterion is multiplied with the priority for that criterion. This is done for all criteria and then these products are added up to arrive at a score.
    - Then the contractors are ranked on the basis of their total score.

4.7 IDENTIFICATION OF PREQUALIFICATION CRITERIA (PQC)

After identifying the prequalification models that are to be analyzed, the next aspect that was focused on was the identification of prequalification criteria from literature review. An effort was made to use a prequalification criteria set which incorporates almost all of criteria investigated by earlier researchers so that this research is not restricted to just a particular working environment. As was observed earlier in the literature review, the prequalification criteria (PQC) and their relative weights identified by Al-Gobali (1994) for the Saudi construction industry includes almost all of the criteria identified by prominent researchers in this field. The relative weights of the prequalification criteria identified by Al-Gobali were used as they are the only data of such type available for general Saudi construction industry. Al-Gobali's study even though undertaken in 1994, has been used in this research as the comparative analysis required a set of prequalification criteria and weights irrespective of their adequacy. The PQC and their respective weights identified by a study such as Al-Gobali can be used for the purpose of comparison without detracting from the significance of this research.

The list of PQC and their respective weights identified by Al-Gobali (1994) after surveying respondents for the Saudi construction industry is as in the following table:

Table 4.1: Prequalification Criteria and Their Respective Score.

S.No	PQC Description	Score
1	Work Experience & Past Performance	30
2	Financial Stability	6
3	Quality Assurance/Quality Control	6
4	Contractor Organization & Management Capability	15
5	Capacity of Contractor	10
6	Planning, Scheduling and Cost Control Expertise and Techniques	5
7	Equipment Resources	8
8	Safety Consciousness	4
9	References and Claims Attitude	9
10	Purchasing Expertise & Material Handling	4
11	Home Office Location	3
	Total Score for All Items	100

CHAPTER FIVE

ANALYSIS OF THE PREQUALIFICATION MODELS

5.1 INTRODUCTION

The comparison analysis of the short listed prequalification models was performed both quantitatively as well as qualitatively. Hence this segment was sub divided into two parts, one dealing with the quantitative analysis involving simulation of the prequalification models and the other dealing with comparison analysis using qualitative criteria.

5.2 QUANTITATIVE ANALYSIS

Simulation analysis was carried out on the three prequalification models selected. The predefined list of PQC was used for the purpose. For the defined set of PQC and their respective weights, contractor profiles are generated such that each contractor profile has its own unique set of values or points for the respective PQC. These contractor profiles are essentially hypothetical data. A contractor profile consists of unique values for all the respective PQC under consideration. For example, if two criteria are selected with the value of the first criterion being a possible 0 or 1 while the values of the other criterion being a possible 0, 1, 2, and 3. Then the contractor profiles generated for such values and number of criteria would be as given below:

1. C1 = [0, 0]

2. C2 = [1, 0]

3. C3 = [0, 1]

4. C4 = [0, 2]

5. C5 = [0, 3] so and so forth till all possible combinations are exhausted.

In the list above C1, C2, C3 etc represent a unique contractor profile with the first value in the brackets representing the value for the first criterion and the second value in the brackets representing the value for the second criterion. The combination of these two values comprises of a contractor profile.

The reasons behind using such hypothetical sort of data have already been explained in the earlier chapter (Chapter 2.3.1).

The following were the features of the simulation analysis undertaken:

- The analysis starts with utilizing the prequalification criteria (PQC) and the range of possible values for them which were selected earlier as has been discussed in the previous chapter.
- Since the number of contractor profiles is tremendous with the number of profiles being more than 2.5 billion, it was physically impossible to analyze all the contractor profiles. It was calculated that even with the computer running continuously; the program would run for almost a year before results would be obtained if it was executed for all the profiles. Thus the simulation analysis was conducted for fewer profiles that would be easily analyzed. This number of profiles has been referred to as the maximum number of profiles.
- For an efficient simulation analysis, the contractor profiles were broken down into batches of n profiles each and then analyzed by each prequalification

model. This was done because when all the profiles are analyzed together, the computer was not able to handle such vast amounts of data and was getting stuck in the process.

- The batch size for analyzing profiles was calculated to be:

$$n = \frac{Maximum\_no\_of\_profiles}{10}$$

- After generating every n number of contractor profiles, the program moved onto the analysis segment with the profiles being used as an input for the prequalification models. The Point Allocation model was analyzed first followed by the Weighted Score and the AHP models respectively. The output of each prequalification model was a list of ranks respective to the contractor profiles used as input for them. These three lists of ranks were then used as inputs for the correlation segment. The Point Allocation list was compared with the Weighted Score list and so on and so forth. The respective rank correlation coefficients were then tested for the null hypothesis and were then finally plotted.
- Care was taken as such so that no profile would be eliminated by generating contractor profiles randomly rather than sequentially. Thus ensuring that every profile has an equal chance of being analyzed which would not have been the case if the sequential generation of profiles had been used.
- The simulation analysis was carried out by using MATLAB software.

The program started with specifying the PQC that will be used for the comparison analysis as well as specifying the range of possible values that each criterion could assume. Then the batch size (n) was specified. After this step, the random generation of contractor profiles began while incrementing the value of a variable (tmp) by 1 for every profile generated. When the value of tmp equates n, the analysis segment of the program is executed. This segment comprises of the three prequalification models. The input for this segment is the ‘n’ number of contractor profiles generated. After execution of the analysis segment, three lists of ranked profiles are obtained. These three ranked profiles correspond to the ranking of profiles according to the Point Allocation, Weighted Score and Analytic Hierarchy Process respectively. These three lists are then compared in the correlation segment, with the Point Allocation list being compared to the Weighted Score list etc. The correlation segment also comprises of testing for the null hypothesis as well. After the completion of the correlation segment, the program again reverts back to generating the next batch of ‘n’ profiles and the whole process is again executed.

The working of the models has already been explained earlier. But the process of actually executing them in terms of a program needs to be explained. The aspect of analyzing the models objectively also needs to be explained which is as given under:

1. Initially the prequalification criteria and their respective weights as researched by Al-Gobali (1994) are specified in the form on a matrix. For example:
    a. PQC (1) = [1 2 3 4 5 . . . 30]
    b. PQC (2) = [1 2 3 4 6] and so on. This representation means that the value PQC (1) can take ranges from a minimum of 1 to a maximum of 30 and so on for other PQC as well.
2. Contractor profiles are generated randomly using the all the PQC specified and the values that they can take. For example, a sample of the contractor profiles from the specified PQC is:

a. C (1) = [1 4 …]

b. C (2) = [2 5 …] and so on. The first element in the contractor profile represents the value or points gained by the contractor for PQC (1), the second element in the profile represents the points gained by the contractor for PQC (2) and so on for other PQC as well.

3. After "n" numbers of contractor profiles have been generated, these profiles are used input for the three prequalification models.

4. The Point Allocation method is analyzed first. The contractor profiles used as input for this model comprise of:

   a. C (1) = [1 4 …]

   b. C (2) = [2 5 …] and so on. The model is then evaluated as explained below:

      i. Since this model requires the addition of points to arrive at a total score, the total score for C (1) is computed by adding up the elements of the profile.

      ii. Thus the total score for C (1) = 1 + 4 + …. and the total score for C (2) is 2 + 5 + …

      iii. This is done for all the contractors to calculate their total scores; these contractors are then ranked with the highest score getting the first rank.

5. The Weighted Score method is analyzed next. The contractor profiles being used here are the same as those used in the earlier model. The weights for each prequalification criterion are specified here. To maintain objectivity,

these weights are the same as the maximum limit defined for each criterion in step 1. For example:

a. The weight for PQC (1) = 10.

b. The weight for PQC (2) = 5. Subsequent to specifying these weights, the points for each criterion in the contractor profiles need to be translated onto a scale of 1 – 10 as the points allocated for each criterion in this model have to be on that scale. This is done in the following manner.

   i. C (1) is initially assigned 1 point out of a maximum of 10 for PQC (1). This is converted onto a scale of 10. Thus C (1) gets 1 point out of 10 for PQC (1). This similarity in points is due to the fact that the maximum value for PQC (1) is 10 which is the same as the maximum range of points from which C (1) has to be assigned in this model.

   ii. C (1) is initially assigned 4 points out of a maximum of 5 for PQC (2). This is converted onto a scale of 10 for this model. Thus C (1) gets 8 points out of 10. This is calculated as:

$$Points\_on\_a\_scale\_of\_10 = \frac{Points\_scored\_originally \times 10}{Maximum\_points}$$

   Which in this case is $\frac{4 \times 10}{5} = 8$ and so on for all other criteria.

   iii. The new contractor profile for C (1) is as [1 8 …] and so on.

   iv. These new profiles are then used to analyze the Weighted Score method. The points in the contractor profile for each contractor are multiplied with the respective weights for that particular criterion and these subtotals are added up to get a total score. For example: the total score for C (1) = 1 x 10 + 8 x 5 + …. And so on for all contractor profiles. These contractors are then ranked according to their scores with the highest score getting the first rank.

6. The original contractor profiles are again used as input for the Analytic Hierarchy Process. The priorities for each PQC are specified here. To maintain objectivity, the maximum limit that a PQC can take is divided by 100 to get the priority for that PQC. For example, the priority for PQC (1) is its maximum value it can take divided by 100 which is equal to 10/100 = 0.1, while the priority for PQC (2) is 5/100 = 0.05. Thus the sum of priorities for all PQC is equal to 1. The preferences levels of points scored by one contractor over the other is derived by the following method:
    a. The priority matrix for each PQC is computed by dividing the points scored by one contractor over the other.
    b. The resulting quotient is then compared on a predetermined scale and if it falls in a particular range, a preference level for that particular level is assigned. For example: Generating a priority matrix for PQC (1) involves dividing the points scored by C(1) for PQC (1) by itself and going on dividing the points scored by other contractors for PQC (1) by the points scored by C (1) for PQC (1).

c. The first element in the priority matrix is the preference level of C (1) over itself. That is 1 is divided by 1. Since both of these are equal, the preference level of 1 is selected.

	C (1)	C (2)
C (1)	1	
C (1)		

d. The second element in the priority matrix is the preference level of C (1) over C (2). That is 2 is divided by 1. The resulting quotient is compared with predetermined scale to arrive at a preference level. As on this scale, a quotient of 2 was assumed to be moderately preferred thus a preference for C (2) over C (1) is set to 3.

	C (1)	C (2)
C (1)	1	3
C (1)		

e. The rest of the elements in the priority matrix are derived using the same procedure.

f. After completion of calculating preferences in the priority matrix, the priorities are calculated for all contractors.

g. The same procedure is followed for all calculating priorities of contractors over all PQC.

h. Then to arrive at a total score for each contractor, the priorities of a contractor for a PQC is multiplied with the overall priority of that PQC, then these sub totals are added up to arrive at a total score for that particular contractor.

i. The contractors are then ranked according to their scores with the highest score getting the first rank.

The flow charts for the programs are specified subsequently. Figure 5.1 represents the main program and this is further broken down into Figures 5.2 to 5.5 to explain in further detail the working of the sub programs.

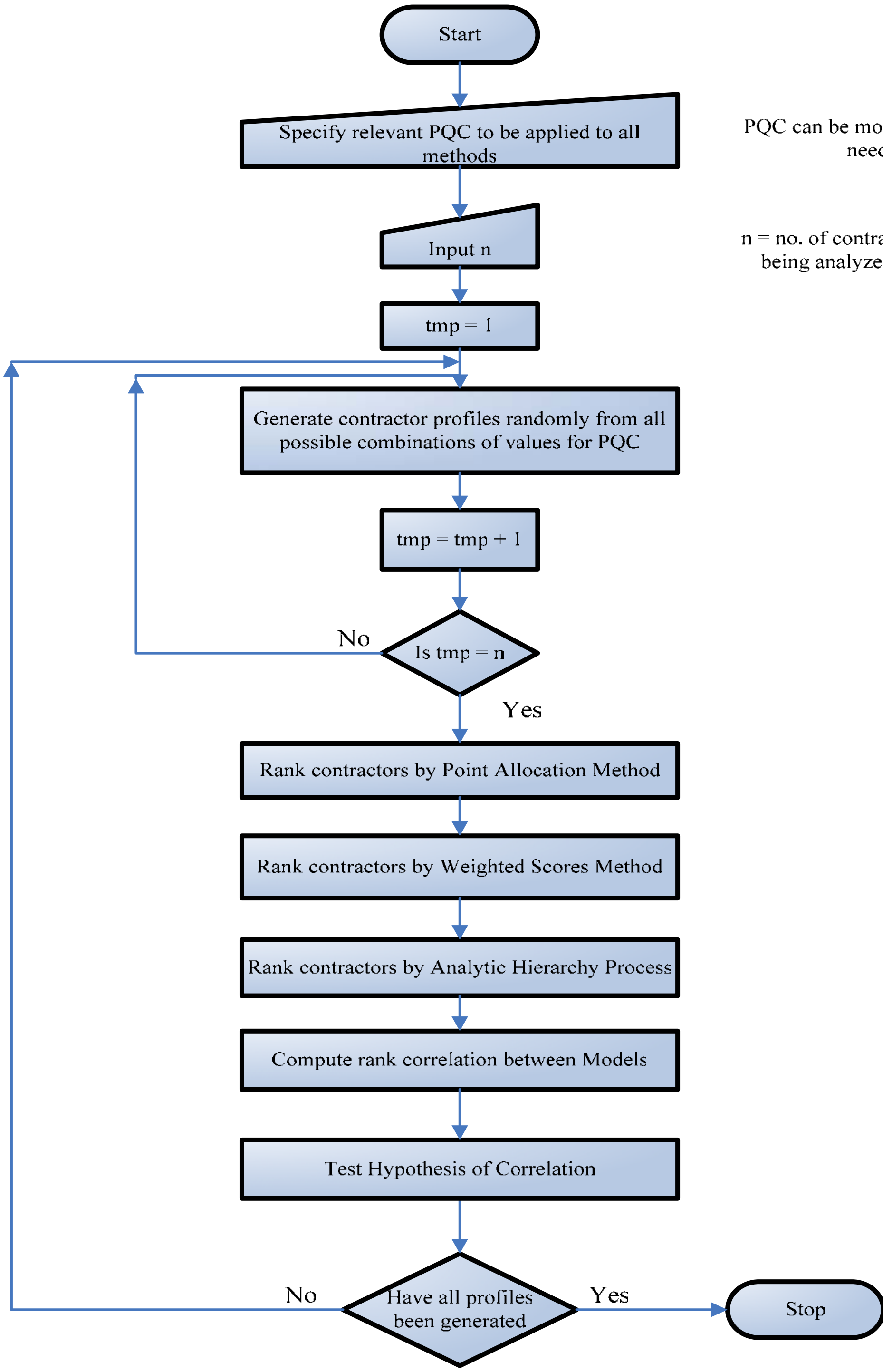


Fig. 5.1: Main Program Flow Chart

5.2.1 POINT ALLOCATION METHOD

The Point Allocation Method was the first prequalification model to be analyzed. This segment starts with adding up the points or values for each contractor profile. Then the contractors are ranked according to the respective totals with the highest score getting the first rank and so on. The flow chart of the program for this model is as depicted in Figure 5.2:

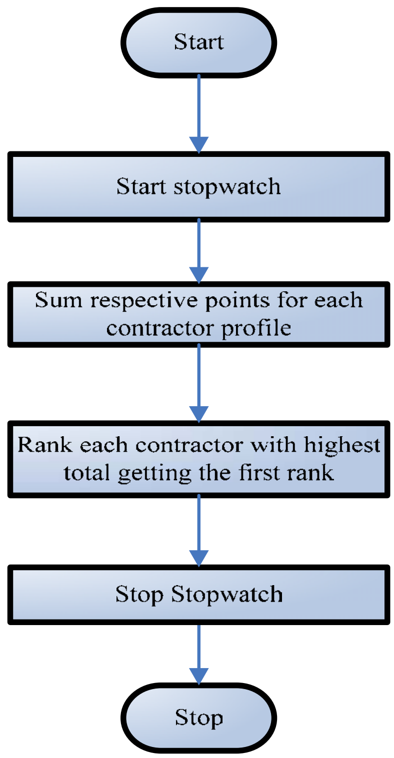


Fig. 5.2: Point Allocation Method Flow Chart

5.2.2 WEIGHTED SCORE METHOD

The Weighted Score Method was the second prequalification model to be analyzed. This segment begins with specifying weights derived by Al-Gobali (1994) for the respective prequalification criteria (PQC). These weights are then multiplied with the respective points scored by each contractor profile. Then these are added up to arrive at a total score. Finally the contractor profiles are ranked according to their scores with the highest score getting the first rank. The flow chart for this model is as depicted in Figure 5.3:

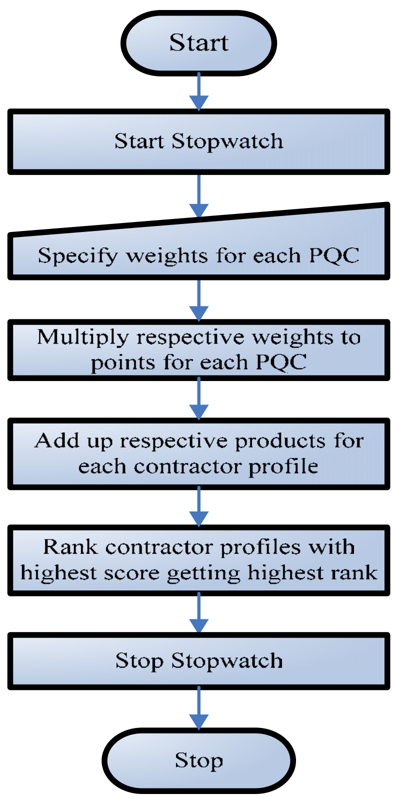


Fig. 5.3: Weighted Scores Method Flow Chart

5.2.3 ANALYTIC HIERARCHY PROCESS METHOD

This segment begins with specifying the priorities for each PQC. Then it goes on to specifying the preference ratings for each contractor profile. Then the segment generates priority matrices for each PQC. Multiply the priorities of each PQC with the priority matrices of contractor profiles. The products are then added to get scores for each contractor profile. These contractor profiles are then ranked according to their scores with highest score getting the first rank. The flow chart for this prequalification model is as depicted in Figure 5.4:

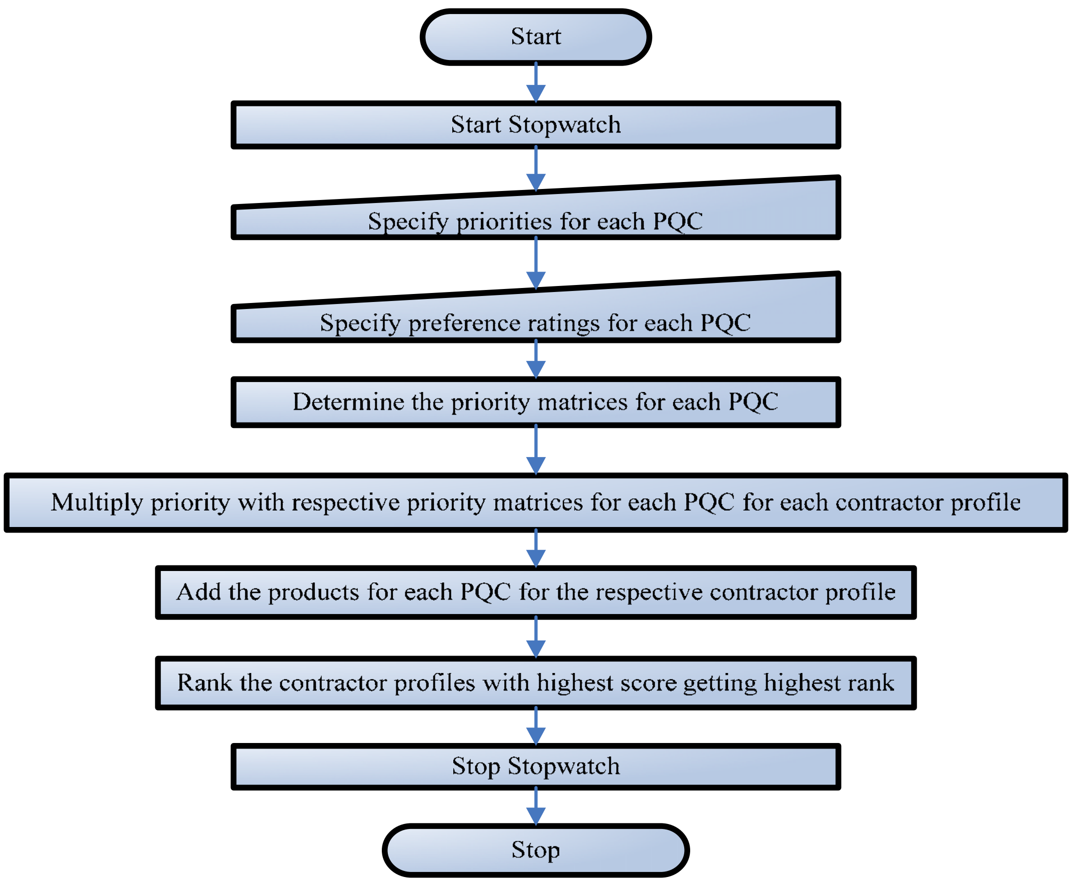
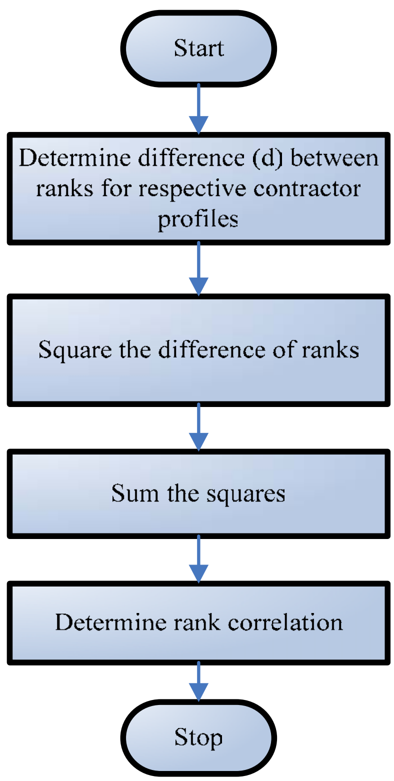


Fig. 5.4: Analytic Hierarchy Process Flow Chart

5.2.4 RANK CORRELATION

The rank correlation program is executed after executing the former three models. Subsequent to the analysis of the three prequalification models, three lists of contractor profiles are obtained which are ranked by the three methods. These three sets of rankings are then correlated using the Spearman's rank correlation coefficient. In this segment, the difference between the ranks (d) of ranked contractor profiles is calculated initially. This difference is squared, and then the squares are added. Finally the formula for the Spearman's rank correlation is used to compute the correlation coefficient. The flow chart for rank correlation is shown in Figure 5.5.



$$r_S = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2 - 1)}$$

Fig. 5.5: Rank Correlation Flow Chart

5.2.5 TESTING SIGNIFICANCE OF DIFFERENCE BETWEEN RANK CORRELATION

To compute the significance of the difference between two correlations from independent samples Blalock (1972) proposed the following procedure:

The correlation coefficient is transformed into a z-score for purposes of hypothesis testing. This is done by dividing the correlation plus 1, by the same correlation minus 1; then taking the natural log of the result; then divide that result by 2. The formula for which is as follows:

$$Z = \frac{\ln\left[{(r+1)}\big/{(r-1)}\right]}{2}$$

The end result is Fisher's z-score transformation of Pearson's r. Fisher's transformation reduces skew and makes the sampling distribution more normal as sample size increases. Then the standard error of difference between the two correlations is calculated as:

$$SE = \sqrt{\frac{1}{n_1 - 3} + \frac{1}{n_2 - 3}}$$

where n_1 and n_2 are the sample sizes of the two independent samples

Then z value for the difference between the correlations is computed by dividing the difference between the two z-scores with the standard error. If this z value is 1.96 or higher, the difference in the correlations is significant at the .05 level. While 2.58 is the cutoff for significance at the .01 level.

5.2.6 RESULTS OF THE SIMULATION ANALYSIS

The simulation analysis was carried over various combinations of batch sizes as well as number of maximum profiles analyzed to ensure that the results obtained are consistent over the different combinations of batch sizes and maximum profiles.

5.2.6.1 BATCH SIZE OF 100 TO 1000 IN INCREMENTS OF 100

The results of the comparisons between the batch size and the average rank correlation coefficients are as displayed beginning with Figure 5.6.

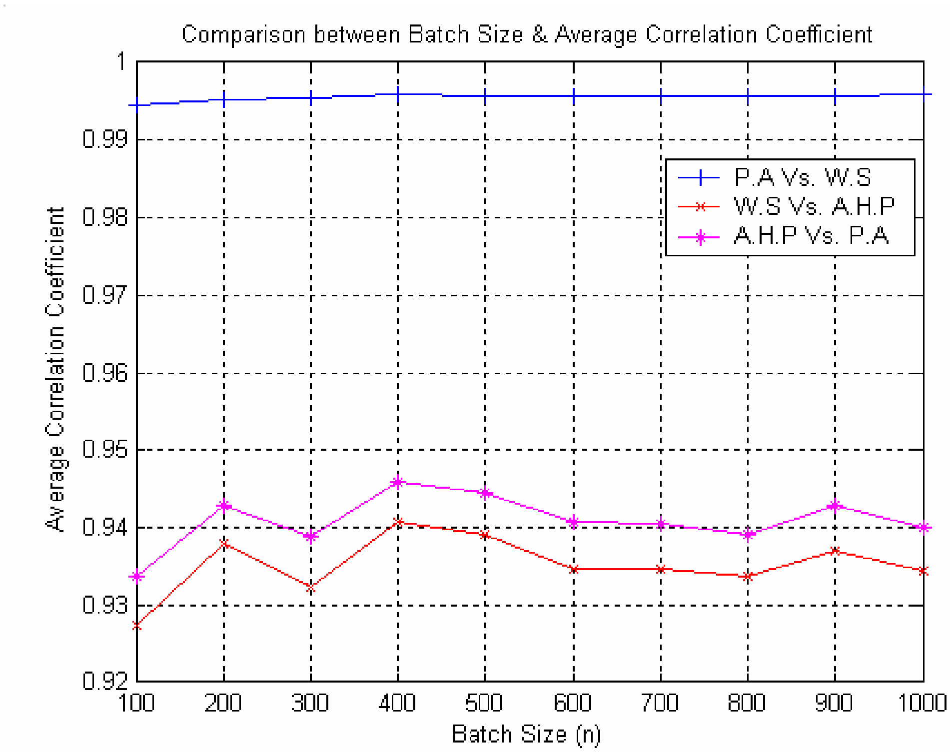


Fig. 5.6: Comparisons between Batch Size and Average Correlation Coefficients

In the figure, it can be seen that for various batch sizes, the correlation between Point Allocation and Weighted Score method is very strong and is approximately linear. On the other hand, even though the other two correlations namely the one between Point Allocation and AHP, and the one between Weighted Score and AHP are very strong but they are not as high as the earlier one. These correlations do not vary linearly but have their corresponding highs and lows. The correlation between Weighted Score and AHP is lesser than Point Allocation and AHP. This comparison can be alternatively viewed from the comparison between the maximum number of profiles analyzed and the respective rank correlation coefficients between Point Allocation and Weighted Score, Point Allocation and AHP, and Weighted Score and AHP respectively beginning from Figure 5.7 to 5.9.

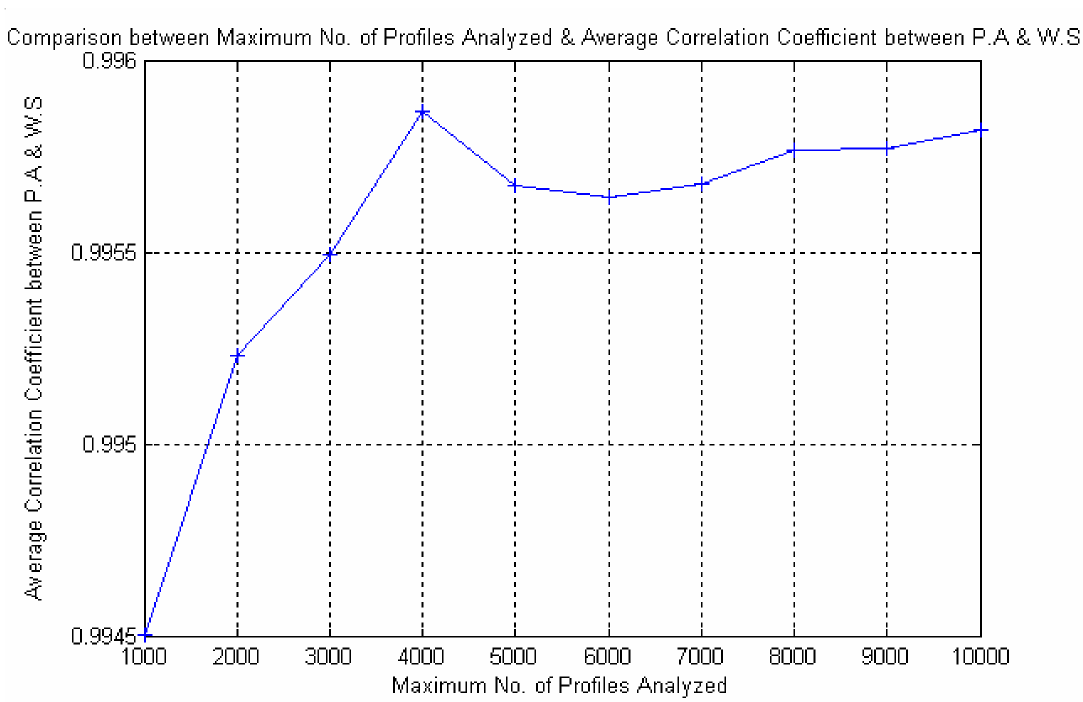


Fig. 5.7: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and Weighted Score Model

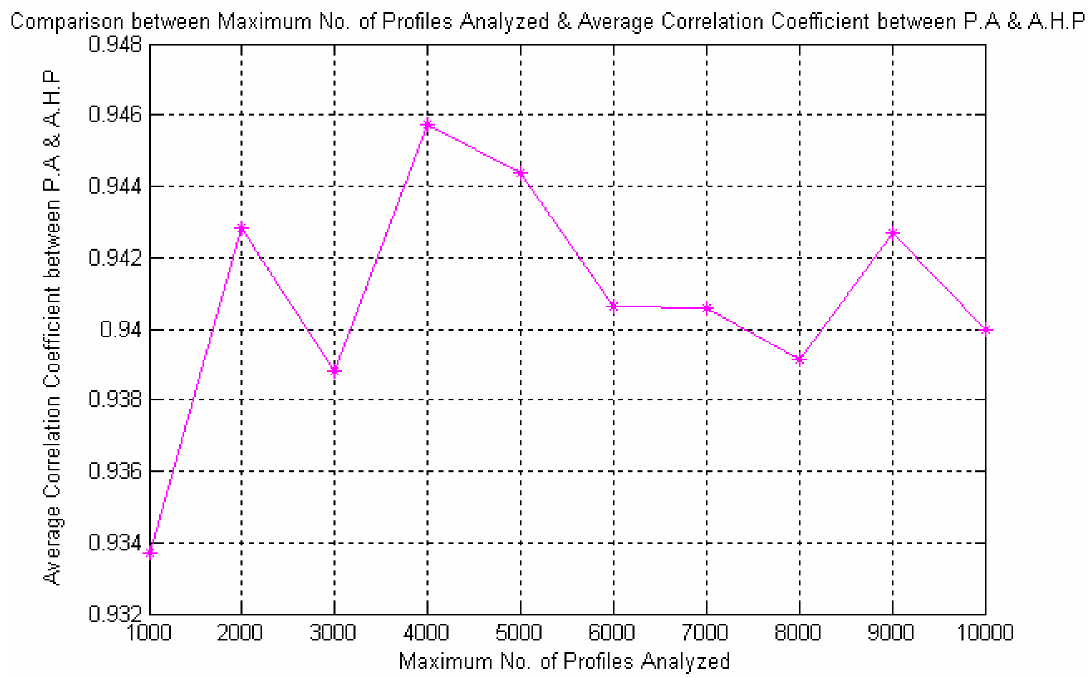


Fig. 5.8: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and AHP

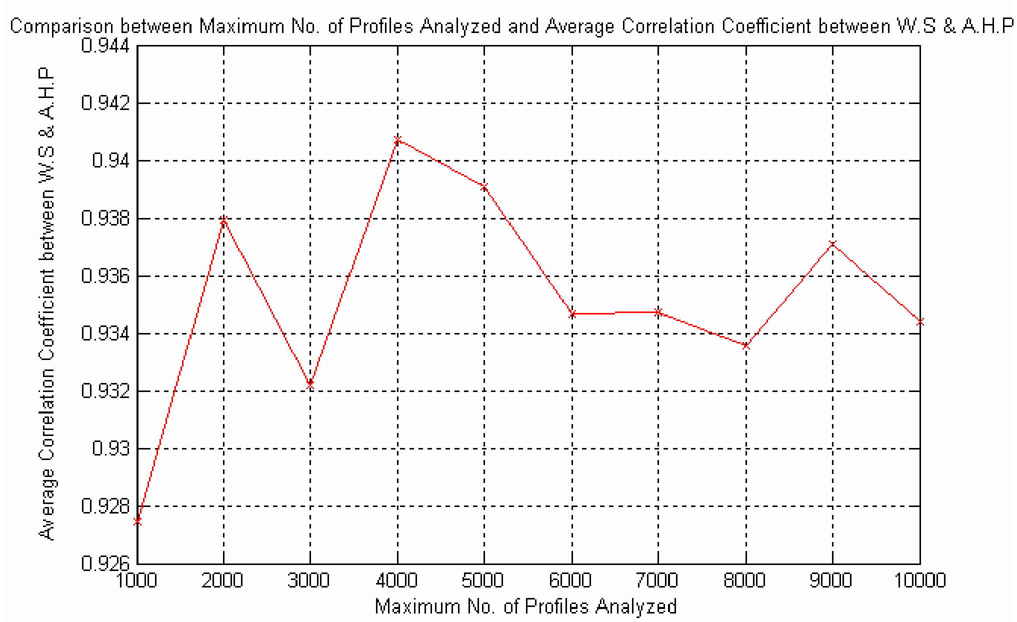


Fig. 5.9: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Weighted Score Model and AHP

5.2.6.2 BATCH SIZE OF 100 TO 1500 IN INCREMENTS OF 100

In the figure below (figure 5.10), it is observed that the correlation between Point Allocation and Weighted Score method for different batch sizes (n) is very strong and is almost a straight line. On the other hand, even though the other two correlations namely the one between Point Allocation and AHP, and the one between Weighted Score and AHP are very strong but they are not as high as the earlier one. These correlations do not vary linearly but have their corresponding highs and lows. The correlation between Weighted Score and AHP is lesser than Point Allocation and AHP. This comparison can be alternatively viewed from the comparison between the maximum number of profiles analyzed and the respective rank correlation coefficients between Point Allocation and Weighted Score, Point Allocation and AHP, and Weighted Score and AHP respectively beginning from Figure 5.11 to 5.13.

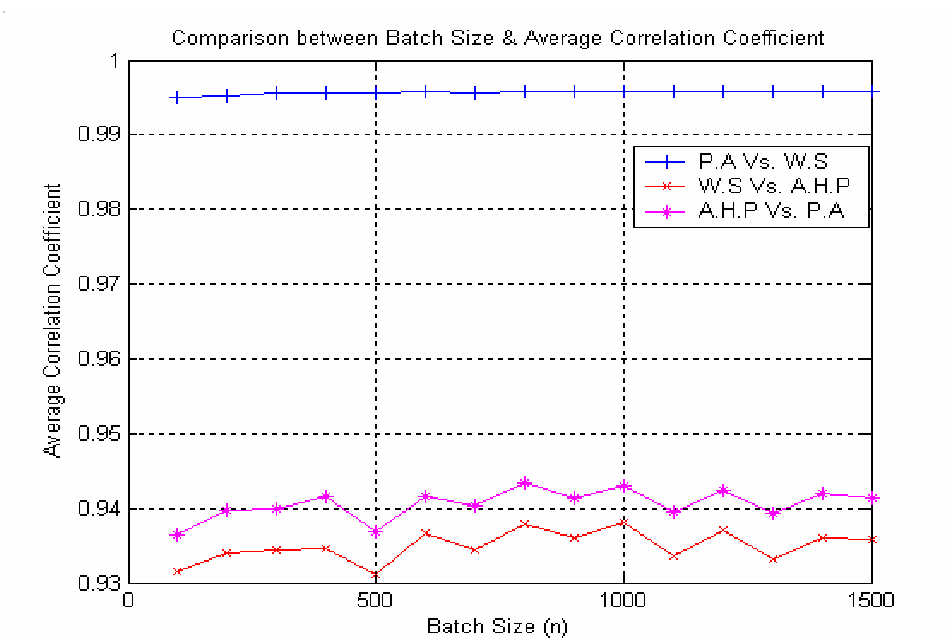


Figure 5.10: Comparisons between Batch Size and Average Correlation Coefficients

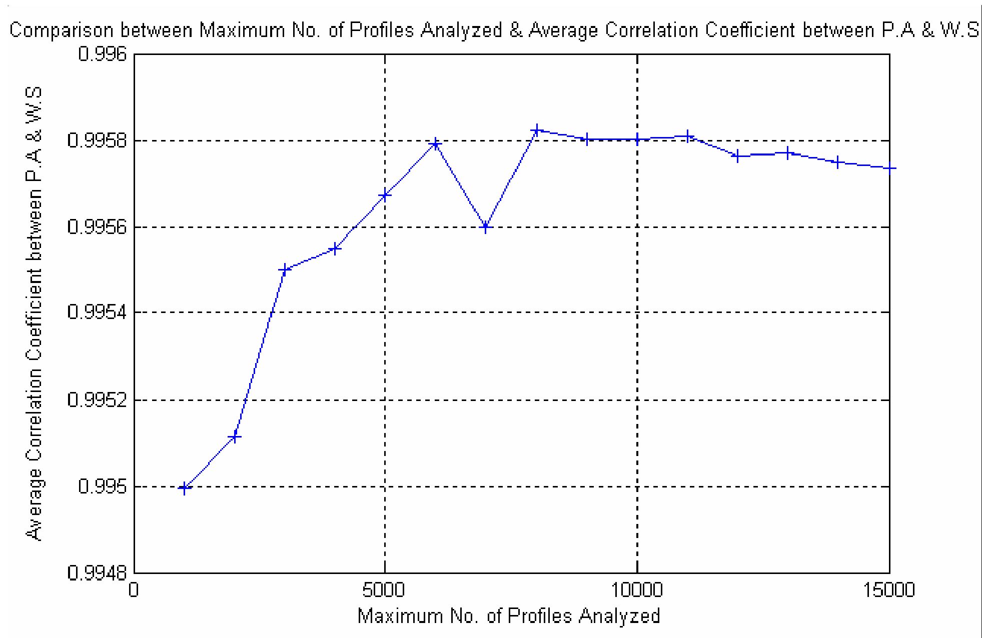


Fig. 5.11: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and Weighted Score Model

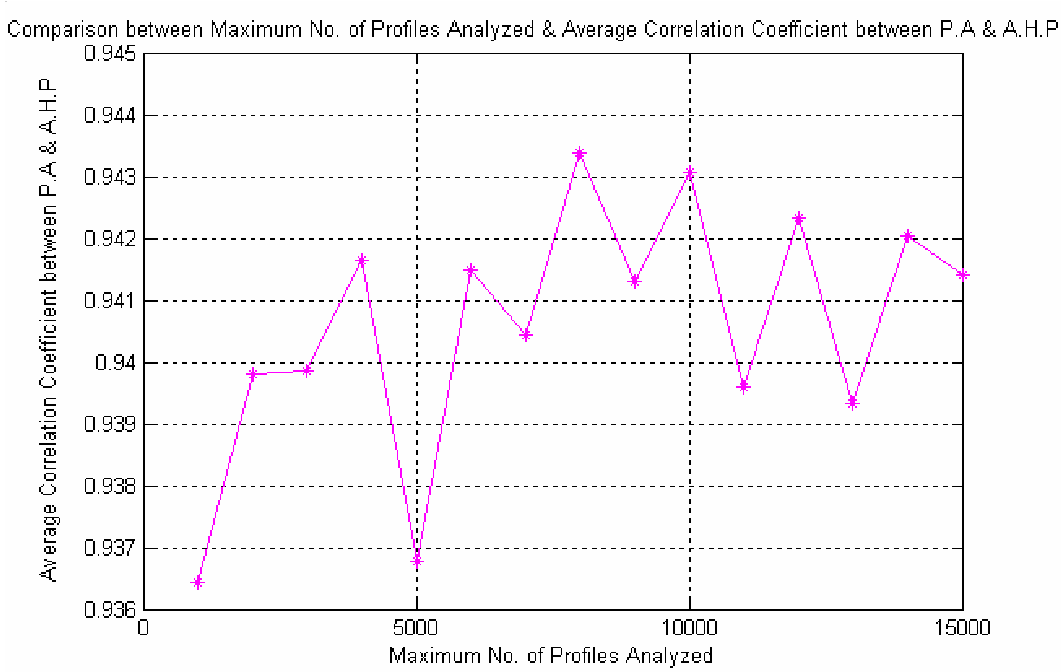


Fig. 5.12: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and AHP

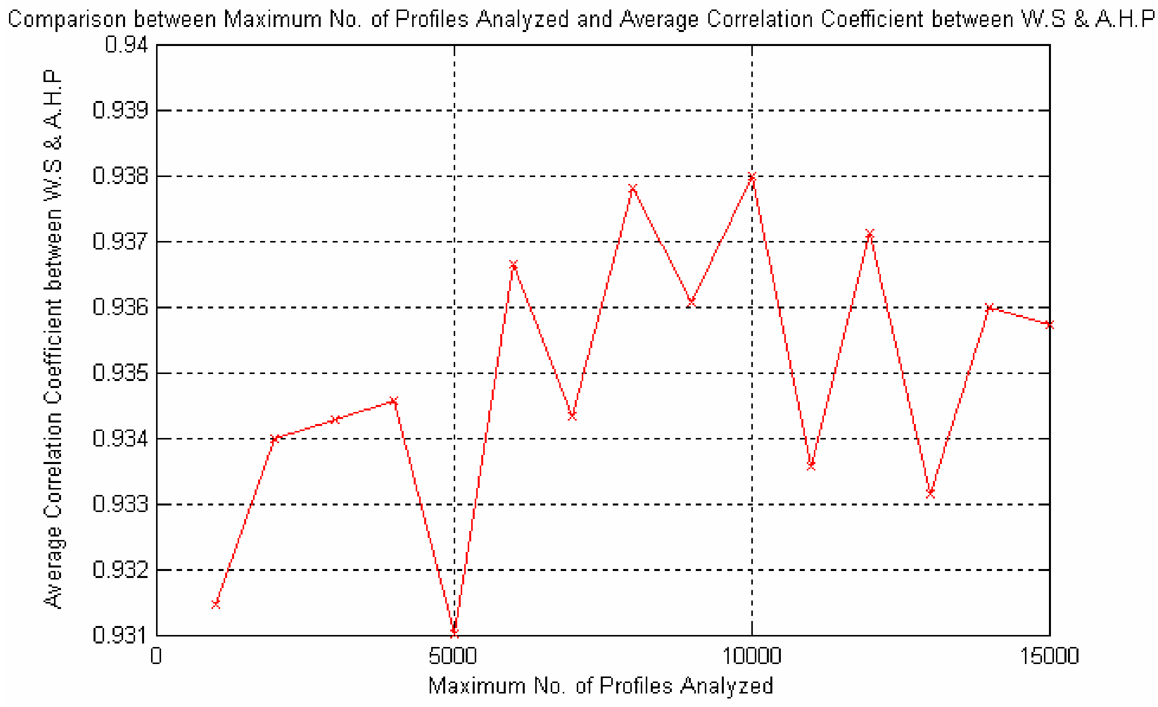


Fig. 5.13: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Weighted Score Model and AHP

5.2.6.3 BATCH SIZE OF 200 TO 2000 IN INCREMENTS OF 200

In the figure below (figure 5.14), it can be seen that for various batch sizes, the correlation between Point Allocation and Weighted Score method is very strong and is approximately linear. On the other hand, even though the other two correlations namely the one between Point Allocation and AHP, and the one between Weighted Score and AHP are very strong but they are not as high as the earlier one. These correlations do not vary linearly but have their corresponding highs and lows. The correlation between Weighted Score and AHP is lesser than Point Allocation and AHP. This comparison can be alternatively viewed from the comparison between the maximum number of profiles analyzed and the respective rank correlation coefficients between Point Allocation and Weighted Score, Point Allocation and AHP, and Weighted Score and AHP respectively beginning from Figure 5.15 to 5.17.

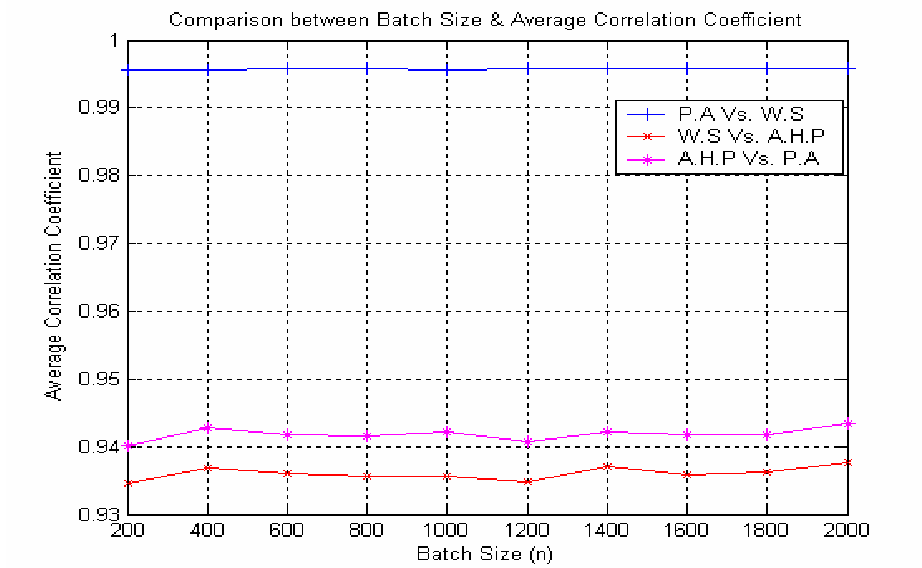


Figure 5.14: Comparisons between Batch Size and Average Correlation Coefficients

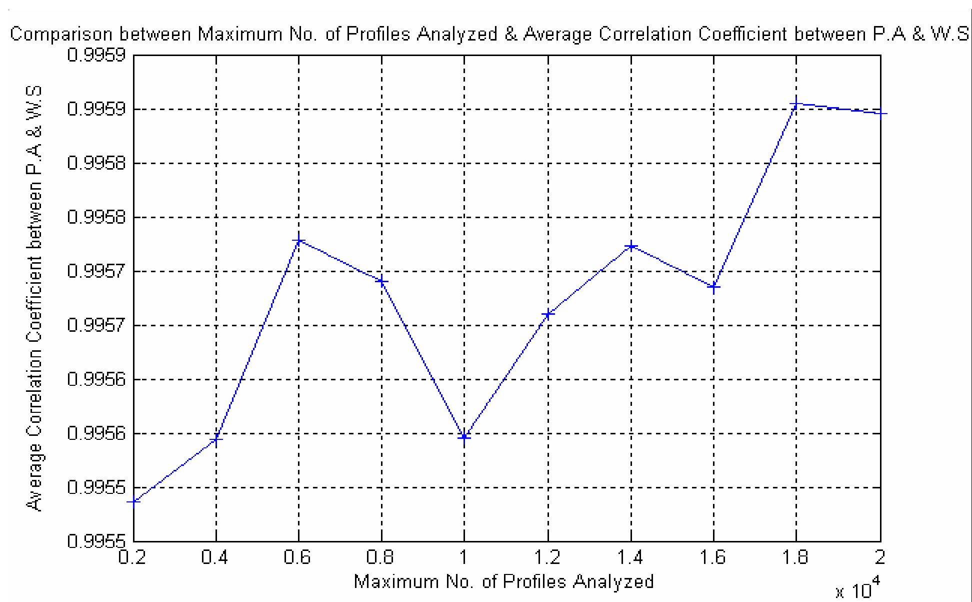


Fig. 5.15: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and Weighted Score Model

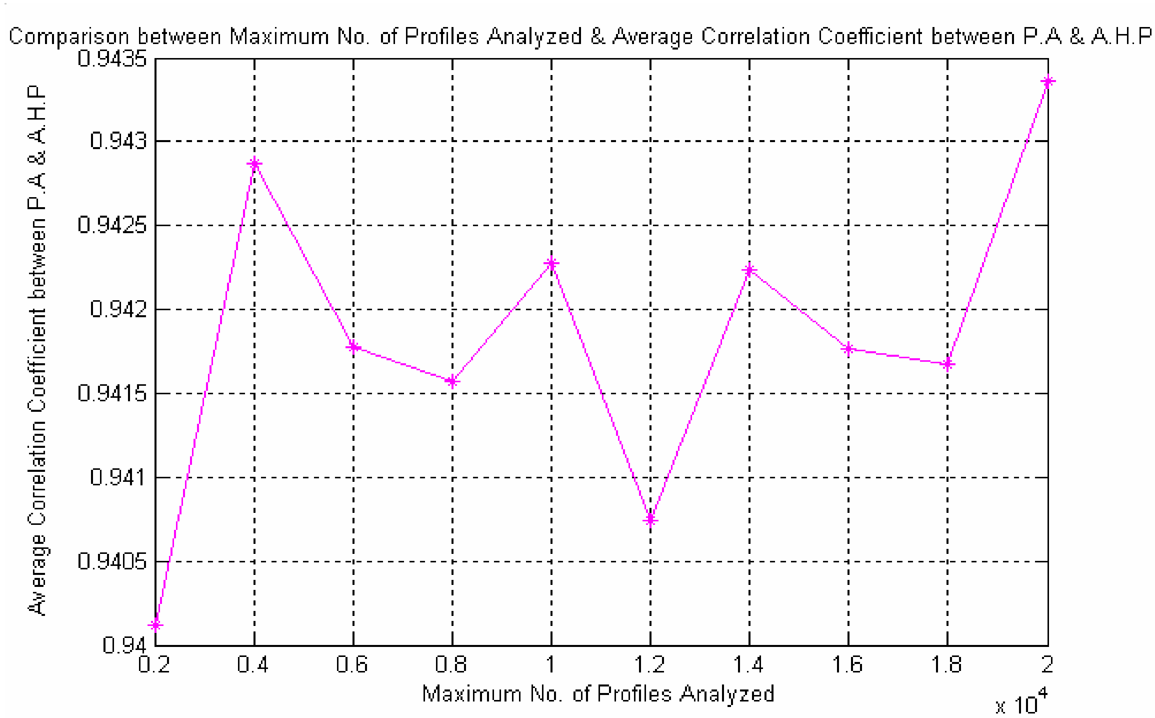


Fig. 5.16: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and AHP

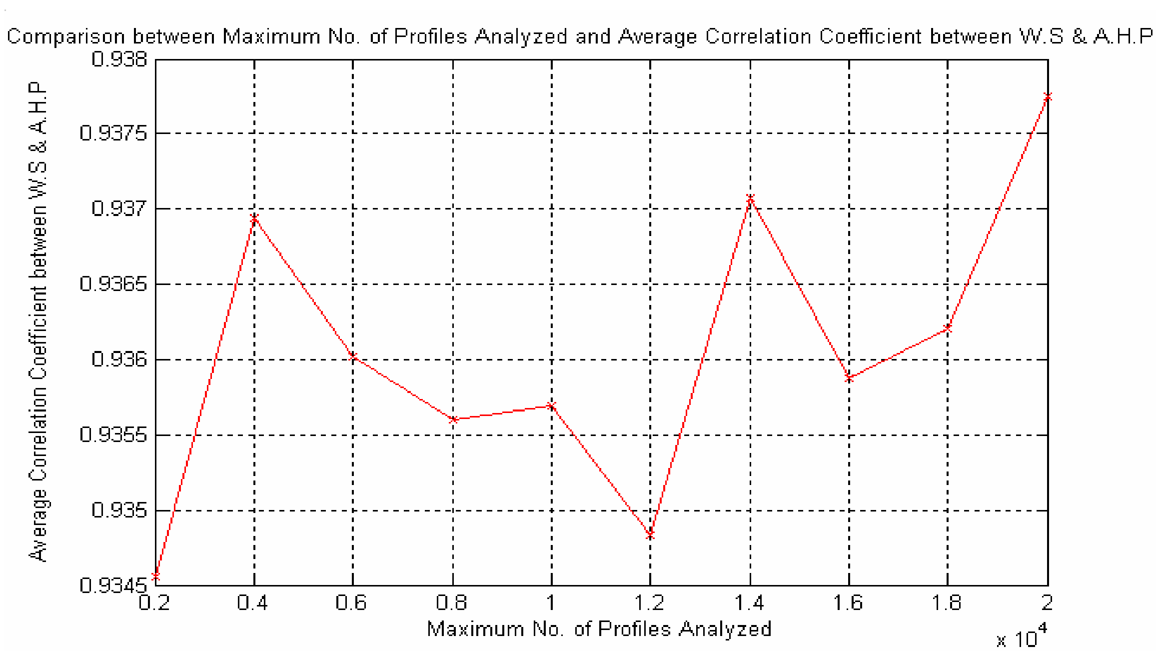


Fig. 5.17: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Weighted Score Model and AHP

5.2.6.4 BATCH SIZE OF 250 TO 2500 IN INCREMENTS OF 2500

In the figure below (figure 5.18), it can be seen that for various batch sizes, the correlation between Point Allocation and Weighted Score method is very strong and is approximately linear. On the other hand, even though the other two correlations namely the one between Point Allocation and AHP, and the one between Weighted Score and AHP are very strong but they are not as high as the earlier one. These correlations do not vary linearly but have their corresponding highs and lows. The correlation between Weighted Score and AHP is lesser than Point Allocation and AHP. This comparison can be alternatively viewed from the comparison between the maximum number of profiles analyzed and the respective rank correlation coefficients between Point Allocation and Weighted Score, Point Allocation and AHP, and Weighted Score and AHP respectively beginning from Figure 5.19 to 5.21.

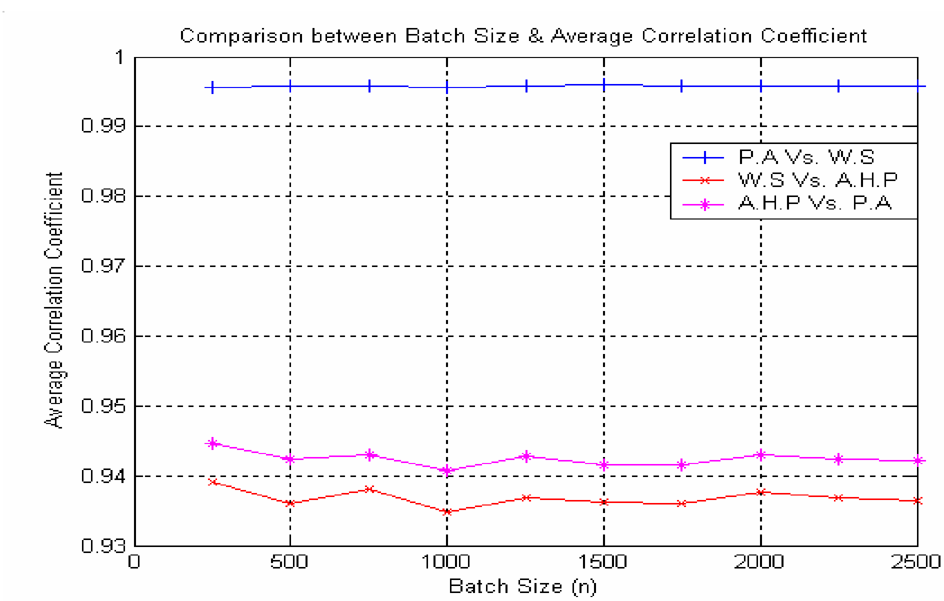


Figure 5.18: Comparisons between Batch Size and Average Correlation Coefficients

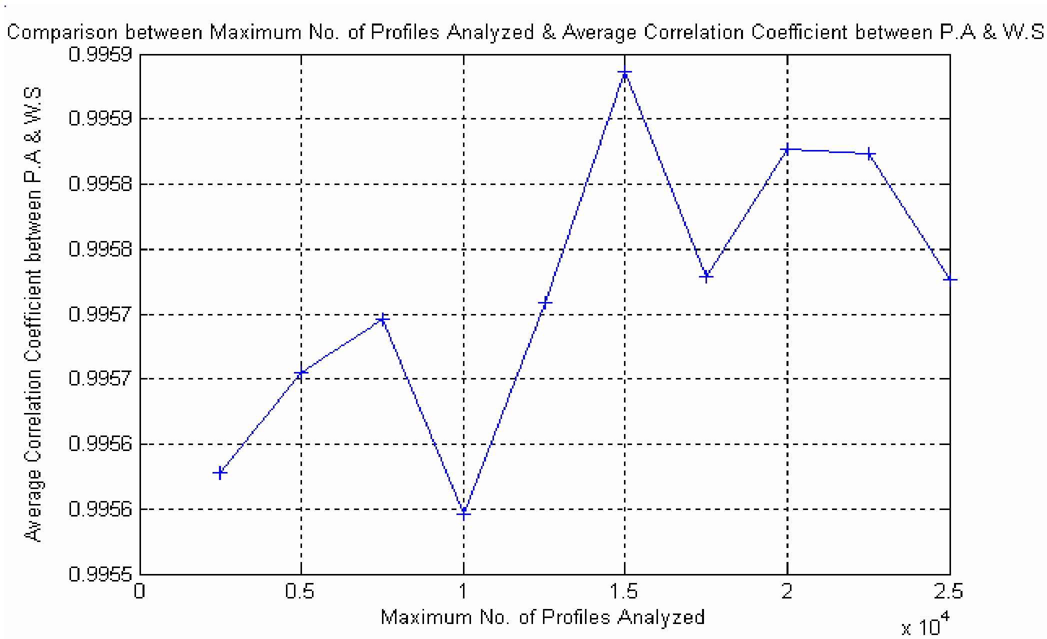


Fig. 5.19: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and Weighted Score Model

Fig. 5.20: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Point Allocation Model and AHP

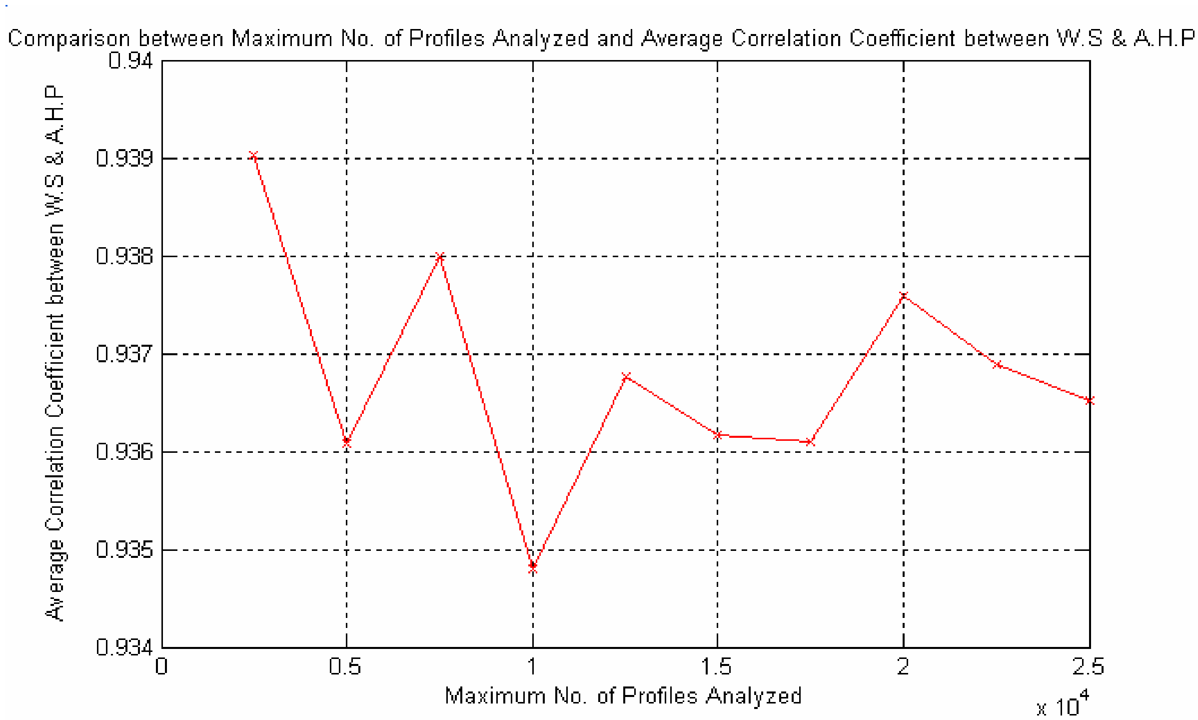


Fig. 5.21: Comparisons between Maximum No. of Profiles and Correlation Coefficient between Weighted Score Model and AHP

5.2.7 VARIATION IN THE CORRELATION COEFFICIENT WITH RESPECT TO CHANGE IN THE NUMBER OF PREQUALIFICATION CRITERIA USED

In this section, the effect of varying the number of prequalification criteria being used on the correlation between the three prequalification models is investigated. This exercise is performed in two approaches. First the results of the prequalification models are compared with each other for different number of prequalification criteria. Then the results of the prequalification models are compared among themselves for different number of prequalification criteria. The procedure adopted and results observed are explained in the following sections.

5.2.7.1 COMPARING PREQUALIFICATION MODELS WITH EACH OTHER FOR DIFFERENT NUMBER OF PREQUALIFICATION CRITERIA

The objective of this exercise is to determine whether the correlation coefficient would increase or decrease with the change in the number of prequalification criteria. An increase in the correlation coefficient with the reduction in number of the criteria used implies that the sophisticated model is sensitive to the number of criteria being used for prequalification. This would mean that selecting a simpler prequalification model which is easier to implement for a lesser number of prequalification criteria would be a better decision than opting for a complex model. A decrease in the correlation coefficients with the reduction would mean that the decision of using a complex model for prequalification holds well for a lesser number of prequalification criteria. If there is no particular trend observed in the correlation with the change in the number of prequalification criteria, then it can be concluded that there is no significant effect of the change in the number of criteria upon the correlation between the three prequalification models.

The methodology for this exercise is that after every simulation run and calculation for correlation coefficient between the three models the number of prequalification criteria is reduced by one for the next simulation run and so on till the number of criteria equal a bare minimum (in this case the minimum was selected as four). In much simpler terms, the simulation run is started by using all the eleven criteria and calculating the correlation coefficients, then this number is reduced by one and the simulation run is again started with ten criteria. This process is repeated till the last simulation run which uses four criteria only. The simulation run was also executed by selecting a few specific criteria. These criteria possessed greater importance when compared to other criteria as surveyed by Al-Gobali (1994). They consist of:

- Experience
- Contractor Organization and Management Capability
- Capacity of Contractor
- Equipment Resources
- References & Claim Attitude

The results of this analysis are displayed in the table below:

Table 5.1: Variation of Correlation Coefficient with respect to change in the number of prequalification criteria used.

S. No.	No. of prequalification criteria used	Correlation Coefficient between		
		P.A & W.S	W.S & AHP	P.A & AHP
1	11	0.996625	0.938818	0.944421
2	10	0.994884	0.923743	0.929878
3	9	0.996007	0.931181	0.934971
4	8	0.995999	0.946966	0.953369
5	7	0.995259	0.931149	0.937168
6	6	0.995635	0.949517	0.945616
7	5	0.995006	0.931441	0.938701
8	4	0.994924	0.946625	0.949858
9	5 (Specific criteria selected)	0.995333	0.93089	0.936564

The same can be displayed in the form of a graph as given in the figure below.

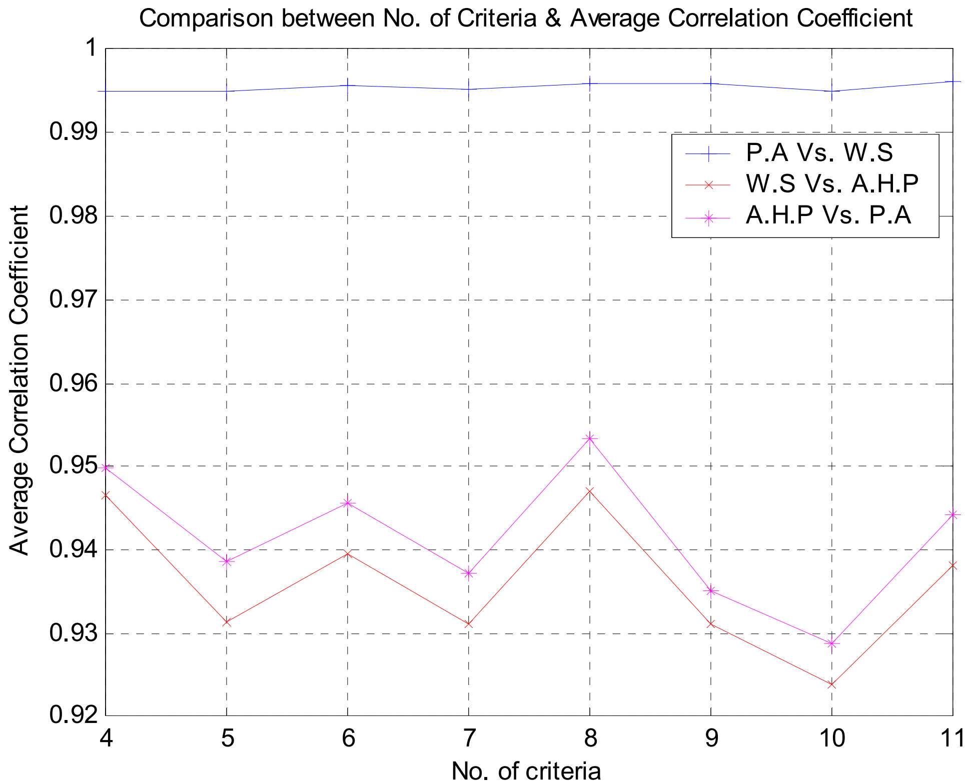


Fig. 5.22: Variation of Correlation Coefficient with respect to change in the number of prequalification criteria used

It can be observed from the figure above that no significant trend is observed in the variation of correlation when the number of prequalification criteria changes from eleven through to four. The simulation run using the major criteria also provided the same level of correlation among the three prequalification models. Thus it can be concluded that reducing the number of prequalification criteria does not affect the relative robustness or accuracy among the three prequalification models.

5.2.7.2 COMPARING PREQUALIFICATION MODELS AMONG THEMSELVES FOR DIFFERENT NUMBER OF PREQUALIFICATION CRITERIA

This comparison of contractor rankings produced by the prequalification models has been performed by using two cases. The first case was the one in which Al-Gobali's (1994) weights were used for the prequalification process and the second case in which equal weights were assigned to all the prequalification criteria. The coefficient of concordance was used to ascertain the agreement of the results between the three prequalification models and also as a means to check on the correlation results.

In the first case, the results of the three models are compared among themselves while changing the number of prequalification criteria being used. Initially a fixed number of contractor profiles are generated randomly using the prequalification weights identified by Al - Gobali's (1994) research (In this case 1000 profiles were generated). The Point Allocation method is analyzed first using all the eleven PQC, then the number of PQC used are reduced by one for every simulation afterwards till a fixed number of PQC is reached (In this case five was set as the minimum number). For every simulation run, the PQC dropped is the one with the lowest percentage of weight. For example, after the first simulation run using all the eleven PQC the next simulation run is repeated using 10 PQC with the one criterion dropped being "Home Office Location" which constituted only 3% of the total weight of all the PQC. Likewise for every simulation run, one criterion is dropped till only five criteria remain in the last simulation run. The total weight of these criteria is 72 % of the total weight of all the PQC.

After obtaining the resulting ranks of the contractor profile set, these ranks are compared with each other to ascertain the extent of correlation between them using the Spearman's Rank Correlation Coefficient. For example, $P.A_{11}$ is compared with $P.A_{10}$ where $P.A_{11}$ is the ranks of contractors obtained by using the Point Allocation method while utilizing all the 11 PQC and $P.A_{10}$ is the ranks of contractors obtained by using the Point Allocation method while utilizing just 10 PQC. This is carried on till all the contractor ranks are compared with each other. The same procedure is repeated for the other two prequalification models as well namely the Weighted Score Method and the Analytic Hierarchy Process. The correlation between contractor ranks using 11 criteria and ranks using 10 criteria is 0.9966 for the Point Allocation Method and so on. The rest of the results are as follows:

Table 5.2: Correlation coefficient for all the three prequalification models when different number of criteria are used

No. Of Prequalification Criteria							
	11	**10**	**9**	**8**	**7**	**6**	**5**
Point Allocation Method	1	0.9966	0.9885	0.9784	0.9726	0.9538	0.9394
Weighted Score Method	1	0.9965	0.9895	0.9786	0.9727	0.9551	0.9371
Analytic Hierarchy Process	1	0.9962	0.9894	0.9803	0.9749	0.9653	0.9468

The results of all the three prequalification models are plotted to better visualize the change in the correlation coefficient for different number of prequalification criteria.

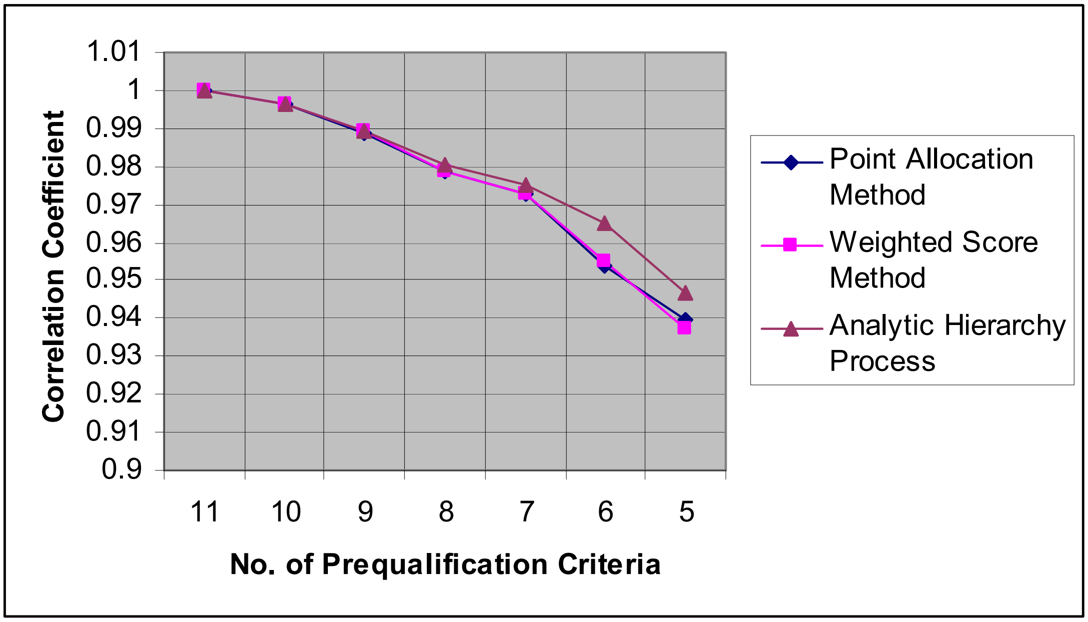


Fig. 5.23: Variation of Correlation Coefficient with respect to change in the number of prequalification criteria used for the three prequalification models.

After analyzing data from the tables and the graphs, it is evident that the correlation between the model results decreases with decreasing number of prequalification criteria. It is observed that the maximum correlation obtained is 0.9966 when the ranks of Point Allocation method are compared for 11 criteria and 10 criteria. The least correlation obtained is 0.9394 when the ranks of Point Allocation method are compared for 11 criteria and 5 criteria. The difference between these two correlations is statistically significant for significance level of 0.01. The same holds true for the rest of the results comprising of the Weighted Score Method and the Analytic Hierarchy Process.

The loss of agreement between the results of the model itself is investigated further. It is assumed that the accuracy of the prequalification model when all the

11 prequalification criteria are used is 1 while the accuracy of the model for lesser criteria is denoted by the correlation coefficient between result of using 11 criteria and the result of using lesser criteria. For example, if the accuracy of the point allocation method for 11 criteria is assumed to be 1 then the accuracy of the method for 10 criteria is the correlation between the two i.e. 0.9966 and so on. This loss in accuracy is compared against the reduction of the percentage weight of the criteria being considered. The loss of accuracy in this case is:

Accuracy Difference (A_d) = (Accuracy of model using all 11 criteria) – (Accuracy of model using 10 criteria)

$$= 1 – 0.9966 = 0.0034.$$

The corresponding reduction in the percentage weight of the prequalification criteria in this case:

Cumulative reduction of percentage weight = (Percentage weight of all 11 criteria) – (Percentage of 10 criteria)

$$= 100 - 97$$

$$= 3 \%$$

Therefore the loss of accuracy for a corresponding reduction in percentage weight of prequalification criteria used is computed as:

Loss of accuracy (L_a) = 0.0034/3 = 0.0011 for every 1 % reduction in the percentage weight of criteria being used.

Similarly the loss of accuracy (L_a) for other combinations of 11 criteria with 9 criteria, 11 criteria with 8 criteria etc can also be computed. The results for the loss of accuracy are displayed below:

Table 5.3: Loss of Accuracy using Point Allocation Method

No. of Criteria	Corresponding % reduction in weight	Loss of Accuracy(L_a)	Total Loss of Accuracy
11	0	0	0
10	3	0.0011	0.0033
9	7	0.0016	0.0112
8	11	0.0019	0.0209
7	16	0.0017	0.0272
6	22	0.0021	0.0462
5	28	0.0021	0.0588

Similar calculations for other prequalification models are as follows:

Table 5.4: Loss of Accuracy using Weighted Score Method

No. of Criteria	Corresponding % reduction in weight	Loss of Accuracy(L_a)	Total Loss of Accuracy
11	0	0	0
10	3	0.0011	0.0033
9	7	0.0015	0.0105
8	11	0.0019	0.0209
7	16	0.0017	0.0272
6	22	0.002	0.044
5	28	0.0022	0.0616

Table 5.5: Loss of Accuracy using Analytic Hierarchy Process

No. of Criteria	Corresponding % reduction in weight	Loss of Accuracy(L_a)	Total Loss of Accuracy
11	0	0	0
10	3	0.0012	0.0036
9	7	0.0015	0.0105
8	11	0.0017	0.0187
7	16	0.0015	0.024
6	22	0.0015	0.033
5	28	0.0019	0.0532

These results are plotted together to obtain the following graph:

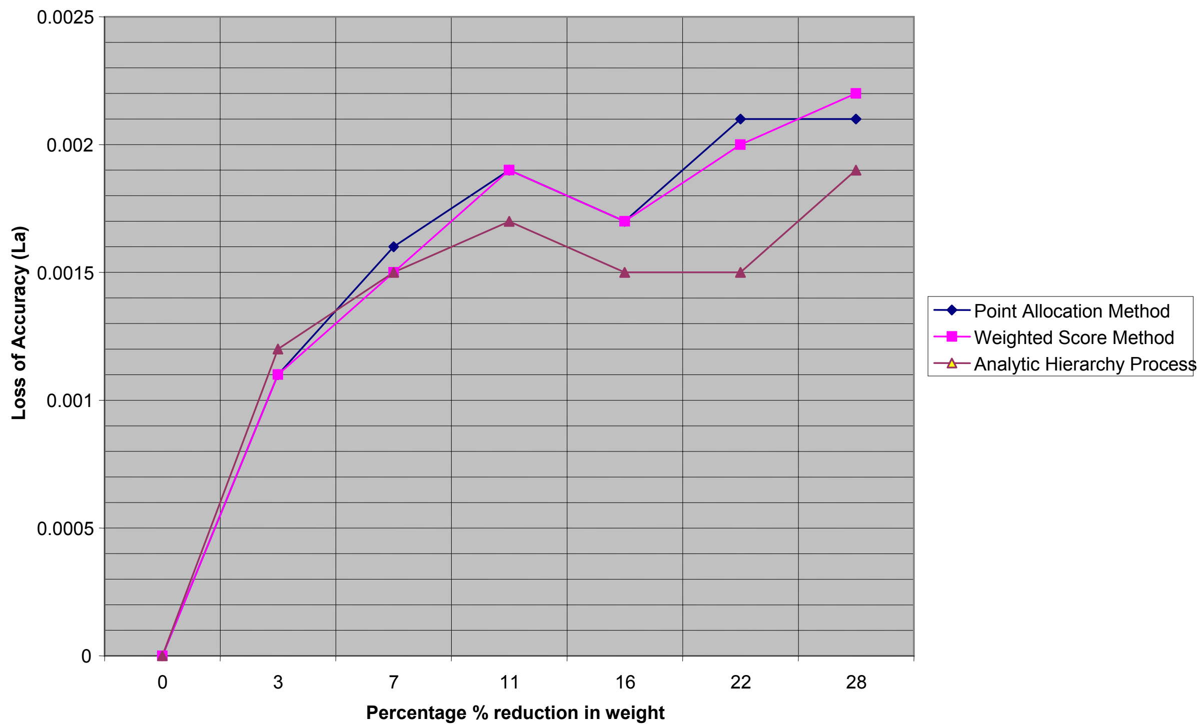


Fig. 5.24: Variation of the Loss of Accuracy (L_a) with respect to the percentage reduction in weight

It can be observed from the graph that Point Allocation method and the Weighted Score method have approximately the same Loss of Accuracy (L_a) trend while the Analytic Hierarchy Process initially follows the same trend but then the Loss of Accuracy (L_a) reduces and finally ends up much lesser than that of the Point Allocation and the Weighted Score Methods. The results of this analysis are a further reinforcement of the conclusions obtained by using the rank correlations. This exhibits that the Analytic Hierarchy Process is robust enough to furnish a better quality result for lesser criteria than the other two prequalification models. This fact can only improve the confidence of the owner/architect in the result of the prequalification process if some minor criteria were disregarded while selecting criteria for the prequalification process. It also enforces the fact that significantly more attention should be devoted to decision making for the criteria whose weights contribute more to the total.

For the second case, the results of the three models are compared among themselves while changing the number of prequalification criteria being used. Initially a fixed number of contractor profiles are generated randomly by using 50 criteria having equal weight of 2 %. This was undertaken to have a large number of data points so that any significant trend can be detected. The Point Allocation method is analyzed first using all the 50 PQC, then the number of PQC used are reduced by one for every simulation afterwards and the significance of the difference between the correlations was checked for every drop of percentage weight. For example, after the first simulation run using all the 50 PQC the next simulation run is repeated using 49 PQC with the 50th criterion being dropped. After obtaining the resulting ranks of the contractor profile set, these ranks are compared with each other to ascertain the extent of correlation between them. For example, $P.A_{50}$ is compared with $P.A_{49}$ where $P.A_{50}$ is the ranks of contractors obtained by using the Point Allocation method while utilizing all the 50 PQC and $P.A_{49}$ is the ranks of contractors obtained by using the Point Allocation method while utilizing just 49 PQC. This is carried on till all the contractor ranks are compared with each other. The same procedure is repeated for the other two prequalification models as well namely the Weighted Score Method and the Analytic Hierarchy Process. Likewise for every simulation run, one criterion is dropped and the significance of the difference between correlations is checked till this difference becomes statistically significant. It was found that the Point Allocation and the Weighted Score methods cease to perform satisfactorily when the percentage weight reduced is 18 % while the AHP does not provide satisfactory results when then percentage weight reduced is 22 %. This was observed after checking the significance of the difference between rank correlations obtained for every drop of cumulative percentage weight at a significance level of 0.01. The difference of correlations for both the point allocation and the Weighted Score method become statistically significant when 18% of the cumulative weight is dropped i.e. when 41 criteria are used while the same happens for AHP when 22 % of the cumulative criterion weight is dropped i.e. when 39 criteria are used. Hence it can be concluded from this result that AHP is more robust than the other two prequalification models as it exhibits a better result even when greater criteria percentage weight is dropped.

Table 5.6: Correlation among prequalification models for every drop of criteria percentage weight.

Models	**No. of Prequalification Criteria**														
	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35
P. A Method	0.9889	0.9782	0.9663	0.9567	0.9478	0.9363	0.926	0.9173	0.9101	0.8994	0.8913	0.8812	0.8687	0.8537	0.8474
W. S. Method	0.9889	0.9782	0.9663	0.9567	0.9478	0.9363	0.926	0.9173	0.9101	0.8994	0.8913	0.8812	0.8687	0.8537	0.8474
AHP	0.9903	0.9808	0.9697	0.9605	0.9526	0.9392	0.9329	0.9238	0.9157	0.9078	0.8971	0.8866	0.8727	0.8553	0.8482

These observations can also be plotted in the form of a graph to observe the trend of variation which is as shown below.

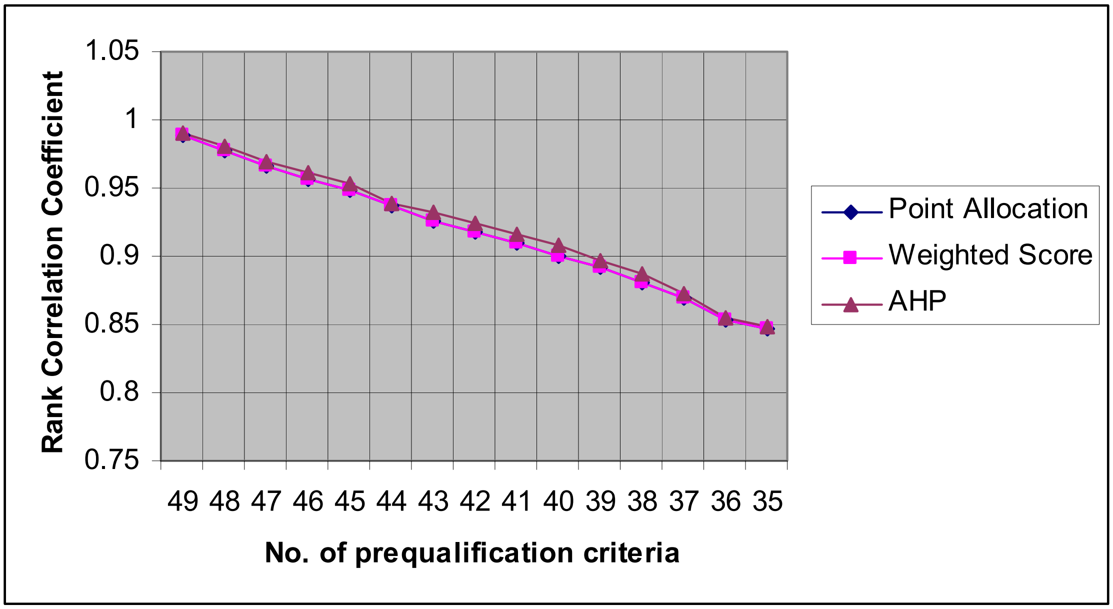


Fig. 5.25: Variation of Correlation among Prequalification models for varying number of prequalification criteria (50 criteria used).

The loss of agreement between the results of the model itself is investigated further. It is assumed that the accuracy of the prequalification model when all the 50 prequalification criteria are used is 1 while the accuracy of the model for lesser criteria is denoted by the correlation coefficient between result of using 50 criteria and the result of using lesser criteria. For example, if the accuracy of the point allocation method for 50 criteria is assumed to be 1 then the accuracy of the method for 49 criteria is the correlation between the two i.e. 0.9889 and so on. This loss in accuracy is compared against the reduction of the percentage weight of the criteria being considered. The loss of accuracy in this case is:

Accuracy Difference (A_d) = (Accuracy of model using all 50 criteria) – (Accuracy of model using X no. of criteria where X = {49, 48, 47…})

= 1 – 0.9889 = 0.0111.

The corresponding reduction in the percentage weight of the prequalification criteria in this case:

Reduction of percentage weight = (Percentage weight of all 50 criteria) – (Percentage of 49 criteria)

= 100 - 2

= 98 %

Therefore the loss of accuracy which essentially is the rate for a corresponding reduction in percentage weight of prequalification criteria used is computed as:

Loss of accuracy (L_a) = 0.0111/2 = 0.00555 for every 1 % reduction in the percentage weight of criteria being used. Similarly the loss of accuracy (L_a) for other combinations of 50 criteria with 48 criteria, 50 criteria with 47 criteria etc can also be computed. The same analysis is performed for both Weighted Score Method and the Analytic Hierarchy Process and the following observations were recorded.

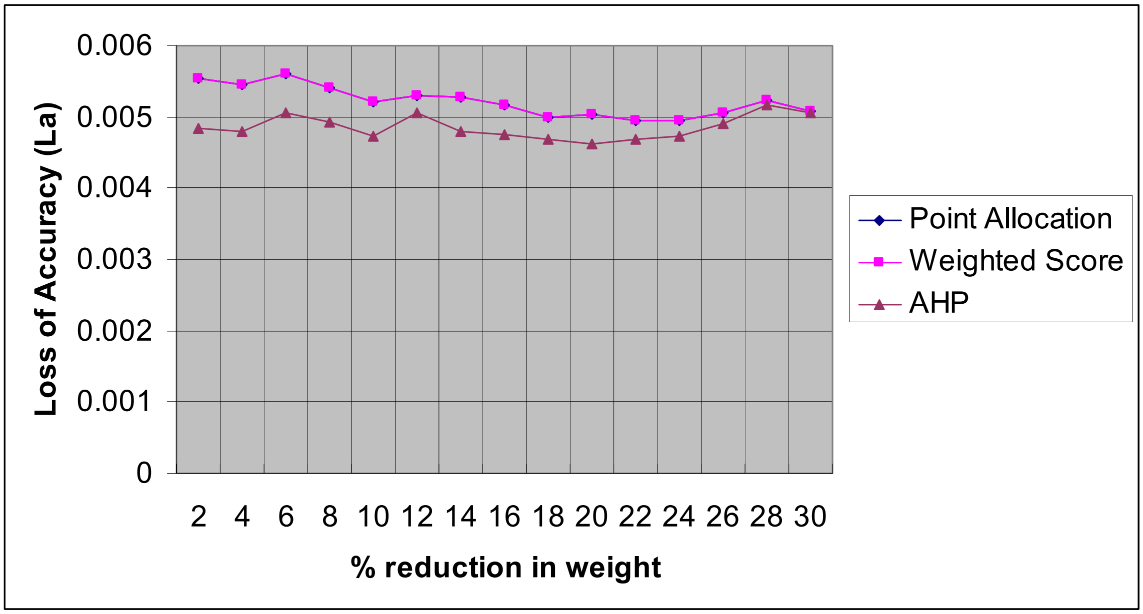


Fig. 5.26: Variation of Loss of Accuracy (L_a) with respect to change to percentage reduction in weight (50 criteria used)

Even though the significance of difference has been evaluated for every drop in the percentage weights, this test is used to obtain a better idea of how the accuracy of the results is affected when the percentage weight of criteria being used is steadily decreased. It can be observed from the graph that the Loss of Accuracy (L_a) is identical for both the Point Allocation and Weighted Score Method. This loss initially is greater than that for the AHP but later on it is observed that they converge together. It can be concluded but not with great confidence from this fact that after a certain percentage weight is dropped the ranking results among the three prequalification models tend to be similar to each other.

It can be observed that the accuracy of the prequalification models decreases when lesser criteria are considered with the corresponding Loss of Accuracy (L_a) being more than the corresponding Loss of Accuracy (L_a) for the similar analysis performed using Al-Gobali's weighting. There is a stark difference between the two analyses i.e. the one using Al-Gobali's weights and the other using equal weights for all the prequalification criteria. In the Al-Gobali weights analysis the loss of accuracy across all the models is minimal but this isn't the case for the equal weights analysis. The Analytic Hierarchy Process exhibits better robustness that the other two prequalification models when Al-Gobali's weights are used but when equal weights are used, its robustness decreases. As a result of these analyses, it can be concluded that AHP is the better of the three models under consideration as its results are satisfactory to a greater extent when compared to the other two models.

It can be also be concluded from these observations that if a prequalification scenario exists in which all the criteria are assigned roughly equal weights then equal attention should be devoted to decision making for all of them. In the possibility that a few criteria are ignored or not carefully evaluated, the reliability of the result of the Analytic Hierarchy Process is clearly suspect. The same holds good for the other two prequalification models but in their case their robustness permits them to still be more reliable than the Analytic Hierarchy Process. It can concluded after the comparison exercise that in case a prequalification criterion is being used which is qualitative by nature or if evaluating contractors for that criterion is difficult and that criteria accounts for just a minor percentage of the total weight, then it can safely ignored and more attention can be devoted to those prequalification criteria which account for the major portion of the total percentage weight and also easy to apply as adjudicating contractors is concerned.

5.2.8 RESULTS OF THE QUANTITATIVE ANALYSIS

The following are the features that were observed from the quantitative analysis of the three prequalification methods.

- Points observed from the graphs regarding the rank correlation coefficient are:
    - The correlation coefficient between all three prequalification models is always in the range of 0.9 to 1.0 which denotes a very strong correlation.
    - The correlation coefficient between the Point Allocation and the Weighted Score Method is the highest with the coefficient value being almost equal to 1 thus exhibiting the highest degree of correlation between the two.
    - The correlation between the Point Allocation and the AHP is also very strong but it is much lesser than the correlation value of the earlier pair. The difference between their correlations was tested and was found to be statistically significant for a significance level of 0.01.
    - The correlation coefficient between the Weighted Score and the AHP is the lowest among all the three comparisons performed.
    - An interesting point to note is that even though the two correlations between Point Allocation and AHP and Weighted Score and AHP have different magnitudes, they exhibit identical variation with respect to the batch size i.e. the two correlation lines have the same ups and downs at identical batch sizes. The difference between these

correlations was tested and found to be statistically insignificant for a significance level of 0.01.

- It was analyzed and observed that when equal prequalification weights are assigned to all criteria, the AHP tends to be more robust than the other two prequalification models.

5.2.9 COMPARISON OF POINT ALLOCATION METHOD AND WEIGHTED SCORE METHOD

The very strong degree of correlation between Point Allocation and Weighted Score Methods deems it necessary that they be further scrutinized in order to clearly identify the reasons behind this the high degree of agreement between the two.

As has already been explained, the Point Allocation method consists of simply assigning points out of a predefined range with respect to every criterion. Then these points are added together to get a score for that particular contractor. For example:

Assuming two criteria are used for the prequalification process with the points of the first criterion having a value of 0, 1 and 2 (meaning that a contractor can score between a minimum of 0 points to a maximum of 2 points for this criterion) while those for the second criterion having a value of 0, 1, 2 and 3, then the point allocation method works in the following manner for a sample of 3 contractors.

Table 5.7: Sample calculation of Point Allocation Method

Contractor	Criterion # 1	Criterion # 2	Total
ABC	0	3	3
DEF	2	0	2
XYZ	2	3	5

Thus the total score could be mathematically represented as:

$$Z_p = \sum_{i=1}^{Y} X_i$$

Where Z_p = Total score;

Y = No. of criteria;

X_i = Points scored by the contractor for the i^{th} criterion.

The Weighted Score method consists of assigning points on a uniform scale (which is generally 10), then multiplying the assigned points with the respective weights of each criterion. These subtotals are then added up, to arrive at a total score for that particular contractor.

Using the above example further the respective weights for the first and second criterion when translated objectively from the Point Allocation method to the Weighted Score method in order to maintain the same level of importance that a particular criterion possesses in both the methods are 2 and 3. The contractors being analyzed for prequalification are assigned points on a scale of 0 to 10. These points are also assigned objectively keeping in view the points that a particular contractor was assigned in the earlier method. For example if a contractor was assigned 2 points from a maximum of 2 then in this method it is assigned 10 points from a maximum of 10 and so on. The Weighted Score method works in the following manner:

Table 5.8: Sample calculation of Weighted Score Method

Contractor	Criterion # 1 Weight (2)	Subtotal	Criterion # 2 Weight (3)	Subtotal	Total
ABC	0	0	10	30	30
DEF	10	20	0	0	20
XYZ	10	20	10	30	50

Thus the total score could be mathematically expressed as:

$$Z_w = \sum_{i=1}^{Y} W_i X_i$$

Where Z_w = Total Score;

Y = No. of criteria;

W_i = Weight of the i^{th} criteria;

X_i = Points scored by the contractor for the i^{th} criteria.

It is observed from the above example that notwithstanding the difference of scores between the two methods for the same contractor, the ranking of the contractor does not change. Contractor XYZ scores a total of 5 in the Point Allocation method and a total of 50 in the Weighted Score method but this does not change its rank since its scores are the maximum among the contractors analyzed for both the methods. Not only that, it is also observed that Z_w:Z_p is in the ratio of 1:10 which can be generalized to a ratio of 1:e where e is the maximum out of which contractors are assigned points in the Weighted Score Method.

This equivalence of scores between the two methods was mainly due to the fact that in Point Allocation method, points scored by the contractor were from a maximum of S_i for the i^{th} criterion while in the Weighted Score method, the weights of the criterion were S_i for the i^{th} criterion and the points scored by the contractor were assigned from a uniform maximum limit of 10 for all the criteria. The points scored by the contractor in Point Allocation on the scale of 0 to S_i were accurately translated onto a scale of 0 to 10 and then assigned to the contractor for each criterion in the Weighted Score method. This is clearly evident in the case of contractor ABC. Contractor ABC scores 0 and 3 for the first and second criterion respectively during the Point Allocation analysis but for the Weighted Score method, these same points of 0 and 3 were translated onto a scale of 0 to with 0 still being 0 but 3 being translated into 10. This is because contractor ABC scored 3 out of a maximum of 3 (i.e. 100 %) for the second criterion which when converted onto a scale of 10 becomes 10 itself since 100% of 10 is again 10.

5.3 QUALITATIVE ANALYSIS

The simulation of the three prequalification models would but naturally generate results in the form of numbers. Hence the three models need to be compared using qualitative criteria before any reasonable conclusions can be drawn from the analysis.

5.3.1 QUALITATIVE COMPARISON

The qualitative points for comparison can be laid out as below:

- Mathematical involvment:
    1. Point Allocation Model: This model is the simplest of the three and involves assigning points for each PQC and then adding them up to arrive at a score for the respective contractor profile.
    2. Weighted Score Model: This model involves assigning points then multiplying them with respective weight of the PQC and then adding the subtotals to acquire a score for a particular contractor profile. Thus making it slightly more mathematically involved than the previous model.
    3. Analytic Hierarchy Process Model: It is definitely the most complicated of the three models under consideration involving assigning preferences and eigenvector manipulation.
- Training required:
    1. P.A Model: Being the simplest of the three models, it naturally requires the least amount of time for getting acquainted with its working.
    2. W.S Model: The underlying concepts behind its working are simple enough therefore the time required to grasp its working methodology is almost the same as that of the earlier model.
    3. A.H.P Model: It is no secret that AHP was developed by Saaty and the amount of literature available explaining its working methodology is

pretty pervasive to say the least. This aspect draws attention to the fact that the AHP methodology is not easily understandable by everyone. Thus underlining the need for more training time to implement AHP properly.

- Hardware and software requirements:
  1. P.A Model: A simple calculator would suffice for computations and as such no software is needed for implementing this model.
  2. W.S Model: The same hardware requirements as that of the earlier model would be sufficient while no software is needed nor any available commercially for implementation.
  3. A.H.P Model: A.H.P Model would also be sufficed by the hardware requirements of the earlier models while soft wares such as Expert Choice, HIPRE and Criterium have been developed to ease the implementation of AHP.
- Check for judgmental errors:
  1. P.A Model: No such test exists.
  2. W.S Model: No such test exists.
  3. A.H.P Model: Consistency Index is computed to verify the consistency of the user's judgment.
- Scaling of the model:
  1. P.A Model: Interval based and depends on decision maker's subjective judgment.

2. W.S Model: Interval based while weights are computed based on their pair wise comparison for each PQC. Depends as well on decision maker's subjective judgment.
3. A.H.P Model: Priorities based.

- Eliciting preferences:
  1. P.A Model: Cognitive; that is the allocation of points to a contractor for a particular criterion is based on empirical judgment without considering the competence of other contractors.
  2. W.S Model: Cognitive.
  3. A.H.P Model: Pair wise comparison.
- Structure of the model:
  1. P.A Model: Matrix form
  2. W.S Model: Matrix form.
  3. A.H.P Model: Hierarchical form.

Table 5.9: Qualitative Comparison of the three prequalification models.

S.No	Criteria of comparison	P.A Model	W.S Model	A.H.P Model
1	Mathematical Involvment	Simplest	Moderately simple	Most complex of the three
2	Training required	Least	Least	Most training required
3	Hardware & Software requirements	Basic	Basic	Basic and existence of commercial software.
4	Check for judgmental errors	None	None	Consistency Index available
5	Scaling of model	Interval based	Interval based	Priorities based
6	Eliciting preferences	Cognitive	Cognitive	Pair wise comparison
7	Structure of model	Matrix form	Matrix form	Hierarchical form

5.3.2 DISCUSSION OF THE QUALITATIVE COMPARISON OF THE PREQUALIFICATION MODELS

In the earlier section, the three prequalification models were compared for a set of qualitative criteria. These criteria are important for the selection of a suitable prequalification model. An owner or his representative has to keep these factors in mind while making the decision.

The mathematical complexity of the model and the training required to understand it well enough to implement it are two of the factors that are tied together.

The more mathematically complex a model is, the more training needs to be given to the evaluator so that the evaluator can understand it well enough to use it without any difficulty. The owner/architect needs to decide whether the nature of the prequalification system is such that can be handled well by a mathematically complex model and consequently be willing to invest a corresponding amount of time for its training. If the Point Allocation model is used for a complex prequalification decision then it will only turn out to be and increase the workload of the evaluator while on the other hand if an evolved model like AHP is used for a simple prequalification process then it would be a waste of resources since for the same process a much simpler Point Allocation model can be used.

The hardware and software requirements for applying a particular prequalification model vary from each other thus a brief knowledge of them is essential for selecting a prequalification model. The Point Allocation and the Weighted Score models are very simple in their working methodologies hence they require neither any sophisticated hardware nor any software to use. This isn't the case with AHP as its evolved methodology necessitates the use of software for analyzing data. This aspect has to be considered by the owner/architect while selecting a model because if a complex prequalification model is selected then its respective requirements should also be taken care of. If the AHP is selected without proper consideration of its requirements then it will only lead to delays and inefficiency in the prequalification process.

The effect of inconsistencies in evaluator judgment could be highly detrimental to the success of a prequalification model. If the evaluator is inconsistent while making judgments then it would surely defeat the whole purpose of prequalification since a deserving contractor could be discarded while an undeserving contractor could be invited for bidding. In an unbiased evaluator environment, the reasons behind judgmental inconsistencies are a large number of prequalification criteria, a large number of contractors who have applied for prequalification, poor operational definition of prequalification criteria. These reasons acting alone or as a combination make the necessary judgmental consistency difficult. For a prequalification process which is simple and will involve a manageable number of contractors, the test for judgmental inconsistency may not be of much use but in case of a large number of criteria or contractors, this feature ensures that the evaluator is being consistent enough with his decisions. AHP has a test for checking judgmental consistency while the other two prequalification models do not thus the AHP is more suited to being used for a complex prequalification process while the other two models are more suited in a case where a fewer number of criteria are considered. An exception to this would be a case where a fewer number of prequalification criteria are used but the project is of such importance that the consistency of the decision making has to be ensured. In such a situation AHP would be selected because it possesses a test for judgmental consistency. The situation in which only a few number of contractors apply for prequalification is not realistic because prequalification is used when the number of contractors applying for it is large. If it is expected right from the initial stages that only a few contractors are going to apply then the whole exercise of prequalification can be discarded and the necessary evaluation can be made during the bidding process. Therefore AHP has a definite edge over the other prequalification models with respect to the test for inconsistencies in judgment.

Scaling and structure of the model are important issues which need to be addressed by the owner/architect before a prequalification model is decided upon. Determining the scaling for a particular model is a function of the complexity of the prequalification criteria that are relevant to the project on hand. If the prequalification criteria are numerous and complex then it will be difficult to decide on an interval based scaling since a rational division needs to be made about the point's interval. On the other hand if a fewer number of prequalification criteria (say 3 or 4) are used then this kind of scaling would be easy to use. A mismatch of the prequalification criteria complexity and their scaling would also increase the chances of making judgmental inconsistencies. For a project which involves a large number of prequalification criteria the AHP is easier to use as it uses pair wise comparison of criteria to determine their priorities which in turn makes the whole process of determining the importance of each criteria much simpler. The same is true for the structure of the model. The matrix structure of the model is one in which each contractor is evaluated one after the other giving it the form of a matrix with number of criteria denoting the columns and the number of contractors denoting the rows of the matrix. The hierarchical form is that in which each contractor is evaluated against the other contractors for every prequalification criteria and then evaluated against all other contractors across all criteria at the next level. The simpler prequalification models possess a matrix structure which is suitable for use in case of few prequalification criteria because using a matrix structure is easy when the criteria are less. The AHP uses a hierarchical structure that makes it more suited for a project with a greater number of criteria because then careful attention can be devoted to all contractors for every particular criteria.

Deciding how good or bad a contractor for a particular criterion is essentially the most difficult decision to be made during a prequalification exercise. After scouring through the relevant documents provided by the contractor, a decision needs to be made how good that contractor is when compared to other contractors for every criterion. The type of documents required for every prequalification model are the same, the time taken to elicit them from the contractors is also the same, the only difference being the ease with which decisions can be made in a model after carefully reviewing the documents. In the Point Allocation and the Weighted Score models, the decision of awarding points to a contractor are based on empirical judgment i.e. the decision of awarding x points to contractor A for a particular criterion is not based on how good contractor A is when compared to the other contractors. For AHP, the decision of how good a contractor is for a particular criterion is based on pair wise comparison of contractors for that criterion i.e. the decision of assigning a priority of x to contractor A for a particular criterion is based on comparing it pair wise with other contractors. The effect of this feature comes into play when the number of contractors applying for prequalification is large enough to make a decision regarding how good contractors really are extremely difficult.

After comparing the three prequalification models for these qualitative criteria, it can be concluded the three prequalification models essentially lead to the same results. The similarities between Point Allocation and the Weighted Score are so strong that it follows natural logic to state that they are essentially the same with the latter model being only slightly evolved from the former prequalification model. Further more the Weighted Score incorporates the use of pair wise comparison to arrive at the weights for prequalification criteria. This pair wise comparison is a major feature of the AHP so it can be concluded that the Weighted Score is a simplified version of the AHP. The only conclusion that can be drawn from all this is that the selection of a prequalification model for a particular project is more or less like the idiom “Horses for courses”. There is no such thing like an ideal prequalification model for all types of projects. The Point Allocation or Weighted Score methods are suitable for simple prequalification exercises involving a fewer number of prequalification criteria. The selection of an evolved model like AHP is suitable for a prequalification process which involves either a large number or complicated criteria since the expenses related to using AHP would then be justified. The conclusions derived from the qualitative analysis of the three prequalification models are applicable for the other models, which the three models studied in this research are representative of.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In this chapter, a summary of the thesis is first presented followed by conclusions of the research and recommendations for future studies.

6.2 SUMMARY

The main objective of this research was to determine the efficacy of the contractor prequalification models or in terms of the quality of the prequalification result of various models. This determination of the efficacy was performed in an environment suited to the local construction industry.

Initially the research identified various prequalification models and as expected, a large variation in the methodologies of the models was observed. Further, these different prequalification models identified were segregated into two groups namely the "Practical" and the "Theoretical" groups. Models comprising of the former group were further investigated to determine their working methodologies since the research was meant to help the informed owner in his choice for the ideal prequalification model based on his project complexities.

After an analysis of their methodologies, only those models were selected for comparison analysis, which were representative of the different groups of working methodologies as well as non rigid in their nature of incorporating any number or nature of prequalification criteria. The selected prequalification models selected were:

- Point Allocation
- Weighted Score
- Analytic Hierarchy Process

Subsequent to their selection, a thorough literature review was undertaken to identify as many prequalification criteria (PQC) as possible in order to illustrate the various PQC being utilized in the models. To make the research more suited to local environment, the prequalification criteria identified by Al-Gobali (1994) for the Saudi Arabian construction industry were utilized.

Then a through quantitative and qualitative comparative analysis was undertaken. For comparing the prequalification models quantitatively, simulation analysis was carried out using the programming language MATLAB. The qualitative comparison of the models was done by considering various criteria such as:

- Mathematical complexity of the model
- Amount of training required
- Check for judgmental errors etc.

6.3 CONCLUSIONS

The following conclusions can be drawn from the results observed in the quantitative and qualitative aspects of comparison.

1. The results of all three models exhibit very strong correlation. The highest correlation is observed in the comparison of the Point Allocation and the

Weighted Score Models and it was also observed qualitatively that there is not much of a difference among the two. Thus conclusion can be drawn that the Point Allocation Method and the Weighted Score Model can be substituted for each other with a very minor loss of a quality result.

2. The correlation between the results of Point Allocation Model and the results of AHP is very strong with a correlation coefficient value generally above 0.93. Superficially it would mean that both these models have more or less the same output. But on a deeper examination, it is revealed that this agreement on the prequalification result is not because of any similar methodology between the two but is because of being rational while making contractor evaluation decisions.
3. Similarly the correlation between Weighted Score Model and AHP is very strong with a lowest correlation coefficient value of 0.93. The same thing could be said about these two models as for the earlier pair but again a deeper examination reveals the agreement on the prequalification result is not because of any similar methodology between the two but rather it is the matter of relying on objectivity instead of subjectivity for making decisions. This conclusion is along the same line as that of the earlier conclusion.
4. Even though the correlation among all the three prequalification models is very strong, the qualitative differences between the three are apparent. The Point Allocation and the Weighted Score Method are very similar to each other while the AHP is very different from them in terms of structure and methodology. A major difference between Point Allocation and Weighted

Score Model on one hand with the AHP on the other is the check for judgmental inconsistencies which the AHP possesses thus scoring a point in its favor. Even though effects of inconsistency have not been investigated in any earlier research, it is natural to assume a certain amount of human error in making judgments. The presence of a check for consistency in such a situation is more of a fail-safe arrangement rather than a question mark over the competency of the judgment maker.

5. The quantitative comparison of the prequalification models has revealed a very strong correlation among the three, but it also has been determined that this high level of agreement exists because of being rational while making decisions during the analysis of the models. This rational thinking which produces such agreement can only be achieved by a machine or a programming language but for a human mind to achieve this level of objectivity would require a tremendous amount of mental effort. Hence it would be better to be on the safe side and opt for a higher level prequalification model when the project characteristics are too complex to be handled by a simple prequalification model like Point Allocation method. Usually prequalification of contractors is performed for projects that are of strategic and/or economic importance and use a large number of prequalification criteria to evaluate the effect of every contractor characteristic on the result. Thus these projects involve large capital and good quality of workmanship. In a situation such as this, a prudent owner would prefer spending a little extra money by selecting a higher level prequalification

model that will make the prequalification process easier and be more confident about the prequalification result rather than save that little extra money by selecting a lower level prequalification model.

6. Selection of the ideal prequalification model for a particular project would depend largely on the owner and project characteristics keeping the other factors common. For example, using a Point Allocation model for prequalifying contractors for a simple project would be enough because of uncomplicated nature of the prequalification exercise, but the same would not be acceptable for a high risk private project which is complicated in structure. In the latter case, owners would naturally prefer being safe rather than sorry by opting for a prequalification model which even though would consume more resources but would assure a quality result and be easier to use for such a situation.
7. The analyses of the prequalification models for their robustness when criterion of equal weights are used has revealed that the Analytic Hierarchy Process is the more robust of the all three models that were studied.
8. The agreement of the models on the results of the prequalification would remain the same irrespective of the number of criteria being used for prequalification as has been observed earlier. But this lesser number of prequalification criteria should be a true reflection of the owner/architects concerns about the issues that are thought to be essential to ensuring the successful completion of the project.

9. Effort and attention devoted to making a decision should be proportional to the importance of a criterion to the owner or his representative. If the prequalification exercise incorporates criteria that are difficult to evaluate contractors on and are of minor importance to the owner then these criteria can be ignored and more attention can be devoted to other important criteria. The subsequent loss of quality result is minimal as has been observed earlier.
10. The three prequalification models studies in this research have turned out to be the same with each being evolved from the other. On closer inspection it was observed that the Point Allocation method and the Weighted Score method are almost the same with very minor differences. While on the other hand it has been observed that the Weighted Score method is a watered down version of the AHP. Since all the three are essentially evolved versions of each other, the only difference between them is the ease with which they can be used for a particular situation.

6.4 RECOMMENDATIONS FOR FUTURE RESEARCH

Based on the above conclusions, a few recommendations for future research can also be suggested:

1. The decision making for AHP is based on deciding preferences between two alternatives. The effect of using different preference levels than those used in this research for the prequalification criteria can be investigated.

2. It would be useful to conduct a comparative study of the two groups of prequalification models namely the Practical and the Theoretical by comparing two or more representative models from each group.
3. Identifying organization and project characteristics should play a major role in the selection of a prequalification model because a simple project using a bare minimum of criteria could easily be handled by the Point Allocation method while a project which is complex in nature and of strategic importance would require the use of a prequalification model like AHP.
4. A structured guide for making decisions when essentially qualitative prequalification criteria are involved would ease the decision making process much simpler and meaningful.

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APPENDICES

APPENDIX "A"

MATLAB PROGRAMS

APPENDIX “A-1”

WHOLE PROGRAM

```
%Generating contractor profiles and analyzing models
clear all
t_of_pa=[];
t_of_we=[];
t_of_ahp=[];
clc
%dc1=work experience
dc1=[1:30];
%dc2=Financial
dc2=[1:6];
%dc3=QA/QC Plan
dc3=[1:6];
%dc4=Management and corporate
dc4=[1:15];
%dc5=Capacity of contractor
dc5=[1:10];
%dc6=Cost,planning and scheduling
dc6=[1:5];
%dc7=Equipment resources
dc7=[1:8];
%dc8=Safety and accident prevention
dc8=[1:4];
%dc9=References and claim
dc9=[1:9];
%dc10=Purchasing
dc10=[1:4];
%dc11=Location of head quarters
dc11=[1:3];
%m=no. of criteria
m=11;
%specifying the number of chunks to be analyzed
n=10;
total_n=[10:2:20];
for tp=1:length(total_n)
    n=total_n(tp)
    x=0;
    terminate = 0;
    max_no_profile=n*10
    max_size(tp)=max_no_profile;
   tmp_stop=1;
   var_rs=1;
   tmp=1;
for tmp = 1:n
prf(tmp,:)=[RANDINT(1,1,[1,30])      RANDINT(1,1,[1,6])      RANDINT(1,1,[1,6])
RANDINT(1,1,[1,15])       RANDINT(1,1,[1,10])       RANDINT(1,1,[1,5])
```

```
RANDINT(1,1,[1,8])  RANDINT(1,1,[1,4])  RANDINT(1,1,[1,9])  RANDINT(1,1,[1,4])
RANDINT(1,1,[1,3])];
                                    if tmp == n
                                       [p_a_rank,time_pa]=point_allocation(prf);
                                       t_of_pa=[t_of_pa time_pa];
                                       [w_e_rank,time_we]=weight_eval(prf,n,m);
                                       t_of_we=[t_of_we time_we];
                                       [ahp_rank,time_ahp]=ahp(prf,n);
                                       t_of_ahp=[t_of_ahp time_ahp];
                                       [r_s1]=spearman_coeff1(p_a_rank,w_e_rank,n);
                                       r_s=r_s1;
                                       [hypo]=hypothesis_testing(r_s,n);
                                       [r_s2]=spearman_coeff2(ahp_rank,w_e_rank,n);
                                       r_s=r_s2;
                                       [hypo]=hypothesis_testing(r_s,n);
                                       [r_s3]=spearman_coeff3(ahp_rank,p_a_rank,n);
                                       r_s=r_s3;
                                       [hypo]=hypothesis_testing(r_s,n);
                                       clear prf;
%                                         now we save rs in another variable and set back tmp
                                       rs1(var_rs)=r_s1;
                                       rs2(var_rs)=r_s2;
                                       rs3(var_rs)=r_s3;
                                       tmp=0;
                                       var_rs=var_rs+1;
                                       x=x+1
                                       display('Yo man Yo')
                                    end;
                                 end;
%                                      now we check condition to make a temp to stop
                                    if tmp_stop==max_no_profile
                                        terminate = 1;
                                        display('we stoped after analysing')
                                        display(max_no_profile)
                                       break;
                                    end;
%                                       here the required variables are incremented
                                    tmp=tmp+1;
                                    tmp_stop=tmp_stop+1;
%                                  this is end for the inner most 'for' loop where all functions are
present
    end;
  t_of_pa;
   t_of_we;
   t_of_ahp;
   avg_rs1=mean(rs1);
```

```
   avg_rs2=mean(rs2);
   avg_rs3=mean(rs3);
    disp(sprintf('The number of batches analyzed is %s.' ,x))
   disp(sprintf('The average spearmans coefficient between point allocation method and Weighted Score method is %s.' ,avg_rs1))
   disp(sprintf('The average spearmans coefficient between analytic hierachy process and Weighted Score method is %s.' ,avg_rs2))
   disp(sprintf('The average spearmans coefficient between point allocation method and analytic hierachy processis %s.' ,avg_rs3))
   avg_tpa = mean(t_of_pa);
   avg_twe = mean(t_of_we);
   avg_tahp = mean(t_of_ahp);
   disp(sprintf('The average time taken by point allocation model is %s seconds.' ,avg_tpa))
   disp(sprintf('The average time taken by weighed score model is %s seconds.' ,avg_twe))
   disp(sprintf('The average time taken by analytic hierarchy process is %s seconds.' ,avg_tahp))
   average_rs1(tp)=avg_rs1;
   average_rs2(tp)=avg_rs2;
   average_rs3(tp)=avg_rs3;
   average_tpa(tp)=avg_tpa;
   average_twe(tp)=avg_twe;
   average_tahp(tp)=avg_tahp;
end
plot (total_n,average_rs1,'b+-');
hold on
grid
plot (total_n,average_rs2,'rx-');
plot (total_n,average_rs3,'m*-');
xlabel ('Batch Size (n)');
ylabel ('Average Correlation Coefficient');
legend ('P.A Vs. W.S','W.S Vs. A.H.P','A.H.P Vs. P.A');
title ('Comparison between Batch Size & Average Correlation Coefficient');
figure
plot (total_n,average_tpa,'b+-');
hold on
grid
plot (total_n,average_twe,'rx-');
plot (total_n,average_tahp,'m*-');
xlabel ('Batch Size (n)');
ylabel ('Average Time Taken for Exection of Model in Seconds (t)');
legend ('P.A','W.S','A.H.P');
title ('Comparison between Batch Size & Time Taken for Execution');
figure
plot (max_size,average_rs1,'b+-');
```

```
xlabel ('Maximum No. of Profiles Analyzed');
ylabel ('Average Correlation Coefficient between P.A & W.S');
title ('Comparison between Maximum No. of Profiles Analyzed & Average Correlation Coefficient between P.A & W.S');
 grid
 figure
 plot (max_size,average_rs2,'rx-');
 xlabel ('Maximum No. of Profiles Analyzed');
 ylabel ('Average Correlation Coefficient between W.S & A.H.P');
 title ('Comparison between Maximum No. of Profiles Analyzed and Average Correlation Coefficient between W.S & A.H.P');
 grid
 figure
 plot (max_size,average_rs3,'m*-');
 xlabel ('Maximum No. of Profiles Analyzed');
 ylabel ('Average Correlation Coefficient between P.A & A.H.P');
 title ('Comparison between Maximum No. of Profiles Analyzed & Average Correlation Coefficient between P.A & A.H.P');
grid
figure
plot (total_n,average_tpa,'b+-');
xlabel ('Batch Size (n)');
ylabel ('Average Time Taken for Exection of P.A Model in Seconds (t)');
title ('Comparison between Batch Size & Average Time Taken for Execution of P.A Model');
grid
figure
plot (total_n,average_twe,'rx-');
xlabel ('Batch Size (n)');
ylabel ('Average Time Taken for Exection of W.E Model in Seconds (t)');
title ('Comparison between Batch Size and Average Time Taken for Execution of W.S Model');
grid
figure
plot (total_n,average_tahp,'m*-');
xlabel ('Batch Size (n)');
ylabel ('Average Time Taken for Exection of A.H.P Model in Seconds (t)');
title ('Comparison between Batch Size & Average Time Taken for Exection of A.H.P Model');
grid
```

APPENDIX “A-2”

POINT ALLOCATION FUNCTION

```
function [p_a_rank,time_pa]=point_allocation(prf);
%Point Allocation Model
global t_of_pa;
tic;
p_a_score=sum(prf')';
a=p_a_score';
b=sort(-a');
for i = 1:length(a)
   z=find( b == -a(i));
   if length(z)>1
      z=mean(z);
   end;
   p_a_rank(i,1)=z;
end;
time_pa=toc;
t_of_pa=[t_of_pa time_pa];
```

APPENDIX “A-3”

WEIGHTED SCORE FUNCTION

```
function [w_e_rank,time_we]=weight_eval(prf,n,m);
%Weighted Score Model
% global t_of_we;
tic
weight=[30 6 6 15 10 5 8 4 9 4 3];
conv=[1/3 5/3 5/3 2/3 1 2 5/4 5/2 10/9 5/2 10/3];
for i=1:m
   prf_1(:,i)=prf(:,i)*conv(:,i);
end
prf1=ceil(prf_1);
for i=1:n
   prod(i,:)=weight.*prf1(i,:);
end
w_e_score=sum(prod')';
a=w_e_score';
b=sort(-a');
for i = 1:length(a)
   z=find( b == -a(i));
if length(z)>1
   z=mean(z);
end;
w_e_rank(i,1)=z;
end;
time_we=toc;
```

APPENDIX “A-4”

AHP FUNCTION

```
function [ahp_rank,time_ahp]=ahp(prf,n);
%analytic hierarchy process
tic;
weight=[0.3 0.06 0.06 0.15 0.1 0.05 0.08 0.04 0.09 0.04 0.03];
rw_dc1=[1 2 2 2 2 3 3 3 3 4 4 4 4 5 5 5 5 6 6 6 6 7 7 7 7 8 8 8 8 9];
rw_dc2=[1 3 4 6 7 9];
rw_dc3=[1 3 4 6 7 9];
rw_dc4=[1 2 2 3 3 4 5 5 6 6 7 7 8 8 9];
rw_dc5=[1 2 3 4 5 5 6 7 8 9];
rw_dc6=[1 3 5 7 9];
rw_dc7=[1 3 4 5 6 7 8 9];
rw_dc8=[1 3 5 9];
rw_dc9=[1 2 3 4 5 6 7 8 9];
rw_dc10=[1 3 5 9];
rw_dc11=[1 5 9];
%comparison and priority matrix for decision criteria 1
rw=rw_dc1;m=1;
prit_mat_dc1=prioritymat(prf,rw,n,m);
rw=rw_dc2;m=2;
prit_mat_dc2=prioritymat(prf,rw,n,m);
rw=rw_dc3;m=3;
prit_mat_dc3=prioritymat(prf,rw,n,m);
rw=rw_dc4;m=4;
prit_mat_dc4=prioritymat(prf,rw,n,m);
rw=rw_dc5;m=5;
prit_mat_dc5=prioritymat(prf,rw,n,m);
rw=rw_dc6;m=6;
prit_mat_dc6=prioritymat(prf,rw,n,m);
rw=rw_dc7;m=7;
prit_mat_dc7=prioritymat(prf,rw,n,m);
rw=rw_dc8;m=8;
prit_mat_dc8=prioritymat(prf,rw,n,m);
rw=rw_dc9;m=9;
prit_mat_dc9=prioritymat(prf,rw,n,m);
rw=rw_dc10;m=10;
prit_mat_dc10=prioritymat(prf,rw,n,m);
rw=rw_dc11;m=11;
prit_mat_dc11=prioritymat(prf,rw,n,m);
for i=1:n

ahp_score(i,1)=prit_mat_dc1(i)*weight(1)+prit_mat_dc2(i)*weight(2)+prit_mat_dc3(i)*
weight(3)+prit_mat_dc4(i)*weight(4)+prit_mat_dc5(i)*weight(5)+prit_mat_dc6(i)*weig
ht(6)+prit_mat_dc7(i)*weight(7)+prit_mat_dc8(i)*weight(8)+prit_mat_dc9(i)*weight(9)
+prit_mat_dc10(i)*weight(10)+prit_mat_dc11(i)*weight(11);
end
a=ahp_score';
```

```
b=sort(-a');
for i = 1:length(a)
z=find( b == -a(i));
if length(z)>1
   z=mean(z);
end;
ahp_rank(i,1)=z;
end;
time_ahp=toc;

function [prit_mat]=prioritymat(prf,rw,n,m)
prf_tmp=prf(:,m);%prf is x by 11 matrix
comp_mat_dc=[];
for i=1:3
   for j=1:3

      temp_mat(j)=prf_tmp(i)-prf_tmp(j);
      if temp_mat(j)>= 0
         temp_mat(j)=rw(temp_mat(j)+1);
      else
         temp_mat(j)=1/rw(abs(temp_mat(j))+1);
      end;
   end;
   comp_mat_dc=[comp_mat_dc; temp_mat];
end;
comp_mata_dc=sum(comp_mat_dc);
for j=1:n
   for i=1:n
      comp_matb_dc(i,j)=comp_mat_dc(i,j)/comp_mata_dc(:,j);
   end
end
prit_mat=mean(comp_matb_dc,2);
```

APPENDIX "A-5"

CORRELATION FUNCTION

```
function [r_s,time_rs]=spearman_coeff1(p_a_rank,w_e_rank,n);
%Calculating spearman's coefficient
for i=1:n
   diff(i,1)=p_a_rank(i,1)-w_e_rank(i,1);
   d(i,1)=power(diff(i,1),2);
end;
rows=sum(d);
r_s=abs(1-6*rows/(n*(n*n-1)));
```

APPENDIX “B”

RANK CORRELATION COEFFICIENT

Spearman’s rank correlation coefficient is defined as follows for a set of paired data, (x_i,y_i), i = 1, 2, 3, …n, that are ranked separately so that for each data set, the highest value has rank 1 and rank n is that of the lowest value:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n\left(n^2 - 1\right)}$$

Where d_i is the difference between the ranks given to x_i and y_i. Under the null hypothesis of no correlation between the X and Y series, the distribution of r_s can be closely approximated by the normal distribution with $\mu_{rs} = 0$ and $Var(r_s) = 1/(n - 1)$.

VITAE

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