Fuzzy Multiple Criteria Decision System for Contractor Selection

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ABSTRACT

Though the construction industry is one of the most dynamic, challenging and rewarding industries, it is also one that is full of uncertainties and associated risks. The proliferation of contracting firms due to low entry barriers to the industry, cutthroat competition as a result of shrinking construction markets in developed and developing countries and the unique nature of construction have led many construction clients to a crucial dilemma and that is which contractor to select for their jobs. As contractors play a pivotal role in any construction project, the crucial task of the selection by the client of ‘the right contractor for the right project’, therefore, constitutes the critical fulcrum upon which the overall success or otherwise of a construction project is precariously balanced.

The increasing demands by clients and complexity of construction projects in recent years have necessitated the appraisal of the capability of candidate contractors with respect to a multiple set of criteria rather than solely based on ‘lowest-price-win’ approach. Many researchers and construction practitioners have proposed different methods or procedures for contractor selection. However, all existing contractor selection models have some shortcomings that are associated with the methods or procedures adopted for the model, for example, lack of simultaneous consideration of multiple criteria and multiple decision-makers and uncertainty and risks associated with the subjective nature of decision-making. This research thus aims at developing a fuzzy multiple criteria decision system for contractor selection that is well-structured in approach and robust in analysis, in order to assist construction clients in making complex decisions regarding contractor selection in a systematic, realistic and productive way. A financial evaluation model is also developed to assess the changes in the financial health of candidate contractors during the contractor selection process.

In an attempt to gather the state-of-the-art knowledge regarding contractor selection, various literature of research works on contractor selection practices, selection criteria used by construction clients in various countries, a range of evaluation techniques used for the

assessment of the capabilities of the contractors, is explored. Then, an industry-wide questionnaire survey is conducted with the objectives of identifying important criteria for inclusion in the selection system, investigating selection criteria preferences of construction practitioners and establishing weights for those criteria from their perceived importance determined through the questionnaire survey.

Based on the knowledge acquired through literature review and the questionnaire survey, a computer-interactive contractor selection system that is developed using Visual Basic and Microsoft Excel is proposed. The system employs the fuzzy set theory to deal with the uncertainty and vagueness surrounding the subjective nature of the decision-making and multiple attribute decision method to handle the simultaneous consideration of multiple criteria and multiple decision-makers. Using actual contractor selection cases, the applicability and flexibility of the system are ascertained by testing its validity in terms of user friendliness, functionality, usefulness and sensitivity range. The system predictions show a high level of accuracy and a reasonable representation of the actual cases results.

The use of the proposed contractor selection system, though no panacea for all potential problems of decision-making regarding contractor selection process, would assist construction clients in performing more realistic, linguistic assessment of candidate contractors. It would help them to select 'the right contractor for the right project' so that the risk to the client of project failure due to the selection of an inappropriate contractor is reduced and more efficient utilization of resources by all parties associated with the selection process is ensured. The proposed system is, however, not intended to supplant the work of decision-making teams in contractor selection process. Rather, it should be used to help them make quality evaluation of the available candidate contractors. It is recommended that the results from the system should be used with the experiential judgment of the decision-makers to arrive at the final decision for the selection of the most appropriate ***(right)*** contractor for the job.

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List of Abbreviations

AHP	:	Analytic Hierarchy Process
BCA	:	Building and Construction Authority
BOT	:	Built-Operate-Transfer
C&C	:	Completeness and Conformance
CF	:	Cash Flow
CL	:	Current Liabilities
CONQUAS	:	Construction Quality Assessment System
CSC	:	Contractor Selection Criteria
DB	:	Design and Build
DBB	:	Design-Bid-Build
DIA	:	Degree of Importance Assigned
DM	:	Decision Maker
EBIT	:	Earning Before Interest and Taxes
GDP	:	Gross Domestic Product
HDB	:	Housing and Development Board
LTA	:	Land Transport Authority
MAUT	:	Multi-Attribute Utility Theory
MCDM	:	Multi-Criteria Decision Making
MPMC	:	Multi-Person Multi-Criteria
NW	:	Net Worth
REV	:	Revenue
P&P	:	Performance and Potential
PPP	:	Public Private Partnership
TA	:	Total Assets
TL	:	Total Liabilities
WC	:	Working Capital
Wt	:	Weight

Chapter 1
Introduction

1.1 Chapter Overview

With a brief introduction of the role and importance of the construction industry in the socio-economic development of a nation, this chapter explains the rationale for the development of a comprehensive, well-structured contractor selection system. It lays down the objectives that are to be achieved in this research work. It also discusses the significance of the development of an effective and easy-to-use contractor selection system. The chapter then concludes on the organization of the thesis.

1.2 Introduction

The construction industry plays a pivotal role in the socio-economic development of any nation. It is oftentimes regarded as the 'engine' that powers the pace of the socio-economic growth of the nation owning to its significant contribution to Gross Domestic Product (GDP), often in the range of 5% to 15% (Mawhinney, 2001). The industry has an estimated global market size of nearly US$4 trillion in 2003 (DLSI, 2005) with its strong inter-sectoral linkages and its employment generating potential. In the socio-economic development of Singapore, especially in its early stages of economic development, the construction industry was one of the principal factors that gave Singapore a competitive edge over many other developing countries in the region. The construction industry was the fastest growing sector of the country's economy in the early post-self-government years of infrastructural development (1960-65) and its contribution to GDP was 3.5 to 8.5 percent and to capital formation 30.5 to 59.7 percent during 1960-86 (Ofori, 1988). By contributing about 4.25 to 9.4 percent to GDP during 1998-2005 (Statistics Singapore, 2003; 2005), the Singapore construction industry still enjoys the status of being one of the highest contributors to GDP.

The construction industry is one of the most dynamic, challenging and rewarding industries, but it is also full of uncertainties and associated risks and these arise from the nature of the industry itself. Low entry barriers to the industry has encouraged in many countries mushrooming of contracting firms which range from small-scale firms to large firms. For example, in Singapore, there are around 4500 construction-related firms (BCA, 2003) vying for the construction pie of about Singapore dollar (S$) 12 billion in the year 2004.

The proliferation of these construction firms, along with the shrinking construction markets in developed and developing countries, has led to a fierce competition for the limited number of construction projects. Contractors usually compete in a volatile environment, full of uncertainties and associated risks that do not exist in other industries or that are at very different levels. In addition, the peculiarity of construction is that no two projects are identical in terms of site conditions, design, use of construction materials, labors requirements and plants and equipment requirements, construction methods, technical complexity and level of management skill required. In such a situation, the dilemma often faced by all construction clients is which contractor to select for the job.

A construction project is generally carried out through a contract system- an agreement between the client and the construction agency. Based on the specific requirements of the project and the objectives of his organization, the client decides an appropriate tendering procedure and contractual arrangement to ensure that *best value for money* to the client, and *fitness for purpose*, i.e., satisfaction to the end-users are equally achieved in the absence of claims and counter-claims. As the contractor plays a pivotal role in any construction project, the crucial task of the selection by the client of the right contractor for the right project, therefore, constitutes the critical fulcrum upon which the overall success or otherwise of a construction project is precariously balanced.

The success level of any construction project is largely dependent on time, cost and quality standards of the completed product. Since it is often difficult for the all three criteria to be achieved in any construction project, construction clients must balance the optimality of this time-cost-quality triangle. Therefore, the aims of any contractor selection exercise are to find a contractor who demonstrates a reputation for quality product, timely completion, high technical and managerial capabilities, financial soundness, good business record and can deliver the project for the lowest possible price. Construction clients in various private sectors practise different procedures for contractor selection and tender evaluation. They mostly develop their own procedures for the purpose. In public sectors, however, the tender price is the most dominating criterion used for awarding the contract (Barrie and Paulson, 1992), because clients are publicly accountable and must demonstrate that the best value for their money has been achieved (Merna and Smith, 1990). The selection of a contractor based on lowest tender price may not be a true indication of the cost and quality of the project upon completion (Vorster, 1977; Lewis, 1981; Pearson, 1985; Grogan, 1992; Klein, 1994). Hatush and Skitmore (1998) opined that the selection of the contractor based on the lowest tender price is one of the major reasons for project delivery problems, as contractors desperately quote low prices by reducing their quality of work and hope to be compensated by submitting claims. Moreover, by such a selection the client may run the risk of having problems at later stages of the project because there is an increased possibility of schedule and cost overruns, poor quality standards, and financial collapse of the contractor (Russell and Jaselskis, 1992a; Kwakye, 1994; Holt, *et al.*, 1995a) and has to appoint others, in frustration, to complete the works as required (Murdoch and Hughes, 1996). Therefore, the capability of the contractor to execute the project should be gauged against a set of multiple criteria which in the opinion of the clients or their representatives are necessary for the successful completion of the project under consideration. And this assessment is mostly to be made on the basis of past experience, incomplete information, imprecise data, judgment and perceptions of the decision makers (DMs). Hence, contractor selection is in essence a multi-criteria decision-making (MCDM) problem involving human subjectivity and uncertainty.

Though a considerable number of contractor selection models or methodologies have been proposed by many researchers (e.g., Diekmann, 1981; Hardy *et al.*, 1981; Nguyen, 1985; Russell *et al.*, 1990; Holt *et al.*, 1994a, 1994b; Hatush and Skitmore, 1998; Sonmez, M. *et al.*, 2001; Mahdi, I. M. *et al.*, 2002; Pongpeng and Liston, 2003a), these models or methodologies generally lack simultaneous consideration of multiple criteria and multiple DMs or consideration of uncertainty and risks associated with mapping of one's judgment into a number.

Therefore, a methodology or a contractor selection system capable of dealing with the uncertainty inherent in the nature of construction project, multiple decision criteria, uncertainty and vagueness surrounding the decision-making would be beneficial for construction clients in selecting the most appropriate contractor for the job. A comprehensive contractor selection system that incorporates the concept of fuzzy set theory and multiple criteria decision-making technique is proposed and developed. The developed system, which is capable of performing performance and potential (P&P) qualification of candidate contractors or P&P qualification plus tender evaluation, will assist construction clients in performing more realistic assessment of the contractors in multi-criteria environment to ensure 'the right choice of the contractor for the right project'.

1.3 Problem Statement

As discussed in the previous section, selection of the contractor based on the lowest price could lead to serious project delivery problems and therefore the capability of the contractor to execute the project should be evaluated using a multiple set of selection criteria including reputation, past performance, performance potential, financial soundness and other project-specific criteria.

The selection of a contractor is a decision-making process requiring simultaneous consideration of multiple criteria and participating of multiple DMs. The models or methodologies that have been previously developed for contractor selection process lack simultaneous consideration of multiple criteria and multiple DMs or flexibility in adapting the dynamic and complex nature of construction projects or consideration of risk and uncertainty associated with mapping of one judgment to a crisp number.

Therefore, there is a need for an effective contractor selection system capable of

- dealing with multiple criteria and multiple DMs;
- handling risk and uncertainty associated with the nature of decision-making;
- adapting the dynamic and complex variables of construction projects.

1.4 Research Objectives

The overall objective of this research is to develop a contractor selection system that is well-structured in approach and robust in analysis, capable of assisting construction clients in making complex decisions regarding contractor selection in a systematic, consistent and more productive way. The motivation for this research work is threefold:

a. The lack of an effective, comprehensive and easy-to-use contractor selection system capable of dealing with uncertainty inherent in the nature of construction and subjectivity and vagueness surrounding the nature of decision-making in contractor selection process.

b. Developing such a system will provide the client with a systematic and more efficient way of comparing the capabilities of the contractors during evaluation process so that the risk to the client of project failure due to the selection of an inappropriate contractor is reduced.

c. Developing a computer-interactive contractor selection system will reduce the excessive expenditure of time and effort from all the parties involved in the selection process.

The key objectives of this research are:

1. To investigate the construction clients' contractor selection preferences;

2. To establish a set of multiple contractor selection criteria (CSC) to be used in the proposed contractor selection system;

3. To establish the relative importance or weight of the CSC selected to be used in the proposed contractor selection system;

4. To develop a comprehensive decision-making method capable of dealing with uncertainty and vagueness surrounding the contractor selection process and of producing a decision that reflects the preferences of multiple DMs;

5. To develop a computer application to enhance the flexibility of the system in adapting the preferences of decision criteria in relation to the specific requirements of the project under consideration;

6. To perform sensitivity analysis to determine the effect of variation in input parameters resulting from uncertainty and subjectivity of human judgment; and

7. To test the validity of the system using real cases of contractor selection.

1.5 Scope and Methodology of the Research

Construction projects are generally procured through different procurement methods. A project procurement method or project delivery system is a framework by which the clients or their representatives and contractors attempt to accomplish the project as per requirements. A wide range of procurement options is available to construction clients today and different types of contracts are fundamental to all options. The objectives of the client organization, the specific requirements of the project under consideration and, in some cases, local authority regulations have significant influence on the selection of procurement method by the client for the project under consideration. The principal procurement arrangements include traditional Design-Bid-Build (DBB) approach, Design-

Build (DB) method and Public Private Partnership (PPP) arrangement. Although DBB and DB have found a wide range of applications in almost all kinds of construction projects, PPP has its limited application mainly in privately financed infrastructure projects. A wide spectrum of variations of these procurement arrangements, which are in practice, can be found in the literature (e.g., Chevin, 1992; Maxwell, 1994; Levy, 1996; and Kiong and Yun, 1998).

In many countries, for example, the UK, the USA and Singapore, DBB is the prevalent procurement method (Bennett *et al.*, 1996 and Ling *et al.*, 2000). The statistics by Singapore's Building and Construction Authority (BCA) on the percentage of projects awarded in Singapore from 1995 to 2004 (BCA, 2005) highlights the fact that most of construction projects- approximately 80% of total projects awarded (except 67.5 % in 1997 and 70.4 % in 2001) were procured using traditional DBB arrangement. Therefore, the main focus of the research will be on the development of the contractor selection system that can be used to assist construction clients in selecting the most appropriate contractor for DBB projects. However, the flexibility inherent in the structure of the proposed system will allow construction clients, with slight modification, to use it for the selection of the contractor for DB projects also.

In this study, the 'contractor selection' means both P&P qualification, which includes the evaluation of a contractor's reputation, technical, managerial and financial qualifications with respect to the specific requirements of the project under consideration as well as tender evaluation which includes the evaluation of the attractiveness of a contractor's tender proposal and best value determination. With an aim to address the problem of interpreting the information conveyed by financial ratios during the assessment of financial soundness of contractors this study also focuses on the development of an effective evaluation system for financial health of contractors. The concept of entropy method is employed for developing the financial evaluation system. It also includes the development of an integrated computer application for the proposed contractor selection system so that the developed system can also be employed using different modalities or channels such as stand-alone, intranet or the Internet.

The methodologies adopted in this research include review of literature, conducting questionnaire survey, developing computer-interactive system and testing the system with actual contractor selection cases. The detail of each approach is discussed in Chapter 3.

1.6 Significance of the Research

To overcome all the shortcomings of the current contractor selection models or methodologies, the proposed computer-interactive contractor selection system employs the fuzzy set theory to deal with the uncertainty and vagueness surrounding the subjective nature of the decision-making and multiple attributes decision method to cater for the simultaneous consideration of the multiple decision criteria and multiple DMs. Therefore, the use of the proposed contractor selection system, which is more structured in approach and robust in analysis, can reap the following benefits:

- It will help construction clients select the most appropriate contractor in a systematic, consistent and productive way;

- Therefore, the risk to the client of project failure resulting from awarding the contract to an incompetent, incapable, and inappropriate contractor will be greatly reduced;

- Computer interaction will facilitate more efficient utilization of resources by all parties associated with the selection process;

- It will, therefore, help to some extent improve the performance of the construction industry.

1.7 Structure of the Thesis

With an overview of the importance of the construction industry and the significance of the selection of the right contractor for the right project, Chapter one explains the rationale for the development of a comprehensive, well-structured contractor selection system. It also lays down the objectives to be achieved and the means of achieving them. It also covers the structure of the thesis.

Chapter two covers a comprehensive review of a wide range of literature including books, published journal articles and conference papers covering the issues related to the contractor selection process. It encompasses a synopsis of procurement systems and tendering procedures, various contractor selection practices currently in use, CSC and evaluation techniques used by construction clients in various countries. It also includes a brief review of multi-criteria decision techniques that are potentially useful for complex decision-making such as contractor selection. This provides the current knowledge in decision-making regarding contractor selection process and serves as foundation for formulating strategy for the research.

The third chapter focuses on the research methodology, whereby steps involved in achieving the objectives of the study are clearly outlined. The structure of the methodology adopted includes knowledge mining process to gather all relevant information regarding contractor selection, surveying of industry experts to ascertain the relevance of the information gathered through knowledge mining process, development of conceptual model for contractor selection, structuring the computer-based contractor selection model, testing and validation of the model with real contractor selection cases and discussion of the applicability of the model in real-world situations.

With a detailed description of data acquisition method adopted for the study, Chapter four investigates the multiple criteria selection tendencies of construction clients. The main objective of this chapter is to collect the data from the construction industry to make full use of the industry expertise in developing a multiple criteria decision system for contractor selection. A questionnaire survey was conducted to identify the important CSC for inclusion in the system; to establish weights for those CSC from their perceived importance observed through the questionnaire survey; and to investigate the construction clients' preferences of tender selection and evaluation methods.

With a thorough literature review of the state-of-the-existence in contractor selection practices in Chapter two and acquisition and analysis of data regarding the construction clients' preferences of CSC and evaluation methods in Chapter four, Chapter five embarks on the description of the conceptual framework for contractor selection which is the core of this research work. The proposed contractor selection system employs fuzzy MCDM technique - a combination of fuzzy set theory to deal with the uncertainty and vagueness surrounding the subjective nature of decision-making regarding the contractor selection and multiple criteria decision technique to cater for the simultaneous consideration of the multiple CSC and multiple DMs.

Chapter six focuses on the development of a financial evaluation system for a more effective appraisal of financial soundness of candidate contractors during selection process. It provides a brief overview of existing financial ratio models developed for predicting the financial stability of construction as well as non-construction companies. A financial ratio model that employs the concept of entropy is proposed for observing the changes in financial health of candidate contractors to make comparison of their financial soundness during selection process.

Based on the theoretical concept, knowledge and information acquired in previous chapters a computer-interactive contractor selection system is developed. Chapter seven covers the detailed discussion of major processes involved in the computer-based contractor selection system and elaboration on the logical structure of the system. A step-by-step illustration of the mechanics of the system is presented with the aid of some screen shots from an actual contractor selection case. It also includes the illustration of the application of the evaluation model for financial stability of contractors on tender list.

Chapter eight concentrates on testing of the developed selection system to verify and validate its overall applicability to the actual contractor selection cases. Using real contractor selection cases the system's applicability in terms of its user-friendliness, functionality, and usefulness is tested. The sensitivity analysis is also performed to observe the variation of input parameters on the final outcomes of the system.

Chapter nine, the last chapter of the thesis includes conclusion, limitations of the proposed contractor selection system, implications of the research work and the author's recommendations and suggestions for future work.

Chapter 2

Literature Review

2.1 Chapter Overview

This chapter covers a comprehensive review of a wide range of literature including books, published journal articles and conference papers covering the issues relating to contractor selection process. It encompasses a synopsis of procurement systems and tendering procedures, various contractor selection practices currently in use, selection criteria and evaluation techniques used by construction clients in various countries. It also includes a brief review of multi-criteria decision techniques that are potentially useful for the contractor selection process.

2.2 Overview of Construction Project Procurement Systems

A project procurement system or project delivery system is a framework by which construction client attempts to procure the project in a systematic manner. Based on the specific requirements of the project and the objectives of his organization, the client chooses an appropriate procurement arrangement to ensure the achievement of '*best value for money*' in the absence of claims and counter-claims. Since each construction project has its own distinct characteristics and requirements, the right choice of procurement arrangement for the right project plays a vital role in influencing the success level of any construction project (Alhazami and McCaffer, 2000). It has been estimated that the selection of an appropriate procurement method could reduce construction costs by an average of 5% (Contractual Arrangements, 1982).

Principal procurement routes used for construction projects include design and build (DB), traditional design-bid-build (DBB) and public private partnership (PPP or P3) with a large number of variations of each in practice. Which procurement route to choose for the project is a crucial task faced by all construction project clients or their representatives.

2.2.1 Design and Build Method

The existence and use of DB procurement approach, which has gained more popularity in recent years, can be traced back to ancient times when the master builder, as both designer and constructor, executed each stage of the project from conception to operation. However, with the advancement of technology in construction the structures became more complex, demanding greater expertise in design and construction, the roles and responsibilities of the designer and the contractor were separated. In this procurement method, both design and construction are integrated by awarding the contract to a single contractor who assumes the sole responsibility for delivering the required structure and associated services as per defined standards and conditions and hence, enabling the clients to enjoy a single point of responsibility. The popular arrangements of DB procurement method used in the Singapore construction industry include: Turnkey, Design Development and Package Deal.

2.2.2 Design-Bid-Build Method

In DBB approach, the two major aspects of the project, i.e., design and construction, are separated. The client organization or the client's representative, for example, architectural and engineering consultancy firms selected by the client organization, carry out the preparation of designs, specifications and tender documents for obtaining suitable and competitive offers from a pool of potential contractors and for selecting the most appropriate contractor who then enters into a formal contract with the client to deliver the project on the basis of agreed terms and conditions. During the construction stage, the consultants act as the client's representative to supervise and administer the construction work of the contractor as per contract requirements whereas the role of the contractor is to efficiently organize and execute the project in accordance with drawings and specifications and to deliver the constructed facility to the client as per the requirements in terms of cost, time and quality stipulated in the contract. Many variations of DBB procurement approaches are currently in practice, for example, Design and Manage, Management Contracting, Construction Management and Project Management. Table 2.1 lists some of the benefits and limitations of both DB and DBB procurement which are summarized from Rowlinson (1987), Pain (1993), Gordon (1994), Bennett *et al.* (1996), Chau *et al.* (1996), Songer and Molenaar (1996), Neo (1997), Konchar and Sanvido (1998) and Rizzo (1998).

In many countries, for example, the UK, the USA and Singapore, the use of the DBB procurement method is prevalent (Bennett *et al.*, 1996 and Ling *et al.*, 2000). A study by Ling *et al.* (2000) revealed that Singapore construction clients are reluctant to use DB procurement methods because they are not comfortable with DB approach as it could not lessen their risks, and a finished product which is of good quality and easy to maintain could not be ensured. This view is also supported by the data in Table 2.2 that shows the percentage of DB projects awarded in the Singapore construction industry (BCA, 2005). Though the government has taken some initiatives to encourage the use of DB approach in the industry, the figures in the tables, however, portray a different image of the industry's preference.

2.2.3 Public Private Partnership (PPP)

PPP is a procurement approach that involves the formation of a public-private joint venture built on the expertise of each partner that best meets clearly defined public needs through the appropriate allocation of resources, risks and returns. This procurement approach entails the investment of private sector's capital to design, finance, build, operate and maintain a project for public use for specific term during which a private investment consortium or special purpose vehicle (SPV) is allowed to collect revenue from the users of the facility or by providing the services.

With PPP, the public agency will move away, permanently or over the contract period, from owning and operating facilities, to purchasing services directly from the private sector.

Table 2.1 Benefits and Concerns in Using DBB and DB Procurement Methods

Procurement Method	**Benefits**	**Concerns**
Design-Bid-Build (DBB)	1. Familiarity to participants 2. Complete control over design 3. More realistic pricing 4. Greater price certainty 5. Less financial risk 6. High construction quality	1. No competitive design 2. Less incentive for designers to reduce cost 3. Low constructability 4. Vertical fragmentation 5. Split responsibilities 6. Adversarial environment 7. Longer project duration 8. No contractor involvement in design
Design-Build (DB)	1. One-point responsibility 2. Improve business performance 3. Cost effective, innovative design 4. High constructability 5. Cost effective construction methods and materials 6. Conducive working environment 7. Faster construction speed 8. Shorter project duration 9. Low construction cost	1. Lack of clear design brief 2. High tender cost 3. Less price certainty for clients 4. Difficulty in assessing the certainty and comprehensiveness of the tender proposals received 5. Non-conformance of constructed facility to the clients' requirements 6. Difficulty in deciding form of and terms of contract to use

Table 2.2 Percentage of DB Projects Awarded in Singapore
(Source: BCA, 2005)

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
% of annual construction turnover	32.5	21.1	22.7	16.7	29.6	5.6	8.0	12.9

According to the specific features of the project, the objectives and risk sharing attitude of the client's organization an appropriate procurement method is selected. The procurement route selected significantly influence the choice of tendering system and contractual arrangement for the project.

2.3 Overview of Tendering Procedures

If the client decides not to assume direct responsibility for construction himself, he will need to select a contractor with the appropriate experience and expertise to assume that responsibility. Tendering procedure is a process by which clients attempt to obtain the competitive offers from the contractors so that the most appropriate contractor among a pool of potential contractors can be selected for the project. There are several tendering procedures used by construction clients to select the most appropriate contractor and the selection is normally influenced by the objectives and requirements of the project under consideration and sometimes by regulatory requirements.

2.3.1 Open Tendering

Open tendering is a procedure by which any contractor, large or small who wishes to bid for the project is permitted to submit a tender. The process begins by placing an advertisement, with a brief description of the location, type, scale and scope of the project, in the media. By this procedure, the client could obtain the biggest possible number of competitive responses to the invitation and thereby achieving maximum possible competition.

Open tendering procedure is commonly used by public clients and the award of the contract is greatly dominated by the 'lowest-price-win' concept as they need to avoid the suspicion of favoritism and to demonstrate that the achievement of best value for public money has been ensured. However, because of its indiscriminate nature, it may not attract top and competent contractors and there is an increased risk of awarding the contract to an inappropriate contractor who is not adequately equipped in terms of experience and resources for the project under consideration. Moreover, there is always a longer list of tenderers placing an unnecessary burden of time, cost and effort on the construction client in particular and the construction industry in general. The problems associated with open tendering method have paved the way for the increased use of selective tendering in recent years (Murdoch and Hughes, 1996).

2.3.2 Selective Tendering

Selective tendering process is carried out usually for very large projects or projects of a complex or specialized nature, where the normal open tender system is not suitable. In this method, a limited number of contractors are generally invited on the basis of their known reputation for past performance or specialized expertise or prior working relationship with the client. The invited contractors are generally required to pass a screening test called pre-qualification and all those contractors who pass through pre-qualification process are asked to submit their tender proposals. Hence, this tendering procedure generally consists of two stages- pre-qualification and evaluation of tender proposal.

2.3.2.1 Pre-qualification

The aim of prequalification process is to select a limited number of candidate contractors who are each financially and technically capable of executing the contract work satisfactorily and with whom the client could enter into a contract (Ng *et al.*, 1995). In prequalification stage, the client invites all the contractors who are interested to bid to apply for a general pre-qualification. Pre-qualification of contractors is generally performed on a periodic basis or on the basis of project specific requirements.

(i) Registration or Periodic Pre-qualification

The aim of registration or periodic prequalification is to identify the qualified candidate contractors from a pool of interested potential applicants and to classify them into different range of work categories and financial grades according to their performance and potential (P&P) parameters. This registration procedure is normally practiced by public bodies in many countries such as Building and Construction Authority (BCA) in Singapore, Works Bureau in Hong Kong, Department of Public Works and Housing, Queensland in Australia. In Singapore, BCA administers the registration of contractors to serve the procurement needs of government agencies and this registration process involves the initial appraisal and periodic (currently every three years) upgrading/downgrading to higher/lower value grade based on their performance parameters (BCA, 2003). Contractor selection procedures practiced by Singapore public sector clients require that only those contractors registered with BCA can tender for contracts.

(ii) Project-Specific Pre-qualification

Project-specific pre-qualification approach, which is more dynamic in nature, is followed by the construction clients to select an array of eligible candidate contractors on a project-by-project basis. In this approach, the client invites a limited number of contractors, who are deemed capable of executing the project, selected from the standing approved list or on the basis of their known reputation or prior working relationship with the client to apply for pre-qualification and their performance attributes are assessed in light of specific requirements of the project under consideration.

Even though different client organizations prefer different pre-qualification criteria, the purpose of prequalification exercise is to prepare a list of eligible candidate contractors according to their P&P parameters which are generally assessed in terms of their financial capability, level of technical and managerial skills, level of achievement and continuous improvement in quality, past performance, health and safety record and post-business attitudes (c.f., Russell and Skibniewski, 1988; Hatush and Skitmore (1997b) and Palaneeswaran and Kumaraswamy, 2001). The principal objectives of pre-qualification exercise (Russell and Skibniewski (1988); Russell (1990a) and Palaneeswaran and Kumaraswamy, 2001) include (i) to identify a group of potential contractors, who can efficiently complete the project, before requesting the tender proposals so that time and resources wasted by unqualified contractors in preparing tender proposals and by the client in evaluating tender proposals are reduced; (ii) to reduce the risk of contractor's failure as a result of awarding the contract to the lowest bidder who may not be properly equipped in terms of performance and potential requirements for the project; (iii) to encourage top, competent contractors to bid with confidence by ensuring healthy competition among genuine competitors; and (iv) to optimize the contractor selection in terms of achieving better balance between price and performance parameters.

2.3.2.2 Tender Evaluation

This stage primarily involves a detailed technical and economic evaluation of tender proposals submitted by all eligible candidate contractors who are short-listed either from the standing approved list of contractors on the basis of their known reputation in the industry and prior working relationship with the client or through project-by-project prequalification process. The contractor submitting the lowest tender price is generally, but not always, awarded the contract considering that he has already met the performance requirement for the project during pre-qualification process.

The major advantages of selective tendering are reduced burden of time, cost and effort on the industry in general and reduced risk of contractor failure as better balance between the price and performance parameters is ensured. One major disadvantage is that it requires longer pre-tender period for short-listing or pre-qualification of contractors and it may be even extended in order to consider new applications for qualification if all preliminary applicants fail to meet the minimal performance requirement, a level below which contractors will not be considered.

2.3.3 Negotiated Tendering

This tendering procedure is preferable in circumstances such as when a quick start is required and the client cannot afford time to go through one of the formal tendering procedures or where the client has the overriding reason to employ a particular contractor owing to the fact that the specific nature of the project requires a particular expertise or specialist plant or continuation of the existing contract. The client may invite one or more of the contractors with whom he has business relationships and negotiate the terms and conditions and tender sum.

Although this procedure is viewed as more radical approach to contract award (Murdoch and Hughes, 1996), all the advantages associated with competitive tendering would be sacrificed. However, according to Smith (1991) what would be regarded as the reasonable excess of negotiated price over those obtained through competitive tendering is only a matter of opinion. One major concern of negotiated tendering is that as the negotiation gets into an advanced stage without arriving at an agreement, the risk of losing all the time so far spent and having to start again in frustration is so serious that the client may be driven to accepting an unduly high tender in order to avoid this (Ibid.).

2.3.4 Partnering

In this approach the client reaches an agreement with various parties that will be engaged in the construction of the project to work together in a team framework for a particular contract or a series of contracts. This partnering method is in general used to overcome all the adversarial relationships between client and contractor resulting from the traditional approach to procurement. Project partnering is gaining considerable attention in the construction industry as a means for transforming hostile, adversarial client-contractor relationships into a more collaborative team (Larson, 1997). This approach of doing business in an environment of trust and mutual respect is a relatively new concept in the construction industry (Osama, 1994). In recent years, there has been a growing interest in the use of partnering in construction (CII, 1989, 1991; CRINE, 1994; Latham, 1994; ACTIVE, 1996; and Black *et al.*, 2000). This approach, however, also defeats the objective of any tendering process that is to obtain competitive offer and price.

There is no systematic approach or procedure or defined set of criteria for negotiation and partnering options that a client can use to assess risks due to the contractor capability to execute the project successfully (Smith, 1991 and Brown, 1994). From the above discussion, a multitude of procurement options is available to construction clients and different types of tendering procedures and contractual arrangements are fundamental to all options. However, the choice of a particular procurement approach is only significant to contractor selection for a project where particular selection criteria are critical and can only be achieved by adopting a specific procurement option.

2.4 Current Contractor Selection Practices

From the previous discussion, it is clear that a large number of procurement options are available to construction clients and five process elements are common to all types of procurement options. They are project packaging, invitation, pre-qualification, short-listing and bid evaluation (Hatush, 1996). For each of these process elements a multitude of practical and possible arrangements of subsystems emerge-- a variety of project packages, invitation forms, pre-qualification procedures, short-listing methods and bid evaluation techniques, offering differing combinations of risk, expertise, flexibility and costs (Nahapiet and Nahapiet, 1985). To choose a combination of alternative subsystems that will ensure the success of the project in terms of time, cost and quality is the underlying concept of formulating a procurement strategy for the project. Therefore, contractor selection is a decision-making process that occurs within the overall procurement strategy for the project.

A contractor may be selected by competition or negotiation. Public sector clients are generally bound, by legal regulations in many countries, to use an open competitive approach to avoid suspicion of favoritism and to demonstrate that the achievement of best value for public money has been ensured. Use of partnering through negotiation by some public bodies in the USA, for example, US Army Corps of Engineers (Weston and Gibson, 1993), has witnessed better project performance in terms of time, cost and quality. However, private sector clients are not subject to any such regulation or accountability, and hence they may use more flexible alternative approaches available to them for the purpose.

Figure 2.1 highlights the alternative routes to the final award of contract by construction clients. There may also be other routes to final contractor selection depending upon the objectives of the client organization and the specific requirements of the project under consideration. Whichever route is selected for the final selection, the prime aim is to select the right contractor who will give the client good value for money.

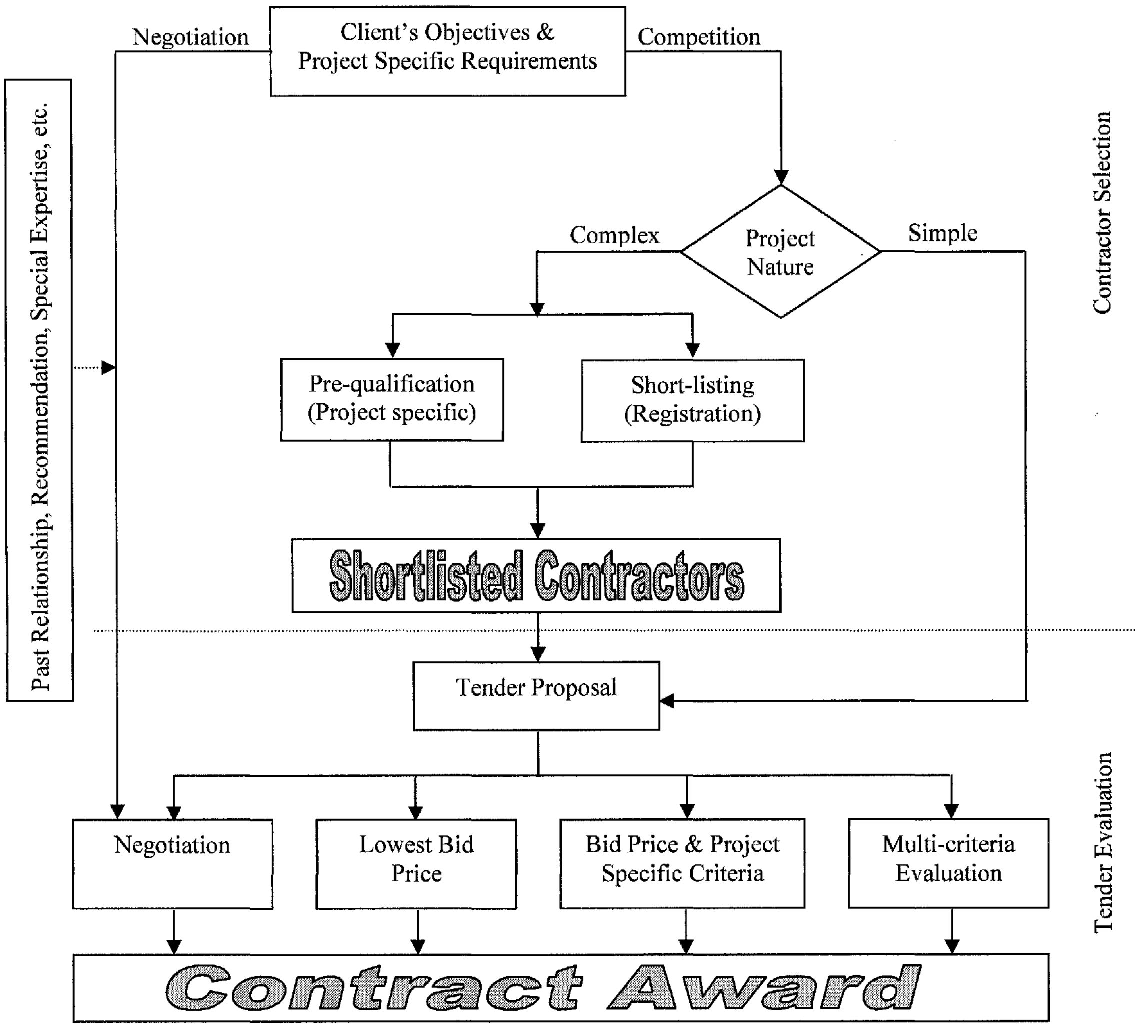


Figure 2.1 Various Routes to Final Contractor Selection (Adapted from Singh *et al.*, 2003)

The current literature review has suggested some indication of paradigm shift in contractor selection practices, that is, from 'lowest price win' selection approach (e.g., Russell and Skibniewski, 1988; and Merna and Smith, 1990) to multiple criteria selection approach (e.g., Wong *et al.*, 2001). Because of paradigm shifts in procurement methods, for example, moving more and/or different risks on to the contractors, deeper and wider evaluation of contractors' P&P parameters has become more important and necessary (Kumaraswamy, 1996), requiring consideration of broader sets of criteria and involvement of multiple decision makers. This has led many construction researchers and practitioners to look for efficient and effective evaluation techniques for contractor selection which take into account simultaneous consideration of multiple criteria and multiple decision-making parties.

2.4.1 Contractor Selection Criteria

As a contractor plays an important role in the success or otherwise of the project, decision criteria selected for the appraisal of contractor P&P parameters play an important role in making the right choice of the contractor. Since the training, background and experience of DMs varies considerably, the selection criteria used by DMs also varies equally. Different researchers and construction practitioners have proposed different sets of decision criteria for assessment of contractor P&P parameters during the selection process. Hunt *et al.* (1966) considered the technical, managerial and financial standing of the contractor.

Merna and Smith (1990), delved into different types of contract documents and evaluation methods used in awarding the contracts for various types of construction projects in UK public sectors, and concluded that criteria pertaining to financial stability, managerial capability, technical expertise and experience of comparable construction are used by the clients for assessing the overall suitability of the contractor for the project. Based on the findings of the survey study of the USA construction industry, Russell *et al.* (1990) used criteria relating to a contractor's reputation, experience record, past performance, financial stability, technical expertise, current workload and available resources in their knowledge-based contractor pre-qualification system. Another work by Russell *et al.* (1992) proposed a set of prequalification criteria consisting of references, experience, past performance, financial stability, contractor's capacity, project control procedure, location of home office, location of project, safety record, project management capability, organization, labor resources, and company resources. In a study conducted in Australia, Liston (1994) identified past performance, business location, capacity, financial, resources, procedures, and quality assurance as important criteria to be considered for selecting the right contractor.

Kumaraswamy (1996), out of his experience in the USA, the UK, Sri Lanka and Hong Kong suggested the use of financial, technological, personnel and experience criteria for evaluating contractors. Hatush and Skitmore (1997a), after extensive literature review and a Delphi interview study conducted with nine construction professionals with extensive experience in contractor selection process, came up with the conclusion that the most common criteria considered by construction clients during contractor selection process are those pertaining to financial soundness, technical ability, management capability, and health and safety performance of contractors. Alsugair (1999) considered nine factors in his bid evaluation framework developed for the Saudi Arabia construction industry. They include financial evaluation, bid understanding, project location, contractor qualification, completion of bid document, experience and reputation, organization of contractor, alternative offer, and regulatory factor in case of foreign companies. He also suggested the use of permissible maximum financial capacity of a contractor during pre-qualification process such that a contractor is disqualified if the project cost exceeds the difference between the contractor's maximum financial capability and the value of uncompleted work. In Japan, construction contractors are ranked in five categories based on the criteria such as the average annual construction volume, equity, current ratio, fixed assets to equity ratio, net profit to total assets ratio, number of engineers, and number of years in business (Liston, 1999).

To investigate the tender evaluation preferences of the UK construction clients, Wong *et al.* (2001) used 37 decision criteria relating to manpower resources, plant and equipment resources, project management capabilities, geographical location knowledge, location of home office, contractor's capacity, project execution capacity of the proposed project, technical-economic analysis, and other relevant project specific criteria. Their analysis showed that all criteria selected for the study are important in the selection of the contractor.

From the study of Palaneeswaran and Kumaraswamy (2001), in Queensland, Australia, only contractors registered with the Pre-Qualification Criteria (PQC) system developed by Department of Public Works and Housing, Queensland Government are eligible to bid for public building projects with a value of more than Australia dollar 100,000, with a cap on allowable maximum project value that is 33% of allowable annual turnover. Moreover, a contractor is allowed to bid for a project only if he has PQC rating more than the project rating. The pre-qualification criteria for contractors and sub-contractors suggested by the Construction Industry Development Agency of Australia include technical capability, financial capacity, quality assurance, time performance, health and safety, human resource management and skill formation with some additional criteria such as claim performance, research and development, to be used by the clients at their discretion. After extensive literature review and a survey of construction industry experts from the USA, the UK, Australia, Hong Kong and Singapore, Palaneeswaran and Kumaraswamy (2001) also proposed a decision support system for pre-qualification of contractors. The suggested criteria for the appraisal of contractors' response to the contract document and P&P parameters to be used in their proposed system include promptness, realism, completeness, conformance, performance, other criteria (such as quality achievement), resources, experience, constraints (current workloads, etc.) and management and organization.

In a distinct approach to the evaluation of contractor capability, Ng and Skitmore (2001) considered 38 categories of contractor information (decision criteria) in terms of 'value to client', 'contractor costs', 'client costs', and 'value for money' for assessing the capability of candidate contractors in prequalification screening. They argued that prequalification of contractors should be based on decision criteria that have significant benefits to the decision process but with minimal costs to the parties involved as the main aim of prequalification is to reduce the cost of bidding while retaining the benefits of pure competition. Based on their cost-benefit model, they also advocated establishing a set of cost-effective decision criteria for contractor prequalification.

The Singapore BCA also maintains a Contractors Registry with the aim of streamlining and facilitating the contractor selection process by ensuring a good match between the performance capabilities of contractors and the size, nature and complexity of projects. The legal regulations in Singapore require that contractors who are willing to bid for public projects be registered with BCA. In appraising the capabilities of contractors, BCA considers company reputation, qualification of management and technical personnel, track record (such as completed projects relevant to particular workhead, post-business attitudes), quality achievement certificates (for e.g., ISO 14000) and financial resources. BCA classifies eligible contractors into seven grades based on their proven relevant experience, financial, technical and management capability (BCA, 2004a). They are Grade A1, A2, B1, B2, C1, C2 and C3 and the allowable maximum project values contractors from each grade can bid are unlimited, up to (Singapore) S$ 65 million, 30 million, 10 million, 3 million, 1 million and 500,000 respectively. Though the validity of any registration is for a period of three years, BCA requires the contractors registered in Grade A1 and A2 to submit their audited accounts annually and meet financial requirements (paid-up capital and net worth must not be less than 10% of tendering capacity) to retain in their respective grades. BCA allows the registered contractors after having gained sufficient experience in their current grades to apply for upgrading to a higher grade.

In order to encourage contractors to continuously improve their quality achievement, BCA has set up a Bonus Scheme for Construction Quality (BSCQ) to confer better-performing contractors, those who achieve CONQUAS (CONstruction QUality Assessment System) (BCA, 2004b) scores higher than threshold scores set for particular building category, a tender price advantage of up to 3% of effective contract sum or S$ 2 million whichever is lower in future government contracts. However, if a contractor has accumulated CONQUAS default points in the latest five (5) contracts, a price-loading of 0.2% for each CONQUAS default point, subject to a maximum of S$2 million, will be applied against any tender proposal by the contractor in the evaluation of tender. If a contractor fails to fulfill the registration requirements or earns five default points in the latest five contracts it may be downgraded by one grade or debarred/de-registered from the Registry if ten default points have been accumulated in the latest 5 projects. In case of foreign companies that are not registered with BCA but willing to bid for a public project, they are required to joint-venture with a (local) company, from the standing list of BCA, to be eligible to bid for the project. However, joint venture between foreign and local contractors currently enjoys a margin of S$ 5 million over foreign firms bidding on their own. In addition to tender price and all other mandatory requirements such as registration with BCA, the critical selection criteria generally considered by Singapore's public sector clients, for example, Land Transport Authority (LTA) and Housing and Development Board (HDB) include, performance potential with respect to financial, technical and managerial aspects, experience on similar type of project, and experience and qualification of the proposed staff for the project. Table 2.3 summarizes various selection criteria suggested or used by construction clients and researchers.

From the above review of contractor selection criteria used by construction clients in various countries, it is clear that different client organizations prefer different sets of evaluation criteria according to their requirements. Therefore, the identification of evaluation criteria is an important aspect of contractor selection process. And it becomes more complicated when there are many stakeholders with significant interests in the project outcomes. Each of these stakeholders will likely have different ideas about what the decision criteria should be and how they should be evaluated, making group decision much more complicated and fuzzier.

2.4.2 Tender Evaluation Techniques

The most difficult task faced by the construction clients in tender evaluation process is establishing the weight or relative importance of criteria, designing an appropriate scale of preference structure to be used by DMs for assessing the capabilities of contractors, selecting a suitable technique to aggregate the ratings of DMs on subset of criteria into an overall performance value, ranking of contractors in situations when one contractor scores

Table 2.3 List of Main Criteria Used for Contractor Selection

Selection Criteria	Source
- technical, managerial, and financial capability;	Hunt *et al.* (1966)
- financial stability, managerial capability, technical expertise, and experience of comparable construction;	Merna and Smith (1990)
- reputation, experience record, past performance, financial stability, technical expertise, current workload, and resources;	Russell *et al.* (1990)
-references, experience, past performance, financial stability, contractor's capacity, project control procedure, location of home office, location of project, safety record, project management capability, organization, labor resources, and company resources;	Russell *et al.* (1992)
- technical capability, financial capacity, quality assurance, time performance, health and safety, human resource management, claim performance, and research and development;	CIDA (1993)
- past performance, business location, capacity, financial, resources, procedures, and quality assurance	Liston (1994)
- financial, technical, personnel and similar experience;	Kumaraswamy (1996)
- financial soundness, technical ability, management capability, and health and safety performance;	Hatush and Skitmore (1997a)
- financial soundness, bid understanding, project location, contractor qualification, completion of bid document, experience and reputation, organization, alternative offer, and regulatory requirements;	Alsugair (1999)

Table 2.3 (Cont'd)

Selection Criteria	Source
- average annual construction volume, equity, number of engineers, current ratio, fixed assets to equity ratio, net profit to total asset ratio, number of years in business;	Liston (1999)
- conformance, promptness, realism, completeness, performance, resources, experience, constraints, management and organization, and other specific criteria;	Palaneeswaran and Kumaraswamy (2001)
- manpower resources, plant and equipment resources, management capability, geographical knowledge, location of home office, contractor's capacity, project execution capacity, technical-economic analysis, and other project specific criteria;	Wong *et al.* (2001)
- value to client, contractor costs, client costs, and value for money;	Ng and Skitmore (2001)
- financial, technical and managerial aspects, experience on similar type of project, experience and qualification of the project team;	LTA and HDB (c.f., Singh *et al.*, 2003, 2005)
- reputation, qualification of management and technical staffs, track record, quality achievement, and financial resources;	BCA (2004a)

better than others on a subset of criteria and but much worse on at least one criterion from the complementary subset of criteria. Different researchers and construction practitioners have developed various methods or techniques for evaluating the tender proposals. For example, fuzzy set theory by Nguyen (1985); logistic regression technique by Russell and Jaselskis (1991); multiple regression technique by Holt (1995); multi-attribute utility theory by Hatush and Skitmore (1998); analytic hierarchy process by Fong and Choi

(2000), and Mahdi *et al.* (2002); a combination of utility function and social welfare function by Pongpeng and Liston (2003a).

On the basis of 'at-a-glance' review, it seems that all methodologies offer equal scope for contractor selection problem. However, each methodology has its associated merits and demerits. In order to have better insights into their applicability to practical contractor selection problem, all methodologies that are potentially useful for contractor selection process will be discussed in the later sections of this chapter.

2.5 Decision-Making in Contractor Selection

Decision-making is the process of selecting the most appropriate alternative (course of action) from a given or available set of alternatives to achieve a predetermined goal(s) under a given situation. Making decisions is a part of our daily life and we are more often than not confronted with difficult choices where to decide which one is the best choice between a number of imperatives with confidence is not an easy task. The main concern is that all decision problems have multiple, usually conflicting, criteria and uncertainty that always exist in real-world cases. Selection of a construction contractor is also a decision-making by the clients based on their previous experience, intuitive judgment and a set of criteria which might vary between projects and clients.

Multiple criteria decision-making is a process in which decision regarding the selection of best alternative is made in the presence of a set of multiple criteria. In the contractor selection process, the capability of a contractor to deliver the project on time, within budget and as specified is evaluated against a number of important decision criteria such as tender price, past performance, performance potential, etc. It is often true that no one contractor will exist that can better satisfy all decision criteria (Russell and Skibniewski, 1990). Therefore, contractor selection is, in essence, a MCDM problem involving multiple, usually conflicting decision criteria and the trade-off between the decision criteria plays an important role in selecting the most appropriate contractor among a pool of potential candidate contractors.

2.5.1 Multi-Criteria Decision Making Methods

There are a large number of decision-making techniques that utilize the multiple criteria decision approach. Some of them which are potentially useful for decision-making regarding contractor selection include:

2.5.1.1 Conjunctive (Satisficing Method)

In this method the minimum acceptance levels (cut-off values) for all criteria (attributes) are established to filter out the unacceptable alternatives. An alternative that does not meet the minimum acceptable level for all attributes is simply rejected. It means that for an alternative A_k to be acceptable,

$$x_{ki} \geq x_i^*, \forall i$$

where, x_i^* is the minimum acceptable score for attributes x_i and x_{ki} is the score of alternative A_k on attribute i. This method is usually preferred for dichotomizing the alternatives into acceptable/not acceptable class (Hwang and Yoon, 1981).

2.5.1.2 Disjunctive

In this method, an alternative is selected on the basis of its greatest value of an attribute. A minimum acceptable level for each attribute is specified and alternatives which equal or exceed those levels in any one of attributes are selected. Like conjunctive, disjunctive also aims at filtering out unacceptable alternatives, which score below acceptable level on any one of attributes. One major disadvantage with both conjunctive and disjunctive methods is that if an alternative scores below cut-off value on any one of attributes, it will be rejected even though its scores on all other attributes are well above the cut-off values.

2.5.1.3 Dominance

Dominance is a technique in which two alternatives are compared and the dominated one is discarded. An alternative is dominated if there is another alternative which excels it in one or more attributes and at least equals it in the remaining attributes (Zeleny, 1982). The selection procedure consists of comparing first two alternatives and if one is dominated by the other, the dominated one is discarded (Calpine and Golding, 1976). Then the undiscarded alternative is compared with a third alternative and the dominated alternative, if any, is discarded. This process is continued till the set of non-dominated alternatives is determined after (m–1) stages of comparison if there are m alternatives. As this dominated set usually has many elements in it, this dominance method is useful when initial filtering of alternatives is required before the final choice is made (Terry, 1963).

2.5.1.4 Elimination by Aspects

The elimination by aspects method requires that the attributes be arranged in order of discrimination power in a probabilistic mode. Alternatives are compared on one attribute at a time, starting with the attribute having most discriminating power, and the alternatives that do not satisfy some predetermined acceptance levels are eliminated from the process. This elimination process continues with the next attribute in order of discrimination power and so on until only one alternative is left or until all the attributes have been considered.

2.5.1.5 Lexicographic Method

The lexicographic method requires that the attributes be ranked in order of importance. Alternatives are compared with respect to the most important attribute and the alternative having highest value on that particular attribute is selected, as it is the most preferred alternative. If there are several alternatives that are tied on that attribute, then the subset of tied alternatives is resolved with respect to the next most important attribute and this process continues till only one alternative is left or all attributes have been considered. This method is useful in situations where a single attribute seems to predominate. For example, if the tender price were the most important selection criterion, the candidate contractor that offers the lowest price would be selected.

2.5.1.6 Lexicographic Semi-Order

This method is more or less similar to the lexicographic method in procedure. However, in this method an indifference threshold or tolerance value (t) for each attribute is determined in order to allow bands of imperfect discrimination so that one alternative is not judged better just because it has a slightly higher value on the predominated attribute (Luce, 1956). The concept is that two alternatives A_i and A_k are considered as indifferent or tied relative to attribute j if and only if $|A_i - A_k| \leq t_j$. Like the lexicographic method, this method also first compares the alternatives with respect to the most important attribute and the alternative(s) with highest value on that attribute or with a value within the tolerance limit are selected. Then this comparison process proceeds with the second most important attributes and so on until only one alternative is left or until all attributes have been considered.

One major drawback of all the methods discussed so far is that they do not compare all alternatives across all attributes in a simultaneous manner, and hence only a small part of information is utilized in making a final selection. Therefore, these methods do not seem to be mature for their application in complex decision-making problems, such as contractor selection, which requires simultaneous consideration of decision criteria.

2.5.1.7 Maximax

The Maximax method selects the alternatives with highest attribute values for each attribute and the alternative with the largest attribute value is finally selected. It is simply selecting the best alternative among the best alternatives in each of the attributes. The final alternative A^* is selected such that

$$A^* = \{A_k | = \max_k \max_i x_{ki}\}, \forall k, \forall i$$

This method is quite useful in situations where the decision makers are optimistic about the decision-making situation.

2.5.1.8 Maximin

In contrast to maximax, the maximin method selects an alternative by its poorest attribute value rather than its best attribute value. It is a method of selecting the best alternative among the worst alternatives in each of the attributes. Underlying concept of this method is that the chain is as strong as its weakest link (Hwang and Yoon, 1981). The final alternative A^* is selected such that

$$A^* = \{A_k | = \max_k \min_i x_{ki}\}, \forall k, \forall i$$

This method is useful in situations where the decision makers are quite pessimistic about the decision-making situation.

Both maximax and maximin methods have some shortcomings in the decision-making process. Both compare the alternatives with respect to one attribute at a time and hence run the risk of selecting an alternative, which is clearly inferior in all but one attribute which is above average, over another alternative that is clearly superior in all but one attribute which is below average. These methods also make use of only a small part of information in making final selection as alternatives are not compared across all attributes simultaneously. Therefore, these two methods are also not adequate for multiple criteria problem such as contractor selection that involves the simultaneous consideration of decision criteria (attributes).

2.5.1.9 ELECTRE Family of Decision-Making Methods

ELECTRE (**EL**imination **E**t **C**hoix **T**radusant la **RE**alite) methods consist of a pairwise comparison of alternatives in which the concept of outranking relationship is used. The outranking relationship of two alternatives A_k and A_i says that even though the two alternatives do not dominate each other mathematically, the DM accepts the risks of regarding A_k as almost surely better than A_l (Roy, 1973). In these techniques, for each pair of alternatives the set of decision criteria is divided into two distinct subsets- concordance set which is composed of all decision criteria for which the first alternative is preferred to the second and discordance set which is composed of all other decision criteria for which the second alternative is preferred to the first. In order to determine the dominance of one alternative over the other, threshold values are arbitrarily specified for both concordance and discordance indexes, which are equal to the sum of the weights associated with those criteria contained in each subset. Then the aggregate dominance matrix that gives the partial-preference ordering of alternatives is obtained by calculating the intersection of dominance matrices containing concordance and discordance indexes as elements (For detailed procedure please refer to Hwang and Yoon, 1981).

2.5.1.10 PROMETHEE Family of Decision-Making Methods

PROMETHEE (**P**reference **R**anking **O**rganization **METH**od for **E**nrichment **E**valuations) methods also consist of pairwise comparison of alternatives as in ELECTRE methods. In ELECTRE methods, preference threshold values are taken 1 for strict preference and 0 for indifference. However, in PROMETHEE method, pseudo-criterion or quasi-criterion is introduced to avoid jumping of these thresholds values from 0 to 1. Various types of pseudo- criteria can be used depending upon the preferences of the DM (please refer to Brans and Vincke, 1985 for details).

Although these methods utilize the full information contained in the decision matrix, the drawback is the use of threshold values for preferences of the decision makers. The determination of these values is quite arbitrary and these values have significant impact on the selection of the most appropriate alternative. Moreover, if there are a large number of criteria as well as alternatives, the pairwise comparison of alternatives places cognitive burden on decision makers.

2.5.1.11 TOPSIS Method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method considers both the distances from ideal and anti-ideal solutions simultaneously. According to this method the best or most preferred alternative is the one which has shortest distance from the ideal solution and the farthest distance from anti-ideal solution at the same time (Hwang and Yoon, 1981). The ideal solution A^+ and anti-ideal solution A^- are given by

$$A^+ = \{\max_i a_{ij} | j \in J, \forall i\}$$

$$A^- = \{\min_i a_{ij} | j \in J, \forall i\}$$

where a_{ij} is the weighted normalized attribute values. The relative closeness of an alternative with respect to the ideal solution is calculated using separation of each alternative from ideal and anti-ideal solutions given by n-dimensional Euclidean distance, where n is number of attributes.

2.5.1.12 Simple Additive Weighting Method

In this method the most preferred alternative is determined on the basis of the highest score which is calculated by multiplying the relative importance weight of each attribute with the rating of each alternative on the respective attributes. The most preferred alternative A^* is given by

$$A^* = \{A_k \left| \max_k \sum_{i=1}^{n} w_i x_{ki} / \sum_{i=1}^{n} w_i \right.\}$$

where x_{ki} is the rating of alternative k on the ith attribute and w_i the normalized importance weight of the ith attribute. The simple additive weighting method has found widespread application in MCDM problems because of its simple computation and for the reason that it leads to a unique choice since a single number is arrived at for each alternative, and these numbers will be usually different (MacCrimmon, 1968).

Russell and Skibniewski (1990) proposed an interactive model for contractor prequalification, named *Qualifier-I,* using the additive weighting method. In their model, the selected decision criteria were divided into the lower level and the higher level criteria, the importance values of which were derived from the surveyed data using regression technique. The weighted scores of each higher level criterion were obtained by adding the product of score of each low level criterion and their corresponding weights. Then the overall scores of the contractors were obtained by adding the product of higher level criterion scores and their corresponding weights. Ranking of contractors was done based on the overall aggregated scores.

2.5.1.13 Weighted Product Method

The weighted product method determines the aggregate score of alternatives on attributes by raising the rating of alternatives on attributes to the power equal to the respective weight of the attributes. The concept of this method is to penalize alternatives with poor attribute values more heavily. The most preferred alternative A^* is given by

$$A^* = \{A_k \left| \max_k (\prod_{j=1}^{n} (x_{ki})^{w_j}) \right\}$$

where x_{ki} is the rating of alternative k on the ith attribute and w_i is the normalized importance weight of the ith attribute.

2.5.1.14 Multi-Attribute Utility Theory

Multi-attribute utility theory (MAUT) is a method of establishing utility functions by mapping attributes (criteria) values into a constructed scale or mathematical form of preference. Utility is a measure of desirability or satisfaction and provides a uniform scale to compare and/or combine tangible and intangible criteria (Ang and Tang, 1984). A utility function is a mechanism used to quantify the preference of the DM by assigning a numerical index to varying levels of satisfaction of a criterion to the goal (Mustafa and

Ryan, 1990). The utility value of each alternative on each of the attributes is assigned by the decision-maker based on the expected utility function. Hatush and Skitmore (1998) proposed a contractor selection model based on the additive method of utility value which can be represented as

$$U_k = \sum_{i=1}^{n} u_{ki} w_i, \forall i$$

where, U_k is the overall utility value of an contractor k, u_{ki} is the utility of contractor k on the ith attribute and w_i is the normalized importance weight of ith attribute. According to their model, the most preferred contractor is the one with the highest overall expected utility value.

This method combines the advantages of the simple additive method with optimization techniques. MAUT necessitates the establishment of utility function representing the DM's value scale for different criteria, and the utility functions are generally difficult to formulate. Moreover, this approach is time consuming, costly and frustrating to apply as it needs to ask the DM many lottery type questions to establish the utility values for criteria or attributes.

2.5.1.15 Analytic Hierarchy Process

Analytic hierarchy process (AHP), developed by Thomas L. Saaty in 1970s, provides a flexible and easily understood way to analyze and decompose the multiple criteria decision problems. It is designed as a scaling procedure for measuring priorities in a hierarchical goal structure. AHP is a theory of measurement concerned with deriving priorities from pairwise comparisons of homogeneous elements with respect to common criterion or attribute (Saaty, 1994). A pairwise comparison is used to establish the priority importance of each of the decision criteria based on their priority relative to the overall goal. Then alternatives are compared pairwise for each criterion. AHP method involves following steps (Saaty, 1980):

- Identification of overall goal
- Identification of criteria to be used to satisfy the overall goal
- Constructing the hierarchical structure of the decision problem
- Pairwise comparison of decision criteria
- Establishing the weights of the decision criteria using the Eigenvalue method
- Pairwise comparison of alternatives for each of the decision criteria to establish a score for each alternative based on the degree to which it satisfies each of the decision criteria in achieving overall goal.
- Checking the consistency of the judgment

In this method the alternatives are ranked based on the decision maker's judgment concerning the importance of the criteria and the extent to which each alternative satisfies those criteria.

Fong and Choi (2000) and Mahdi *et al.* (2002) proposed contractor selection models based on AHP method. The steps of their models consist of (1) developing the hierarchic structure of decision criteria based on their importance in fulfilling the overall objective; (2) establishing the priority or weight of decision criteria using the Eigenvalue method on the basis of the relative importance of criteria determined by comparing criteria in each level pairwise with respect to their importance to a criterion at a higher lever of hierarchy; (3) establishing a score for each contractor by pairwise comparison of contractors with respect to each criterion; and (4) calculating the overall aggregated scores for contractors using additive weighting method.

2.5.1.16 Goal Programming Method

In goal programming (GP) method, an objective function is set after assembling all decision criteria into a constructed single criterion by specifying a set of aspiration levels or goals for each of the decision criteria as a point of reference. The most preferred alternative is the one that collectively minimizes the deviations from the pre-specified goals. The overall deviation from the pre-specified set of goals for an alternative *k*, d_k is given as

$$d_k = \sqrt{\sum_{i=1}^{n} w_i^2 (x_{ki} - t_i)^2}, \forall i$$

where x_{ki} is the rating of alternative *k* on the *i*th attribute, w_i and t_i are the normalized weight and the target level or goal of the *i*th attribute respectively.

Although the goal programming method is straightforward, the major problem with this method is the difficulty of setting pre-specified goals for decision criteria in a dynamic environment of construction where conditions, requirements and objectives vary between projects and clients (Russell, 1991). Moreover, quantifying the goals poses problem for the DMs, as in some cases many of the constraints or target goals cannot be quantified in a straightforward manner or with a certain degree of accuracy.

2.5.1.17 Multiple Regression Method

Multiple regression is a statistical method to construct an equation or regression model to predict the response variable based on the effect of changes in the multiple independent variables or explanatory variables. A standard regression model can be represented as

$$Y^* = c_0 + \sum_{i=1}^{n} c_i X_i$$

where Y^* is the predicted value of the dependent variable, c_0 is a value representing the y-intercept of the regression line, c_i and X_i are regression coefficient and the value or the score of the *i*th independent variable respectively. An alternative with the minimum residual $|Y^* - Y|$, that is, the difference between the predicted value and the observed value is preferred.

Holt (1995) proposed a multiple regression model for contractor prequalification as

$$P1 = 0.311 + 0.151V_1 + 0.035V_8 + 0.154V_9 - 0.159V_{19} - 0.031V_{20} + 0.232V_{21}$$

where, $P1$= prequalification score; V_1 = size of contractor organization; V_8 = quality of bank reference; V_9 = quality of creditor references; V_{19} = past performance (time overruns); V_{20} = past performance (cost overruns); and V_{21} = past performance (quality achieved).

Although this method is quite useful in predicting performance, its heavy reliance on past/historical data used for developing the regression model and lack of flexibility in adapting the dynamic nature of the construction industry diminishes its applicability to contractor selection problem.

2.5.1.18 Fuzzy MCDM Method

The fuzzy MCDM method is a combination of fuzzy set theory and MCDM method. The central feature of fuzzy set theory is the membership function where the degree of membership of a set is graded between 0 and 1. The possibility of any given statement being true or false can be represented by a range of truth values covering all real numbers from 0 to 1. The fuzzy set, therefore, introduces vagueness (with the aim of reducing complexity) by eliminating sharp boundary dividing members of the class from nonmembers since the transition of member from nonmember is gradual rather than abrupt (Klir and Folger, 1988).

The inclusion of fuzzy set theory or fuzzy logic in the decision-making process enables DMs to incorporate subjective values and feelings into an analytic assessment. The fuzzy MCDM method is very useful and powerful when the decision is to be made in a multiple criteria environment full of uncertainty and vagueness, such as contractor selection. Because of its simplicity in application and vigor in dealing with uncertainty and vagueness in decision-making process, the fuzzy decision theory has found widespread application in almost all areas of study, often requiring a complex decision making – to name a few: diagnosis of health problems (Keree, 1982); wood strength prediction (Ishii and Sugeno, 1985); tender evaluation (Nguyen, 1985); measuring public attitude (Onisawa *et al.*, 1986); evaluation of weapon system (Cheng and Mon, 1994).

Nguyen (1985) proposed a contractor selection system based on fuzzy set theory. In his model, ratings of performances of contractors on decision criteria, i.e. cost, experience and performance are elicited as fuzzy variables which are then converted into real number ranging from 0-1. Then, total scores for contractors are calculated by multiplying the ratings by the corresponding weights of decision criteria. The most preferred contractor is selected using maximin rule explained in Section 2.5.1.8, i.e., selecting the best alternative among the worst alternatives in each of the attributes.

2.5.1.19 Expert System and Artificial Neural Network

An expert system or artificial neural network (ANN) is a massively parallel distributed processor, i.e., a computer-based advisory program that has a natural propensity for storing the rational procedures and knowledge of experts and making it available for use. Russell *et al.* (1990) proposed an expert system, *Qualifier II*, for contractor prequalification process. In their model, the selected criteria were divided into three levels forming a hierarchy. Threshold values or the minimum acceptable values for criteria in each level was set up to establish decision rules by asking "if...then" questions. The attributes of candidate contractors on each criterion is evaluated subjectively by DMs. If any attribute of a candidate contractor does not reach the threshold value set out for a particular "if....then" rule, the contractor is not qualified.

Khosrowshahi (1999) and Lam *et al.* (2001) proposed their prequalification models based on neural network approach. The level of importance of selected criteria and the performance of contractors' attributes on those criteria were measured on a numerical scale. The models were trained using several cases selected for the study and the models predictions were then tested using some independent cases. For a given input situation, their models predict an output relating to qualification status of candidate contractors.

A main advantage of a computer-based advisory model is that the decision rules used for the knowledge base can be modified as per requirements. However, the disadvantage of model based on this approach is its dependence on historical data for establishing the threshold values and its inability to deal with risk associated with prediction based on historical data.

2.5.2 Insights into Other Relevant Decision-Making Approaches

Selection of contractor through competitive tendering process for awarding construction project is generally predominated by the 'lowest price win' doctrine, particularly in public sector procurements, and cost usually remains the single dominating criterion in decision-making process. The main advantage of this method is that it compels the contractors to continuously try to keep the price as low as possible by adopting some innovative approaches. However, there are some innovative decision-making approaches followed by the construction clients where the lowest cost is not a sole winning factor in contractor selection.

2.5.2.1 Average Bid Method

In average bid method, the winning contractor is the one whose bid is closest to the average bid or satisfies a certain relationship with the average of all bid prices (Ioannou and Leu, 1993). Different approaches for determining the average bid price are in use. For example, in Taiwan the winning bidder is the one which is closest to the average of all bid prices and in Italy the contract award goes to the bidder whose price is below the average of all bid prices (Ioannou and Leu, 1993). In France and Portugal the bidders who offer abnormally low bids are disqualified (Russell, 1990b). In Peru the average bid price is determined as follows (Jaafari and Schub, 1990):

(a) When there are only two bidders, the winning bidder is the one who offers the lower bid price or the award goes to the sole contractor if it were the case.

(b) When there are three or more bidders

- The average of all bid prices is calculated
- All bidders that lie 10% below or above the average price are eliminated
- The average of the remaining bid prices is calculated and compared with the client's estimated project budget
- The winning bidder is the one whose price is below the average of the remaining bid prices or closest to the client's estimated budget whichever is smaller.

Some researchers (for example, Jaafari and Schub, 1990; Herbsman and Ellis, 1992; Ioannou and Leu, 1993) hold the opinion that the reason for adopting this average-bid approach is to eliminate the contractors who submit an abnormally low bid, which may be the result of underestimation or of deliberated effort to rely on future claims for compensation or to simply stay in business, and those who submit quite higher price as a result of high indirect cost or profit margin.

2.5.2.2 'A+B' Method

The basic principle of A+B bidding method (Herbsman, 1995), which is also known as cost-time bidding method, is that it uses a value of time factor in determining the winning bid. In this method, each bidder has to submit two proposals- one on the cost (part A) and the other on the time (part B). The 'A' component includes the contractor bid prices for all the works to be performed under the contract and this serves as a basis for cost reimbursement. The 'B' component comprises the dollar value of the contractor's time estimate computed on the basis of the client's estimated value of a time unit, for example road users' cost (such as $/day) in highway construction. The winning bid is the one that has the lowest combined bid (A+B) in terms of dollar value. A+B bidding method has been used by many Departments of Transportation in the United States (AASHTO, 1998). The study by Herbsman (1995) found that the use of A+B bidding method in highway construction has been benefited through time and cost savings gained as a result of reduction of contract time with no addition to the contract cost as compared to the time of similar projects bid under the conventional process, as well as from efficient project management and effective utilization of resources.

2.5.2.3 'A-Q' Method

Like the A+B method, the A-Q bidding method also requires the bidders to submit two proposals- one on the cost (part A) and the other on the non-cost parameters, such as warranty period (part Q). The 'A' component comprises the contractor bid prices for all the works to be performed under the contract. The 'Q' component is the dollar value of non-cost parameters. This 'Q' component value is determined on the basis of the credit value set by the client for a particular project. For example, a contractor provides a 3-year warranty period in excess of the client's minimum requirement and if the client's estimated credit value is $20,000 per year, then the 'Q' value for the contractor will be $60,000. The winning bid is the one that has the lowest combined bid (A-Q) in terms of dollar value. In case of a tie, the winning bidder is the one with longer warranty period. This method is practiced by Maryland Department of Transportation, USA (Palaneeswaran and Kumaraswamy, 2000). Like in A+B method, the A-Q value is only used for selecting the lowest combined value ($) and not for other considerations such as cost reimbursement or liquidated damages or bonus/penalty determination. Some of Departments of Transportation in USA uses this approach or variation of this approach for bridge maintenance projects (Russell *et al.*, 1999).

2.5.2.4 Life Cycle Costing Method

Life cycle costing is a technique, based on the discounted cash flow projections, generally used for economic assessment of the construction projects. It is a most useful and widely used technique for comparing an array of options available for projects- particularly infrastructure projects, with an aim to minimize the whole life cost of the structure by optimizing the operation, maintenance and rehabilitation costs. As in many civil engineering construction projects, for example, bridge and highway construction projects, the operation and maintenance costs significantly exceed the initial cost of construction, the consideration of the whole life cost of the structure during the selection process would result in significant saving of the total cost of the structure. The review of literature shows that Missouri Department of Transportation has evaluated life cycle cost procurement under Special Experimental Project–14(SEP-14) (AASHTO, 1998).

However, these methods are more suitable only when performance parameters such as technical, managerial and financial capabilities of contractors have been taken into consideration and final ranking is to be done solely on the basis of economic parameters. That limits the general applicability of the methods to different levels of selection process.

2.6 Conclusion

This chapter presents a comprehensive review of a wide range of literature covering issues relating to the contractor selection process. This knowledge acquisition process provides an overview of various procurement systems and tendering procedures currently used by the construction clients and advantages and drawbacks of each of them. It also gives some insights into the various contractor selection practices currently in use, selection criteria and evaluation techniques used by construction clients in various countries. The study showed that because of distinct characteristics of each construction project, and differing requirements of client organizations, there is no universal set of decision criteria that can be used in all cases of contractor selection. However, the most common criteria, in addition to tender price, generally considered by construction clients during contractor selection and tender evaluation are those pertaining to Contracting company's attributes, Past performance, Financial capability, Performance potential and Project specific criteria.

The review of multi-criteria decision techniques that are potentially useful for contractor selection process provides insights into various decision-making methods and serves as a knowledge base for selecting an appropriate decision-making method which would be used as a theoretical foundation for the development of the proposed contractor selection system.

Therefore, this knowledge acquisition process helps in establishing the theoretical background and the concept of the subject and provides the state-of-the-existence in decision-making regarding contractor selection process and serves as foundation for formulating strategy for the research work.

Chapter 3
Research Methodology

3.1 Chapter Overview

The overall objective of this research is to develop a contractor selection system capable of assisting construction clients in making decisions, in a more realistic manner, regarding the selection of a contractor capable of delivering the project as per their requirements. In previous chapters, the research objectives are set out for the development of the proposed contractor selection system and the review of literature to gain some insights into the current state of research development in contractor selection is carried out. This chapter presents an outline of various methods that are adopted to achieve the objectives of the research. Underlying this research is the important issue 'how the risk to construction clients of project failure can be reduced by making the right choice of the contractor for the right project'.

'It is the ends that justify the means'. Therefore, the goals and nature of the research dictate the methods to be used to achieve them. Principal methods used for the research include review of literature regarding contractor selection practices, exploring various evaluation techniques that are potentially useful for the development of the proposed contractor selection system, questionnaire survey for data collection, statistical analysis for data mining, developing an integrated computer application for the proposed system and establishing the validity of the developed system. The following sections outline the different phases involved in this research.

3.2 Designing Research Methodology

Research is an organized and deliberate effort to collect new information or utilize existing information for a specific and new purpose such as to provide better understanding of the situations, to improve the quality of decision-making. Research methodology is a tool for obtaining useful information and acquiring answers to the research questions in order to accomplish the research objectives. In order to achieve the overall objective of the research, a methodology is designed, in line with key objectives of the research, as shown in Figure 3.1. The whole research process consists of three phases:

Phase I: Literature review for knowledge acquisition, questionnaire survey for data collection and statistical analysis for data mining;

Phase II: Development of the conceptual contractor selection system and structuring computer application for the system; and

Phase III: Testing of the computer-interactive contractor selection with actual cases of contractor selection and discussion of findings, limitations and recommendations for future works.

Phase I:

3.3 Knowledge Acquisition

Knowledge acquisition is the process of developing a knowledge base and understanding of the previous works or activities in regard to the topic or area being researched. Literature review is a key tool in this process as it provides an insight into the existing knowledge base for taking perceptive, for documenting the status of an issue, and for justifying or motivating additional investigation. It also helps to determine the direction of additional research on the topic, provides specifics for measurement considerations and to assure that the research focuses on the main objectives or purposes of the study. Therefore, an effort was made to conduct a comprehensive review of literature, both published and unpublished, covering the issues relating to contractor selection process so as to establish the theoretical background and the concepts of the subject. The purpose of literature review is to

- better understand the current contractor selection practices and various contractor selection methodologies proposed by previous researchers construction practitioners;

- identify the selection criteria used by construction clients for the assessment of the capabilities of candidate contractors to deliver the project; and

- explore various evaluation techniques potentially useful for contractor selection in multi-criteria environment.

In an attempt to enhance the grasp of the subject in line with these objectives, a wide range of literature on contractor selection practices, selection criteria used by construction clients in different countries, various evaluation techniques used for the assessment of contractor qualifications and capabilities were explored during the review process. This provides the state of the existence in decision-making regarding contractor selection process and serves as foundation for formulating strategy for the research.

This knowledge acquisition process has assisted in organizing thoughts, giving shape to ideas, and achieving new insights for the research. It has also helped in developing a road map and travel plan for the research work.

3.4 Data Collection and Analysis

Obtaining sound data is perhaps the most important and demanding aspect of the research process. Data can be obtained in a variety of ways, in different settings-field or laboratory and from different sources-primary or secondary. There are several data collection methods, each with its own advantages and disadvantages. These methods include interview, questionnaire survey, observation, unobtrusive methods, documents and historical data. The use of appropriate data collection method greatly enhances the robustness of data and, therefore, the value of the research. First of all, preliminary interviews were conducted in an attempt to filter out irrelevant criteria from the preliminary set of decision criteria and sub-criteria selected on the basis of literature review. Based on the information gathered through preliminary interviews, a paper-based questionnaire was designed and sent out by post to the 390 construction practitioners. The Statistical Package for Social Sciences (SPSS) is used to investigate the goodness of data gathered.

3.4.1 Preliminary Study

An initial list of 102 criteria (Refer to Appendix A for details), apart from tender price, is selected on the basis of popularity of their use in the UK, USA, Hong Kong, Australia and Singapore construction industries (Russell *et al*, 1992; Kumaraswamy, 1996; Hatush and Skitmore, 1997; Palaneeswaran and Kumaraswamy, 2001). In order to identify which of these criteria would be significant for the study, several experienced construction practitioners from public agencies and consulting firms were contacted to elicit their opinions on the relevance of these criteria in evaluation process. In order to investigate the relevance of those criteria in assessing the capabilities of contractors, simple fact-finding interviews were conducted. Ten professionals who have been associated with contractor selection and tender evaluation exercise or contract management or construction management participated in the preliminary interviews. Based on the comprehensive and valuable input from those experts, 48 evaluation criteria were selected to be included in the final version of the questionnaire.

3.4.2 Questionnaire Survey

A structured-questionnaire is a pre-formulated written set of questions to which respondents record their answers, usually within rather closely defined alternatives. Questionnaires are an efficient data collection mechanism in situations what is required and how to measure the variables of interest is exactly known. Sound questionnaire design should focus on three area- general appearance of the questionnaire, wording of questions and planning of issues of how the variables will be categorized, scaled, and coded after receipt of the responses (Sekaran, 2003). While designing the questionnaire all these

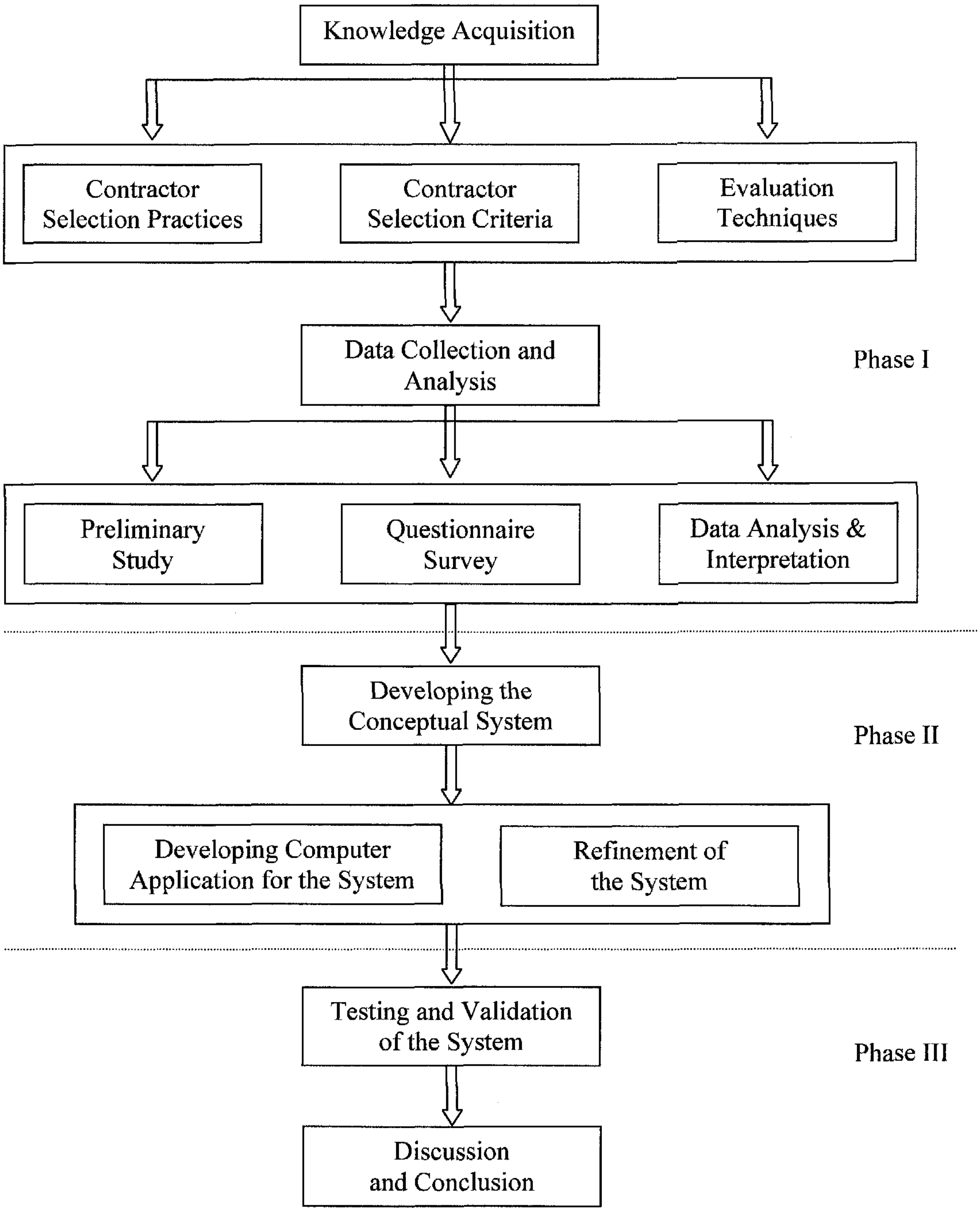


Figure 3.1 Research Framework and Methodology

considerations are taken into account to help respondents enable to understand the questions without difficulty and to provide a meaningful response thereby improving the response rate and increasing the chance of getting more conclusive inferences during data mining process.

The purpose of the questionnaire survey is to elicit the information regarding the selection criteria used for tender evaluation and the criteria evaluation methods used by the construction clients for assessing the capabilities of the contractors so that the relative importance of CSC to be used in the proposed contractor selection system can be established. The relevant and important CSC, in addition to tender price, selected from preliminary round of interviews are categorized as

- Contracting Company's Attributes
- Past Performance of the Contractor
- Financial Capability of the Contractor
- Performance Potential of the Contractor
- Project Specific Criteria

Out of a total number of 390 questionnaires sent out, 300 were posted to clients in Singapore pubic and private sectors who award construction contracts as well as consulting firms who serve as clients' representatives. The remaining 90 were sent out to the contractors with an aim to draw the consensus, from contractors' experiences and standpoints, on the relative importance or weight of those CSC in assessing the capabilities of the contractors to deliver the project. A detailed description on questionnaire design, sample design and sample characteristics are presented in Chapter four.

3.4.3 Data Analysis and Interpretation

Data mining is an activity for identifying hidden relationships and pattern in the data in order to extract intelligent and useful information for knowledge representation. The

The fundamental knowledge regarding the various evaluation methods obtained through review of a wide range of evaluation techniques potentially useful for contractor selection in multi-criteria environment paved the way for the selection of a multiple criteria decision method in combination with fuzzy set theory for the development of the proposed contractor selection system. The underlying reason for selecting this method is that decisions regarding contractor selection are always made on the basis of the past experience and intuitive judgment, making the use of vague terms unavoidable and that the use of linguistic variables in fuzzy decision theory allows the DMs to express their opinions in a more realistic manner in such a situation. In order to avoid the overestimation of the importance of CSC the expected marginal contribution of each of CSC in overall goal of decision-making, that is, to select the most appropriate contractor to deliver the project as specified, is determined by using the concept of the Shapley value (Shapley, 1953). Performances of contractors are first evaluated with respect to each of the CSC to obtain some sort of criterion-specific priority scores which are then aggregated into an overall performance value using simple additive weighting method. A quick and effective evaluation system using the concept of entropy is also developed for observing changes in the financial health of candidate contractors while assessing their financial soundness during selection process.

3.6 Developing Computer Application for the System

The flexibility and data-analysis efficiency of the proposed contractor selection system is to be enhanced through computer interaction, using Visual Basic to enhance the interaction between the users and the system and to provide DMs an easy access to data analysis, which is executed by Microsoft Excel, a powerful package for computation and data analysis. The refinement of the computer-interactive system is carried out throughout the development phase in order to make it free from technical, logical and functional glitches. The computer interaction will assist the DMs in evaluating the ramifications of a complex decision-making problem in order to optimize the choice from all the feasible alternative solutions.

Phase III:

3.7 Testing and Validation

This step includes verification and validation of the system with real contractor selection cases. The purpose of verification is to investigate the workability and flexibility of the proposed model, and the objective of the validation is to check whether the model can perform as it claims to do and to identify the limitations of the developed system. The sensitivity of the developed system, i.e. the effect of variation in input parameters such as weights of the CSC, on the final outcomes of the system is also tested. Eight actual contractor selection cases are used for testing of the developed system.

3.8 Discussion and Conclusion

This includes the summary of the overall findings and implication of the research work, application of the research findings and topics worthy of future research work.

Chapter 4
Data Collection and Analysis

4.1 Chapter Overview

The findings from the knowledge acquisition process in Chapter 2 suggests that there is a strong indication of paradigm shift in the contract award practices, i.e. from 'lowest-price-win' approach to multi-criteria approach or value-based approach. With an aim to corroborate this finding as well as to make full use of the industry expertise in the development of contractor selection system, a questionnaire survey is conducted as a part of data acquisition process. This chapter discusses about the various techniques available for data acquisition process and methodology adopted for the study. It also briefly discusses the interesting findings from the survey.

4.2 Introduction

Contractor selection is a multi-facet decision-making process involving the consideration of multiple selection criteria which are mostly subjective in nature and difficult to gauge. Selection of the contractor for the job has, however, long been primarily based on price alone (Merna and Smith 1990; Holt *et al.*, 1995a). Recently, there is a new substantial literature (Hatush and Skitmore, 1998; Fong and Choi, 2000; Wong *et al.*, 2001; Mahdi *et al.*, 2002; Pongpeng and Liston, 2003a) which suggest that the selection of the contractor for construction projects should be based on a set of decision criteria or multiple criteria such as past performance, performance potential, financial soundness of the firms to execute the project etc., in addition to the proposed tender price. The policy of awarding the contract based on the philosophy of 'lowest-price-win' may not be the indication of the actual cost and quality of the completed project (Voster, 1977; Lewis, 1981; Pearson, 1985; Grogan, 1992; Klein, 1994).

In recent years, the Singapore construction industry has witnessed a spate of project delivery problems. The president of Institute of Architects, Singapore when commenting on the controversial Marine Terrace project (in Singapore) which witnessed the pulling out of three contractors in a single quarter, opined that the problem is not so much the tender exercise or the contract, but the system of the lowest-price tender gets the job (Cheong and Tan 2003). According to Chan Cheok Kai, Managing Director of Fong Hup Engineering, Singapore, desperate companies sometimes quoted prices that are 20 to 30 per cent lower than what government bodies are prepared to pay for a project (Guevara and Tan, 2003). But, the National Development Minister of Singapore revealed that the Housing and Development Board (HDB), Singapore's public housing agency, had rejected a quarter of the lowest bids it received in 2002, which is in contrast with the general practice of awarding contracts to the contractors that quote the lowest tender price (Kaur, 2003). The selection of the lowest bidder is one of the root causes of project delivery problems as contractors, when faced with a shortage of work, desperately quoted low bid price simply to remain in business and hope to be compensated by raising additional income through claims (Hatush and Skitmore, 1997).

Over the past five years, the Housing and Development Authority has terminated 39 of its construction contracts prematurely on account of schedule delay or failure on the part of contractors to comply with contract specifications (Tan, 2004a). The insolvency of 18 construction firms and downgrading of 37 contractors since 2003 (Ibid.) reflect the state of shrinking construction demand and the poor performance of contractors affecting the overall performance of the industry. Two recent accidents in Singapore- the Nicoll Highway collapse and the Fusionpolis cave-in accident in April 2004 (Tan, 2004b) have made construction clients recognize the need for more stringent assessment of attributes pertaining to the safety record of the candidate contractors during the selection process. Though the root causes of these incidents seem to be wide-ranging, for example, from negligence of the contractor to the effect of economic slowdown and the policy of awarding the contracts, all these portray the sorry state of the construction industry reeling from the poor performance of the major players, particularly contractors and have stressed the importance of selecting the contractor whose performance promises a proper balance between the price and non-price attributes. It has also made a call for closer examination of the system of awarding construction contracts in the industry. Therefore, in order to elicit information regarding the preferences of selection criteria and the contract award practices used by construction clients and to investigate the multiple criteria selection tendencies of construction clients, a questionnaire survey was conducted in June-July 2003. The objectives of the survey study are:

- to investigate the selection criteria, in addition to the tender price, used by the construction clients or their representatives for assessing the capabilities of the contractors;
- to observe the construction clients' preference of tender selection and evaluation methods;
- to make a comparison between the level of importance attached to those selection criteria by public and private sector clients and those by contractors; and
- to collect the data from the construction practitioners to make full use of industry expertise in developing a multiple criteria decision system for contractor selection.

4.3 Study Methodology and Sample Coverage

This section highlights the approach adopted for identifying the relevant CSC to be included in the questionnaire, designing questionnaire and sample size.

4.3.1 Preliminary Study

As contractor plays an important role in the success or otherwise of a construction project, decision criteria selected for the appraisal of the candidate contractors' performance and potential parameters play a crucial role in making the right choice of the contractor for the project. Therefore, the identification of critical selection criteria is an important aspect of contractor selection process. A detailed literature review was carried out to gather the CSC and evaluation methods used by construction clients or their representatives in different countries. An initial list of 102 criteria (Refer to Appendix A) were selected on the basis of the review of

- Various literatures regarding CSC popularly used by clients in the UK, the USA, Hong Kong and Australia construction industries (e.g. Russell *et al*, 1992; Construction Industry Development Agency (CIDA), 1993; Kumaraswamy, 1996; Hatush and Skitmore, 1997; Palaneeswaran and Kumaraswamy, 2001);

- Critical selection criteria generally considered by Singapore public sector clients, for example, Land Transport Authority (LTA) and HDB.

In order to identify which of these CSC would be significant for the study and to investigate the relevance of these CSC in assessing the capabilities of the contractors during selection process, some experienced industry professionals were contacted and simple fact-finding interviews were conducted during April-May 2003. Ten professionals who have been associated with contractor selection and tender evaluation exercise or contract management or construction management agreed to participate in interview. Four professionals- one working as public clients' representative with more than 20 years of experience, one very senior professional with more than 35 years of experience with the local construction industry and one contract manager and one quantity surveyor, with more than 10 years and 5 years of local experience respectively, both working for construction firms, voluntarily participated in the personal interviews. All interviews were conducted separately. The other professionals were contacted through email and/or telephone. They were asked to express their opinion (*Yes* or *No*) on whether the selected criteria are relevant in the context of local construction industry. Based on the comprehensive and valuable input from those experts, 48 evaluation criteria, which received at least four '*Yes*' responses from the experts, were selected to be included in the questionnaire.

4.3.2 Questionnaire Design

To gather information about candidate contractors and to assess their capability to deliver the project, clients in different organizations and countries use a mixture of evaluation criteria (for e.g. Hunt *et al.*, 1966; Helmer and Taylor, 1977; Moore, 1985a; Merna and Smith, 1990; Herbsman and Ellis, 1992; Hatush and Skitmore, 1997 and Palaneeswaran and Kumaraswamy, 2001) and these criteria can broadly be regarded as those related to contractor's track record, financial soundness, technical and managerial capabilities. Based on that the selected criteria, apart from price criterion, to be included in the questionnaire are grouped into five main categories (Refer to Appendix B for details) as

- **Group A: Contracting company's attributes**
  These criteria measure the reputation of the contracting company, its post-business attitude, quality achievement, and health and safety record.

- **Group B: Past performance of the contractor**
  These criteria assess the level of expertise offered by the contractor.

- **Group C: Financial capability of the contractor**
  These criteria measure the financial soundness of the construction company and its ability to meet current liabilities, long-term financial obligations and to carry current commitments along with the project under consideration.

- **Group D: Performance potential of the contractor**
  This group of criteria evaluates the availability of resources and experience level of the company in similar type of projects.

- **Group E: Project specific criteria**
  This group assesses the level of technical and management skills of the contractor in light of the project under consideration.

In line with the objectives of the survey outlined in the previous section, the questionnaire is split into five sections:

- Section 1 requests the respondents to assign a level of importance to each of the criteria based on their experience with contractor selection process.
- Section 2 surveys different tendering methods generally used by the construction clients.
- Section 3 asks for different evaluation methods generally used by construction clients for assessing the attributes of the contractors.
- Section 4 requests the respondents to assign the importance value (weight) to main CSC in order to investigate the multiple criteria selection tendencies of construction clients.
- Section 5 requests the respondent's particulars such as designation and work experience and his/her company's details.

In order to measure the respondents' opinions or views towards the statements in the questionnaire, a measurement scale on which the respondents can meaningfully express their views towards the statements or questions is necessary. A good scale should have a sufficient number of response categories to be sensitive enough to discriminate between respondents with differing views. Therefore, a six-point Likert scale is used for recording the rating of statements by the respondents. Respondents are asked to indicate the level of importance of the criteria in assessing the capabilities of the contractor on the scale (Plse. refer to Appendix B for details), where 'IR' means the criterion is irrelevant, 'VL' means the criterion has low importance in assessing the contractors' attributes, 'L' stands for 'low importance', 'M' for 'medium importance', 'I' for 'important' and 'VI' for 'very important'. Later these linguistic terms are converted to numerical values such that IR (0), VL (1), L (2), M (3), I (4) and VI (5) in order to generate a quantified measure of the respondents' views that can be used for statistical analysis. After designing the questionnaire, the industry professionals were again consulted to check its adequacy in terms of reliability, validity and sensitivity.

4.3.3 Evaluating the Adequacy of the Questionnaire

An important aspect of any research is to develop an effective instrument capable of capturing the respondents' characteristics, attitudes and opinions reflecting their overall feeling about an object. The type of questions and the type of rating scales used have major bearing on the measurement level of the data gathered or generated. In other words, the measurement instrument developed should be capable of measuring what it is supposed to measure and producing consistent results. A number of techniques (Shao, 2002) have been developed to assist in calculating coefficients that give a relative indication of the quality of the overall test. In this research work, the questionnaire developed was used to measure the opinions of the industry professionals regarding the importance of selection criteria. The adequacy of the questionnaire constructed can be evaluated based on three criteria-reliability, validity and sensitivity (Ibid.).

4.3.3.1 Reliability

Reliability refers to the stability or consistence of an instrument over time. A number of techniques are available for testing the reliability of instruments. Some of the techniques for checking the reliability of instruments include (Mehrens and Lehmann, 1984):

- **Split-half Reliability**

Split-half reliability measures the degree of consistency across items by randomly splitting a single instrument into two equal sets, with an equal number of items in each set, and examining the correlation between the respondents' total scores derived from the two sets of items. This technique can be used for achievement tests or attitude questionnaire using scales such as rating or Likert (Oppenheim, 1992).

- **Test-Retest Reliability**

This is a simple approach to test the reliability of an instrument and involves administering the same instrument to the same group of respondents on two events.

- **Parallel Forms**

This technique is a way of checking the reliability of an instrument by comparing the responses of a group of respondents with those made by the same respondents group on another instrument that tests the same concept.

- **Cronbach's Alpha (α)**

Cronbach's α is a coefficient that can be used as an indicator of the internal consistency of achievement tests and questionnaires using scales such as rating and Likert (Ibid.) It takes into account the number of questions and the average correlation among questions of a test (Nunnally and Bernstein, 1994).

- **Kuder-Richardson Estimates (K-R 20 Coefficient)**

In this approach, an instrument is split into *n* parts of one item each. K-R method is appropriate for only tests with right/wrong answers.

From the above discussion, it is apparent that only two methods- split-half and Cronbach's α, are appropriate for checking the reliability of questionnaires that use rating or Likert scale. Test-retest and parallel forms are not suitable for this study because of time constraint on the part of industry experts and K-R approach is used for only right/wrong scales which is not the case for this study. Therefore, both tests- split-half and Cronbach's α, are performed to check the reliability of the questionnaire constructed. Tables 4.1 and 4.2 show the SPSS test results of split-half reliability and Cronbach's α. The high coefficients (α) obtained in both tests clearly indicate a high internal consistency and reliability of the questionnaire.

Table 4.1 Results of Split-half Reliability Test

```
****** Method 1 (space saver) will be used for this analysis ******

  R E L I A B I L I T Y   A N A L Y S I S   -   S C A L E   (S P L I T)

Reliability Coefficients

N of Cases =     10.0                     N of Items = 48

Correlation between forms =.9909   Equal-length Spearman-Brown =  .9954

Guttman Split-half =        .9861   Unequal-length Spearman-Brown =.9954

 24 Items in part 1                  24 Items in part 2

Alpha for part 1 =          .9735   Alpha for part 2 =             .9646
```

Table 4.2 Results of Cronbach's Coefficient (α) Test

```
****** Method 1 (space saver) will be used for this analysis ******

  R E L I A B I L I T Y   A N A L Y S I S   -   S C A L E   (A L P H A)

Reliability Coefficients

N of Cases =     10.0                     N of Items = 48

Alpha =     .9848
```

4.3.3.2 Validity

Validity is a measure of a true reflection of the underlying concept an instrument is attempting to measure. In other words, it is an indication of how accurate inferences can be made from the data gathered, which obviously depends on the skillful framing and selection of the questions and the choice of appropriate measurement scale for the test. Various indicators or types of validities are discussed by several researchers (for e.g. Cohen, 1977; Cook and Campbell, 1979; Mehrens and Lehmann, 1984; Oppenheim, 1992 and Nunnally and Bernstein, 1994) that can be used for evaluating validity of an instrument. Some of them include:

- **Content Validity**

Content validity is the extent to which the content or the set of questions of an instrument is representative in measuring what it is supposed to be measuring. It has to do with sample-population representativeness.

- **Criterion Validity**

Criterion validity, also called *concurrent validity*, refers to the accuracy of measures of an instrument and is demonstrated by comparing it with known and accepted standard measures or criteria.

- **Construct Validity**

Construct validity refers to general agreement between a specific measuring instrument and its theoretical concept. It involves drawing inferences from test scores to the theoretical concepts. Good construct validity means that the instrument is measuring that, and only that, it is supposed to be measuring.

- **Statistical Validity**

Statistical validity is the extent to which conclusions can be based on the proper use of statistical tests and not attributed to random errors in sampling and measurement. Increasing the reliability of the instrument, proper selection of sample size, careful design of the research such as effect of sample size and randomization requirements and choice of appropriate statistical tests for analysis are some of the ways to improve statistical validity.

For an instrument that is constructed for studying a complex problem such as contractor selection, it is not easy to test the instrument for content validity because of the complex nature of the problem; for criterion validity because of lack of accepted criteria and measures due to the unique nature of construction, and for construct validity owing to the paucity of parallel theories or difficulty in checking the construct validity of an instrument by comparing with another instrument measuring the same construct because of time and resource constraints. However, a pilot study with those industry experts help improve the intelligibility of the questionnaire by improving the wording of the questions to minimize the possibility of distorted answers due to bias and misinterpretation and thus, enhancing the relevance of the content of the questionnaire. Estimating the sample sizes and appropriate selection of statistical test procedures are discussed in sections 4.3.4 and 4.4.2.

4.3.3.3 Sensitivity

Sensitivity here is concerned with the measurement scale ability to discriminate between respondents who differ even slightly in their opinions regarding what the questionnaire is supposed to measure. Reliability is a prerequisite for sensitivity. Another requirement for sensitivity is that the measurement scale must have sufficient number of items and response categories to facilitate detection of fine variations in the respondents' opinions towards something that is being measured. Since the questionnaire constructed is reliable, as discussed above, and it uses multiple-item, Likert scale for measuring opinions or attitudes, it can be concluded that the sensitivity of the questionnaire is also ensured. Therefore, all the criteria and the scale, with little cosmetic modification, are maintained in the final version of the questionnaire.

4.3.4 Sample Design

The basic purpose of sampling is to generate sample data that can be used to estimate population parameter values as accurately as possible. The accuracy of survey results are significantly affected by the manner in which the sample has been chosen from the target population. The term 'population' is used in a broad sense to designate a group or aggregation of units/elements (persons or objects from which data and information are sought) to be studied where as 'sample' means the proportion of the population selected to be included in the study. In most instances, it is not feasible to cover the entire population for many reasons such as it may not be available for experiment at the time the study are to be made, time and cost considerations, etc. In designing the sample three points are important for consideration (Kapur, 1991). They are: (1) where the sample is to be selected from, (2) the process of selection, and (3) size of the sample. Sampling has two main purposes (Sekaran, 2003): (1) to describe the characteristics of the target population on the basis of information obtained from studying only a small proportion of it - sample, and (2) to ensure that the inferences drawn from the sample study reflect the true characteristics of the target population. The sample design must be consistent with the relevant population of interest, meaning that the sample must be *representative* and *adequate*.

4.3.4.1 Sampling Techniques

Sample technique is a method by which the desired numbers of sample units or elements are selected from the target population for studying and making inferences about the characteristics of interest of the target population. The inferences drawn on the basis of the survey sample cannot be expected to be exactly representative of the population from which it is drawn. This discrepancy may be because of *sampling variability* and *sampling bias*. 'Sampling variability' means the error attributable to mistakes in drawing a sample from a target population. Each time a sample is drawn to estimate a population characteristics, it is always expected to get a different answer. This error may be because of sampling distribution and variability in the population and can be reduced by increasing the size of the sample. 'Sampling bias' refers to the likelihood of sample estimate deviating in an unsystematic way from the true characteristics of the population being studied. This deviation may be the result of incomplete coverage, non-response and deliberate over-representation. In order to minimize the unsystematic errors arising from the sampling variability and to minimize the risk of systematic errors arising from sampling bias, the task of designing a sample is always important in research study.

There are two basic approaches for sampling design- probability sampling method and non-probability sampling method. Probability sampling is an objective procedure in which the probability of selection is known in advance for each population unit. On the other hand, non-probability sampling is a subjective procedure in which the probability of selection for each population unit is not known in advance. Non-probability sampling is more judgmental than objective in the sense that the selection of individual population units is not done on a strictly chance basis; subjective judgment of the researcher plays a role in determining which specific population units get included in the sample. Probability sampling method is usually preferred to non-probability sampling method (Bellenger and Greenberg, 1976). A brief description of various probability and non-probability techniques is provided in the following and the reason for the selection of particular techniques for the study.

The probability sampling methods include:

(i) Simple Random Sampling

In this technique, every sampling element forming the defined target population has a known, equal, nonzero chance of being selected. It is drawn by a random procedure from a sample frame, which is a list containing an exclusive and exhaustive enumeration of all sample elements. Though the simple random sampling method is conceptually simple, it has two associated difficulties (David and Ronald, 1987). The first is that it is often difficult to obtain a complete and accurate sampling frame that will permit a simple random sample to be drawn. The second problem is that one may not wish to have an equal probability of selection of all sample units.

(ii) Systematic Random Sampling

A systematic random sample is one in which each sample element has a known and equal probability of selection. The mechanics of taking a systematic sample are rather simple. Using some form of an ordered list of member units of the target population, random starting point for the first sampled member is selected. Taking into account the size of the sample that need to be drawn from the population, a constant skip interval is determined to ensure the representativeness. Then the skip interval is applied to select every n^{th} member from the random starting point until the necessary sample is drawn. Systematic random sampling is more efficient than simple random sampling (Hair *et al.*, 2003) when elements are ordered with regard to the characteristic of interest as it increases the representativeness. However, the major difficulty with this technique is the problem of estimating the size of the target population and estimating the variance of the universe from the variance of the sample (Hair *et al.*, 2003).

(iii) Stratified Random Sampling

In this technique the target population is divided into different sections, or strata (e.g., regions or age groups) that differ distinctly in respect of the characteristics of interest in the survey. This technique involves three basic steps (Hair *et al.*, 2003): (a) dividing the target population into homogeneous subgroups or strata, (b) drawing random samples from each stratum, and (c) combining the sample from each stratum into a single sample of the target population. In other words, a stratified random sample is one in which a simple random sample is taken from each stratum of interest in the population. This technique aims to reduce the impact of sampling variability by ensuring that different sections of the population or strata are correctly represented in a sample. However, the success of this technique largely depends on the relevance of the stratification factors employed.

(iv) Cluster Sampling

It is formally a method in which a simple random sample or stratified random sample is selected from blocks of all primary sample units, called *clusters* (e.g. regions or work type) that are mutually exclusive. The effect of clustering the sample will depend on two factors: the relative homogeneity of the units of each cluster and the number of units drawn from each cluster for the study. The main advantage of a cluster sampling relative to simple random sampling and systematic random sampling is in overall cost-effectiveness rather than in greater reliability. One primary disadvantage of this method is similarity of responses owing to the tendency for clusters to be homogeneous. This may result in the loss of some of the characteristics of heterogeneity of the target population in the derived sample estimates as all clusters are not represented in the study.

The non-probability sampling methods include:

(i) Quota Sampling

In quota sampling method the target population is dividend into various subclasses or subgroups, based on the parameter of interest such as age, sex, race, income, etc., the sizes of which are first estimated from some external source such as census data. Then the sizes of the quotas for each subgroup are determined to ensure that the sample contains a desired number of units or members from each subgroup. Selection of elements to fill each quota is not necessarily on a random basis but rather on the subjective judgment of the researcher. This great convenience along with the representation of specific subgroups in the desired proportion is the advantage of the quota sampling method. An inherent limitation of this method is subjective process of determining the quota sizes and selection of members to fill each quota.

(ii) Snowball Sampling

In snowball sampling method, which is also called *referral sampling*, initial prospective respondents are selected randomly and other potential respondents are identified on the basis of referrals or other information provided by the initial respondents. This method is typically used in situations (Goodman, 1961) where (a) the defined target population is very small and unique; and (b) compiling a complete list of sampling units is a nearly impossible task. Major advantages of this sampling technique are increased probability of finding desired characteristics of the target population in the sample, cost effectiveness and lower sampling variance. However, this method will induce some bias if there exist significant differences between those people who are known in a specific society and those who are not.

(iii) Convenience Sampling

Convenience sampling is a method of drawing samples as per convenience using a wide variety of *ad hoc* procedures as the study is being conducted. This technique is quite useful during initial phases of the study if target population is homogeneous and sampling units are accessible, convenient and easy to measure and corporative.

(iv) Judgment Sampling

Judgment sampling is a method that utilizes the sound judgment or expertise of an individual or individuals for selecting the members to be included in the sample so that samples that are suitable for the purpose of the study are drawn from the target population.

Even though the representativeness of the sample entirely depends on the expert judgment, this sampling method has relative advantages such as low cost, less time consuming, convenience to use and as good as probability sampling (Vichas, 1982).

It is clear from the above discussion of the various sampling techniques, not all sampling techniques are equally efficient and practical in any research study. Certain factors affect the feasibility of implementing them. For this study, the target population of public sector clients consists of various types of organizations and categories grouped by the nature of works they undertake. In order to ensure that all the characteristics of interest in the target population are included in the chosen samples, the sample selection for private sector clients is done using quota sampling and simple random sampling. Since contractors are grouped under different financial grades, the sample design includes stratification of contractors on the basis of their financial grades and selection of samples using random sampling technique. The following section will focus on determination of sample sizes for each of the target populations.

4.3.4.2 Estimating Sample Size

Determination of an appropriate sample size for the study is always very important task in any research design for the sample size has great impact on the relationship between the population distribution and sampling distribution, which is important in drawing inferences about the population characteristics. If sample size is sufficiently large, i.e., greater than or equal to 30 (Montgomery and Runger, 2003), the sampling distribution approximates the normal distribution irrespective of the population distribution. Three factors play a vital role in determining appropriate sample size (Hair *et al.*, 2003):

- The level of confidence desired in the estimate
- The degree of precision desired in estimating the population characteristics, and
- The variability of the population characteristics under investigation

Many approaches are available for estimating the desired sample size. For this study, the traditional approach is used to estimate appropriate sample sizes. If the sample includes more than 5% of the target population size, which is finite and approximately known, the sample estimate can be determined using the following formula (adapted from Neter *et al.*, 1993)

$$n = \frac{Np(1-p)Z^2}{NE^2 + p(1-p)Z^2} \quad \text{.......................(4.1)}$$

where,

n = the required sample size

N = the size of the target population

p = the planning value for population proportion

Z = the number of standard errors, and

E = allowable error

Based on the equation (4.1), the accepted error range for the estimated sample size can be calculated as

$$E = \sqrt{p(1-p)Z^2(\frac{1}{n} - \frac{1}{N})} \quad \text{........................(4.2)}$$

Hence, this procedure for determining sample size includes,

- Specifying the amount of error (E) that can be allowed
- Specifying the desired level of confidence,
- Determining the number of standard error (Z) associated with the desired confidence level
- Estimating the planning value for population proportion (p)
- Calculating the sample size for the study using the above formula.

The target population for the survey study includes three groups:

- Singapore public sector clients
- Singapore private sector clients
- Construction firms (contractors) operating in the Singapore construction industry.

Construction firms are also considered in the survey with the objective to draw the consensus, from contractors' standpoints, on the importance of those evaluation criteria in assessing the capabilities of the contractors to deliver the project successfully in terms of time, cost and quality standards so that the best value for money is achieved. The questionnaire form sent to the contractors does not include section 2 and 3 mentioned above (Refer to Appendix B).

(1) Sample Estimate for Public Sector Clients

In Singapore, there are around 80 public sector clients (Government of Singapore, 2002) including various contract and procurement departments or sections from government agencies and consulting firms representing the government agencies, that procure construction projects by engaging services of construction firms in the local construction industry. As the size of the target population is very small, all of them are included in the sample group.

(2) Sample Estimate for Private Sector Clients

There are around 910 private sector clients and consulting firms- both building and civil engineering, operating in Singapore construction industry. It includes three subgroups containing around 480 developers firms (REDAS, 2002), around 350 architectural and engineering (A/E) firms (SIA, 2002) and around 80 quantity surveying (QS) and construction management (CM) firms (SISV, 2002). As private sector clients generally engage the service of consulting firms as their representatives in the execution of construction projects, it would be useful to obtain their views regarding the importance of contractor selection criteria. Hence, professional consulting firms are also included in the survey as subgroups of the sample. The appropriate sample size for this target population is calculated using equation (4.1) as follows:

- Assume the desired reliability, i.e., the amount of error that can be allowed is ± 5% (0.05), that is, the sample mean will fall within ± 5% interval of the target population mean.
- Consider the confidence interval as 95%, which is oftentimes used in most of engineering fields to contain the mean of the population (Harrison, 1989).
- Hence, the number of standard error, Z value, associated with the 95% confidence interval is 1.96 (Please refer to Walpole *et al*, 2002, Table A.3, pp 670).
- Value of p is set to 0.5 assuming that 50% of the responses will be returned.
- The target population size, N is 910.

Now, we have

$$n = \frac{910 \times 0.5 \times (1-0.5)1.96^2}{910 \times 0.05^2 + 0.5(1-0.5)1.96^2} = 270.13(271)$$

To assess the appropriateness of the sample size in representing the target population if the sample size (n) is taken as 220, the equation (4.2) can be used to determine the error range as follows:

$$E = \sqrt{0.5(1-0.5)1.96^2(1/220 - 1/910)} = 0.0575 \ (5.75\%)$$

As the error range 5.75% is acceptable, in general 5-10% error range is acceptable if the sample size is 5% or more of the target population size (David and Ronald, 1987), the sample size for the private sector clients group is, therefore, taken as 220. The sizes of the quotas for each subgroup are subjectively determined as 50 A/E firms, 50 QS and CM firms and 120 developers firms. More weightage is given to developers firms as they directly select the contractors for the project or they are the ones who have final say in the selection process albeit they engage the services of the consulting firms for the purpose. Hence, the private sector clients sample group of 220 is finally selected as consisting of 50 A/E firms randomly selected from Singapore Institute of Architects member listing (SIA, 2002), 50 QS and CM firms randomly selected from member directory of Singapore

Institute of Surveyors and Valuers (SISV, 2002) and 120 developers randomly selected from the member list of Real Estate Developer Association, Singapore (REDAS, 2002). Random selection of sample elements was carried out using the simple random sampling procedure in the SPSS program (See Bryman and Crammer, 2001 for details). In this procedure, the numbers of desired sample elements are randomly selected from the list of all sample elements.

(3) Sample Estimate for Contractors

In Singapore, Building and Construction Authority administers the registration of contractors to serve the procurement needs of government agencies. There are around 870 contractors registered with BCA under the workhead of both general building and civil engineering and financial grades of A1, A2, B1, B2, C1 and C2. The grade C3 contractors are not included in this study because they may, in the author's opinion, not be good representatives in the study as the financial limit of the project for which the contractors registered under financial grade C3 can bid is only S$ 500,000 and, hence for such small projects contractor selection procedure is also less stringent and detailed.

The desired sample size for the target population size of around 870 can be calculated using equation (4.1) as follows:

- $N = 870$
- $E = \pm 5\%$
- Confidence interval = 95%
- $Z = 1.96$
- $p = 0.5$ as before

$$n = \frac{870 \times 0.5(1-0.5)1.96^2}{870 \times 0.05^2 + 0.5(1-0.5)1.96^2} = 266.49(267)$$

The accepted error range is calculated using equation (4.2) to assess the appropriateness of the sample size in representing the target population if the sample size (n) is taken 90 as follows:

$$E = \sqrt{0.5(1-0.5)1.96^2(1/90 - 1/870)} = 0.0978 \ (9.78\%)$$

As the estimation error is within the acceptable error range (5-10%), the sample size for the contractor group is taken as 90. Since variances in the strata are not known, an equal weightage for all the three grades is considered more sensible. Therefore, the contractor sample group of 90 finally selected consists of 30 A (A1 and A2) grade firms, 30 B (B1 and B2) grade firms, and 30 C (C1 and C2) grade firms randomly selected from the BCA Contractors Registry (BCA, 2002). A total of 390 questionnaires- 80 to public sector clients, 220 to private sector clients and consulting firms representing them and 90 to contractors, were posted, in June-July 2003, with return envelop pre-stamped and self-addressed.

4.4 Analysis and Results

All returned questionnaires are thoroughly checked for completeness and suitability for use in the statistical analysis.

4.4.1 Sample Characteristics

Thirty-one (31) complete responses were received from the public sector clients, 67 from the private sector clients, and 30 from contractors, giving a response rate of 38.75%, 30.45% and 33.33% respectively. The survey cannot be considered biased following Moser and Kalton (1971), who hold the view that the results of a postal survey are biased if the return rate is lower than the range 30-40% and a 30% response rate is generally considered acceptable (Sekaran, 2003). Table 4.3 shows the details of the sample characteristics. The minimum, average and maximum experience levels of respondents are 4, 15 and 35; 2, 18 and 35; and 5, 16 and 28 years for public sector clients, private sector clients and contractors respectively. As the average experience of respondents from all the three sample groups are quite respectable, their opinions and views on relevance of criteria for contractor selection process obtained through the survey can be regarded as important and reliable.

Table 4.3 Details of Sample Characteristics

Sample Group	Total Sent	Total Return	%	Experience Level of Respondents			
				< 10 Yrs	10-20 Yrs	>20 Yrs	Unknown
Pubic Clients	**80**	**31**	**38.75**	**8**	**8**	**8**	**7**
Private Clients							
Architects Firms	50	12	24.00	1	5	3	3
QS Firms	50	20	40.00	5	4	10	1
Developers	120	35	29.17	4	12	13	6
Total	**220**	**67**	**30.45**	**10**	**21**	**26**	**10**
Contractors							
A1-A2	30	10	33.33	1	2	5	2
B1-B2	30	11	36.67	2	5	4	0
C1-C2	30	9	30.00	2	2	0	5
Total	**90**	**30**	**33.33**	**5**	**9**	**9**	**7**
Overall	**390**	**128**	**32.82**	**23**	**38**	**43**	**24**

4.4.2 Analysis of Data and Discussion of Results

The Statistical Package for Social Sciences (SPSS) for Windows™ version 12 is used to determine whether the criteria identified are important from the respondents' viewpoints in assessing the capabilities of candidate contractors. The statistical tests include ranking of decision criteria based on observed degree of importance assigned (DIA), investigating the association among the respondent types and significant differences in DIA of CSC across respondent groups. Table 4.4 shows the DIA of CSC based on the overall score observed from the ratings of the three respondent groups. The ranking of criteria is carried out on the basis of their observed DIA, that is, the higher the mean DIA value, the higher the rank and vice-versa. At-a-glance study of the results shows that there is slight difference in views of public and private sector clients and between that of clients and contractors as well.

The criterion '*D1: Depth of experience on similar type of project*' is assigned the highest importance value by public sector clients and contractors and the second highest by private sector clients. The private sector clients assigned the highest importance value to the criterion '*E3: Qualification and experience level of project manager*', which was ranked 6 and 6.5 by public sector clients and contractors respondent groups respectively. A possible reason could be that these CSC largely reflect the contractor's ability to troubleshoot a wide range of problems which are usually associated with construction projects, for example, unforeseen underground obstacles, handling the regulation requirements and to efficiently coordinate other parties such as subcontractors and suppliers involved in construction projects and hence they were rated as very important by all the three respondent groups. The criterion '*E7: Availability of testing equipment as quality assurance*' was rated as the least important by the public clients and contractors and the second least important by the private clients who rated the criterion '*D5: Availability of owned construction plant and equipment*' as the least important. A possible explanation could be that a wide range of plant and equipment are available on rental basis in the Singapore construction industry, hence these criteria are not of major concern to both clients and contractors.

One interesting finding is that the criteria pertinent to health and safety '*A4: Health and safety record of the company*' and '*E8: Health and safety setup for the project*' are, from their ranks, not of major concern for both clients and contractors, particularly for private sector clients. This is in contrast with the finding from the study of the UK construction industry by Holt *et al.* (1994b). One possible reason for the low DIA attached to these

Table 4.4 Observed Degree of Importance Assigned (DIA) of CSC

	Public Clients		Privt. Clients		Contractors	
Contractor Selection Criteria (CSC)	**DIA**	**Rank**	**DIA**	**Rank**	**DIA**	**Rank**
A. Contracting Company's Attributes						
A1. Age of the company	3.32258	34.0	3.67164	33.5	3.70000	29.0
A2. Familiarity with regulating authorities	3.29032	35.0	3.92537	21.5	3.56667	34.5
A3. Familiarity with local working culture	2.93548	45.0	3.56716	38.0	3.46667	39.5
A4. Health and safety record of the company	3.70968	23.5	3.65672	35.0	3.80000	21.0
A5. Achievement of quality level (e.g., ISO: 14000)	3.61290	27.0	3.44776	42.0	3.43333	41.0
A6. Post-business attitude	3.53333	30.0	4.14925	8.0	3.80000	21.0
A7. Past failure	3.83871	19.5	4.08955	14.0	3.63333	31.5
B. Past Performance of the Contractor						
B1. Type & scale of the project completed in past 3(5) years	4.16129	5.0	4.14925	8.0	4.03333	8.5
B2. Quality of works in past projects (CONQUAS rating)	3.90323	16.0	3.94030	19.5	3.93333	13.0
B3. Percent of previous works completed on schedule	3.83871	19.5	3.97015	18.0	4.00000	10.0
B4. Standard of sub-contractors' works in past projects	3.25806	36.0	3.92537	21.5	3.90000	15.0
B5. Attitude towards correcting faulty works	3.58065	28.0	4.26866	4.0	4.13333	2.5
B6. Good relationship with past project owners	2.90323	46.5	3.74627	27.5	3.73333	27.0
B7. Relationship with sub-contractors	3.00000	43.0	3.68657	31.5	3.36667	44.0
B8. Relationship with suppliers	2.90323	46.5	3.49254	40.0	3.40000	42.5
B9. Relationship with regulating authorities	3.00000	43.0	3.43284	43.0	3.63333	31.5
B10. Debarment and/or demerit point in past projects	4.35484	2.0	4.11940	13.0	3.93333	13.0
C. Financial Capability of the Contractor						
C1. Current commitments	4.32258	3.0	3.94030	19.5	4.13333	2.5
C2. Authorized and paid-up capital	3.93548	14.5	3.74627	27.5	3.73333	27.0
C3. Working Capital	4.03226	11.0	4.05970	15.0	4.10000	4.5
C4. Current and fixed assets	3.54839	29.0	3.67164	33.5	3.53333	36.5
C5. Net worth	3.74194	22.0	3.64179	36.0	3.50000	38.0
C6. Turnover	3.48387	31.5	3.38806	45.0	3.40000	42.5
C7. Profit generating ability of the company	3.45161	33.0	3.40299	44.0	3.33333	45.0
C8. Liquidity status of the company	4.09677	8.5	4.13433	11.0	3.93333	13.0
C9. Capital structure of the company	3.87097	17.5	3.83582	24.5	3.63333	31.5
C10. Finance Arrangement	3.64516	25.5	3.82090	26.0	3.73333	27.0

Table 4.4 (Continued)

	Public Clients		Privt. Clients		Contractors	
Contractor Selection Criteria (CSC)	**DIA**	**Rank**	**DIA**	**Rank**	**DIA**	**Rank**
D. Performance Potential of the Contractor						
D1. Depth of experience on similar type of projects	4.48387	1.0	4.37313	2.0	4.20000	1.0
D2. Qualification and experience of management staffs	4.25806	4.0	4.13433	11.0	4.10000	4.5
D3. Qualification and experience of technical staffs	4.09677	8.5	4.14925	8.0	4.06667	6.5
D4. Manpower resources	4.09677	8.5	3.83582	24.5	3.83333	18.0
D5. Availability of owned construction plant & equipment	3.09677	39.5	2.95522	48.0	2.93333	47.0
D6. Present workload & capability to support the current project	4.09677	8.5	4.16418	6.0	3.83333	18.0
D7. Quality control and assurance program	3.64516	25.5	4.13433	11.0	3.76667	24.0
D8. Specialized knowledge of particular construction method	3.93548	14.5	3.98507	17.0	3.86667	16.0
E. Project Specific Criteria						
E1. Construction method statement	3.80645	21.0	3.71212	30.0	3.76667	24.0
E2. Proposed project time schedule	4.00000	12.5	4.00000	16.0	4.03333	8.5
E3. Qualification and experience level of project manager	4.12903	6.0	4.40299	1.0	4.06667	6.5
E4. Qualification and exp. Of professional technical staffs	3.87097	17.5	4.19403	5.0	3.96667	11.0
E5. Experience level of project team on similar type of project	4.00000	12.5	4.28358	3.0	3.80000	21.0
E6. Number of direct workers available for the project	3.22581	37.5	3.10448	46.0	3.03333	46.0
E7. Availability of testing equipment as quality assurance	2.83871	48.0	3.02985	47.0	2.90000	48.0
E8. Health and safety setup for the project	3.70968	23.5	3.46269	41.0	3.63333	31.5
E9. The contractor's time and cost saving considerations	3.48387	31.5	3.85075	23.0	3.76667	24.0
E10. Risk sharing level of project owner	3.03333	41.0	3.51515	39.0	3.56667	34.5
E11. Reputation of the subcontractors to be used for the project	3.22581	37.5	3.68657	31.5	3.53333	36.5
E12. Type of performance bond	3.09677	39.5	3.61194	37.0	3.46667	39.5
E13. Cash-out/payment schedule	3.00000	43.0	3.71642	29.0	3.83333	18.0

criteria could be that this sample of respondents might have assumed that there would be little significance in assigning greater importance to these criteria since all construction firms are required by regulatory control to comply with health and safety requirements at worksites. However, another possible, perhaps pessimistic, explanation could be that though the poor safety performance can block the progress of a project and lead to a high costs associated with accident compensations and other hidden costs (Samelson *et al.*, 1981 and The Business Roundtable, 1982), the findings, based on this sample of respondents, gives an indication of a substantial lack of awareness of the importance of health and safety despite the various initiatives taken by the Ministry of Manpower, Singapore (Ministry of Manpower, 2002) and BCA to improve the awareness of the importance of health and safety at all levels of the construction industry. If the Workplace Safety and Health Act is enacted at the end of year 2005 as expected (Tan, 2005) these CSC are likely to gain more attention by construction practitioners. Disparate studies by Pongpeng and Liston (2003b) and Jaselskis and Suazo (1994) also found the similar result. Hence, a further detailed investigation is suggested to find out the degree of awareness of health and safety among the construction practitioners.

It is also interesting to observe that the contractors attach more importance to CONQUAS (CONstrution Quality Assessment System) score (Refer to http://www.bca.gov.sg for details on CONQUAS) which measures the quality of works in the past projects, than both client groups, particularly the public clients. One possible reason for this could be that higher CONQUAS score, besides being a direct measure of quality performance in the previous projects, will give contractors a tender price advantage or discount in future public construction projects, and it also gives the reflection of a company's reputation in quality performance. Though BCA has made the requirement of quality certificate like ISO: 9000 as mandatory requirement for the contractors in the higher financial grades to be eligible for bidding public projects, the finding reveals that both clients and contractors place less emphasis on the criterion '*A5: Achievement of quality level*'. It also reflects the view of some of the interviewees that the achievement of quality certificate has nothing to do with the actual quality level of the finished product. Among those measuring the financial capability of the candidate contractors, criteria '*C1: Current commitments*', '*C8: Liquidity status of the company*' and '*C3: Working capital*' are highly rated. These criteria measure a company's potential cash reservoir to meet its current liabilities and the cushion available to the business for carrying receivables and for financing day-to-day operation because in construction debtors, work-in-progress, retained money by the clients have to be carried by the contractors all along the project life.

4.4.2.1 Comparison of Top 15 CSC

In order to observe the differences in views between respondents groups, the top fifteen evaluation criteria, in order of observed DIA, preferred by public sector clients, private sector clients and contractors respondent groups are listed in Tables 4.5-4.7 respectively. Comparison of these top 15 CSC across respondent types reveals that there are 8 common CSC with varying DIA. All these CSC measure the candidate contractor's past experience, management capability and financial soundness. The criterion '*B10: Debarment and/or demerit point in past projects*', which reflects the candidate contractor's overall performance on quality, safety and management aspects, was considered as (very) important – ranked second by public clients and thirteenth by both private clients and contractors. As most public sector organizations require this as a main selection criterion in most public construction projects in Singapore, it is not surprising why public clients placed more emphasis on the criterion 'B10' than other respondent groups.

Table 4.5 Top 15 Selection Criteria Preferred by Public Sector Clients

Selection Criteria	MR	Rank
1. Depth of experience on similar type of projects	4.48387	1.0
2. Debarment and/or demerit point in past projects	4.35484	2.0
3. Current commitments	4.32258	3.0
4. Qualification and experience of management staffs	4.25806	4.0
5. Type and scale of the project completed in past 3 years	4.16129	5.0
6. Qualification and experience level of project manager	4.12903	6.0
7. Qualification and experience of technical staffs	4.09677	8.5
8. Manpower resources	4.09677	8.5
9. Present workload and capability to support the current project	4.09677	8.5
10. Liquidity status of the company	4.09677	8.5
11. Working Capital	4.03226	11.0
12. Proposed project time schedule	4.00000	12.5
13. Experience level of project team on similar type of project	4.00000	12.5
14. Specialized knowledge of particular construction method	3.93548	14.5
15. Authorized and paid-up capital	3.93548	14.5

Table 4.6 Top 15 Selection Criteria Preferred by Private Sector Clients

Selection Criteria	MR	Rank
1. Qualification and experience level of project manager	4.40299	1.0
2. Depth of experience on similar type of projects	4.37313	2.0
3. Experience level of project team on similar type of project	4.28358	3.0
4. Attitude towards correcting faulty works	4.26866	4.0
5. Qualification and exp. Of professional technical staffs	4.19403	5.0
6. Present workload and capability to support the current project	4.16418	6.0
7. Type and scale of the project completed in past 3 years	4.14925	8.0
8. Post-business attitude	4.14925	8.0
9. Qualification and experience of technical staffs	4.14925	8.0
10. Quality control and assurance program	4.13433	11.0
11. Qualification and experience of management staffs	4.13433	11.0
12. Liquidity status of the company	4.13433	11.0
13. Debarment and/or demerit point in past projects	4.11940	13.0
14. Past failure	4.08955	14.0
15. Working Capital	4.05970	15.0

Table 4.7 Top 15 Selection Criteria Preferred by Contractors

Selection Criteria	MR	Rank
1. Depth of experience on similar type of projects	4.20000	1.0
2. Current commitments	4.13333	2.5
3. Attitude towards correcting faulty works	4.13333	2.5
4. Working Capital	4.10000	4.5
5. Qualification and experience of management staffs	4.10000	4.5
6. Qualification and experience of technical staffs	4.06667	6.5
7. Qualification and experience level of project manager	4.06667	6.5
8. Proposed project time schedule	4.03333	8.5
9. Type and scale of the project completed in past 3 years	4.03333	8.5
10. Percent of previous works completed on schedule	4.00000	10.0
11. Qualification and exp. Of professional technical staffs	3.96667	11.0
12. Liquidity status of the company	3.93333	13.0
13. Quality of works in past projects (CONQUAS rating)	3.93333	13.0
14. Debarment and/or demerit point in past projects	3.93333	13.0
15. Standard of sub-contractors' works in past projects	3.90000	15.0

From the DIA attached to the criterion by all the respondent groups it is, however, apparent that past performance of candidate contractor can be viewed as an important CSC for all the respondent groups.

Other CSC that appear in clients' top 15 lists include '*D6: Present workload and capability to support the current project*' and '*E5: Experience level of project team on similar type of project*'. '*E2: Proposed project time schedule*' appears in the top 15 list of public clients and contractors. No time or schedule related CSC appears in the private clients' top 15 list. Private clients indicated '*A6: Post-business attitude*' and '*B5: Attitude towards correcting faulty works*' as important; whereas contractors considered the criterion 'B5' as important. This result reflects the emphasis placed by private clients and contractors on developing the long-term relationship. Public clients are the only group to have CSC '*D8: Special knowledge of particular construction method*' and '*C2: Authorized and paid-up capital*' appear in the top 15 CSC list. The reason why the criterion 'C2' was given high priority could be that in many public projects this criterion is considered as an important criterion in prequalification process. BCA also considers '*C2: Authorized and paid-up capital*' as a criterion during periodic registration of contractors. CSC that appear only in the top 15 list of private clients are '*A6: Post business attitude*' and '*A7: Past failure*'. '*B2: Quality of works in past project (CONQUAS rating)*', '*B3: Percent of previous works completed on schedule*' and '*B4: Standard of subcontractors' works in past projects*' appear only in the contractors' top 15 list and they all seem to be desirable for contractors to impress the clients in the first place.

The lowest DIA for a particular criterion among all the three respondent groups is 2.84 which is near 'medium importance'. It shows that from the viewpoint of the sample of respondents surveyed, all the CSC included in the questionnaire are relevant for assessing the capabilities of candidate contractors during selection process.

4.4.2.2 Test for Association

In order to investigate the strength and nature of relationship between the pairs of the respondent groups, the Spearman Rank Correlation Coefficient (SRCC) test is conducted. The reason for using SRCC test for the purpose is that there is no knowledge about the distribution of the populations and the respondents' opinions regarding the importance of criteria are measured on an ordinal scale. Correlation test attempts to measure the strength and the nature of relationship between two variables by means of a single number or index called a correlation coefficient, denoted by r_s for SRCC. The value of r_s will range from -1.0 to +1.0 (Montgomery and Runger, 2003), the plus sign (+) occurring for identical ranking of variables whereas the minus sign (-) occurring for reverse ranking of variables by respondent groups, that is

- A value of r_s being +1.0 indicates that the variables are rated by the respondent groups in perfect identical manner.

- A correlation of -1.0 means that the variables are rated by the respondent groups in perfect inverse manner.

- A value of $r_s = 0$ indicates there is no relationship between ratings of variables by two groups.

Table 4.8 shows the results of SRCC tests. The correlation coefficients for different pairs of respondent groups are 0.714 between public and private clients, 0.751 between public clients and contractors and 0.841 between private clients and contractors and they are significant at 1% confidence level. These statistics indicate a strong correlation between different pairs of respondent groups and it in turn confirms the consensus among respondent groups on the importance and relevance of the selected CSC in assessing the capabilities of candidate contractors during selection process.

Table 4.8 Spearman Rank Correlation Coefficient for Different Pairs of Respondent Groups

Respondents		**Public Clients**	**Private Clients**	**Contractors**
Public Clients	Correlation Coefficient Sig. (2-tailed) N (Selection criteria)	1.000 - 48		
Private Clients	Correlation Coefficient Sig. (2-tailed) N (Selection criteria)	0.714** 0.000 48	1.000 - 48	
Contractors	Correlation Coefficient Sig. (2-tailed) N (Selection criteria)	0.751** 0.000 48	0.841** 0.000 48	1.000 - 48

** Correlation is significant at the 0.01 level (2-tailed)

However, these statistics do not reflect which CSC are causing this strong association and which are significantly different from others across the sampling groupings. Since the correlation does not indicate the cause/effect relationship, it is always important to investigate the causal relationship between variables, i.e. which variable causes the other (Bryman and Cramer, 1999: pp 181-82). Table 4.9 shows the coefficient of determination (r^2) for different pairs of the respondent groups.

Table 4.9 Coefficient of Determination

Respondent Types	**Correlation Coefficient (r)**	**Coeff. Of Determination (r^2)**
Public Clients/Privt. Clients	0.714	0.501 (50.1%)
Public Clients/Contractors	0.751	0.564 (56.4%)
Privt. Clients/Contractors	0.841	0.707 (70.7%)

They are 50.1, 56.4 and 70.7% respectively between public and private clients, public clients and contractors, and private clients and contractors. The coefficient of determination explains how far variation in one variable is accounted for by the other. From the values of r^2, from moderate to high causation of DIA variation of CSC in any pair of respondent types is accounted for by the variation of DIA of CSC from each respective respondent pair. However, the results from these tests do not clearly indicate which DIA means are significantly different from each other across the respondent types. The following section will focus on investigating the true differences in perceptions regarding the importance of CSC among the respondent groups.

4.4.2.3 Multiple Comparisons for Investigating True Differences

Figure 4.1 shows the comparison of mean value of observed DIA of CSC among different respondent groups along with the mean observed DIA of all responses (all) which are rank-ordered. The graph provides some visual evidence of significant differences in perception regarding the DIA of CSC among the respondent groups. However, the finding does not clearly indicate which means are significantly different from each other across respondent groups. Therefore, the multiple comparison approach will be employed to pinpoint where such differences exit among the respondent types.

A number of statistical procedures are available for testing significant differences among respondent groups (Winner *et al.*, 1991 and Norusis, 1998). In order to observe the effect of test procedure on the final results, i.e. the power of statistical procedure on the test results, both parametric test and non-parametric test, which require less stringent assumptions about the data (Winner *et al.*, 1991 and Norusis, 1998), are performed on the survey data. Table 4.10 presents the summary of the results of both parametric (ANOVA) and non-parametric (Kruskal-Wallis) tests (Refer to Tables C1 and C2 in Appendix C). From the table, there are 28 criteria showing significant differences among respondent groups in both parametric and non-parametric tests. It is also quite apparent from the results that the respondents show significantly different views on the importance of CSC relating to past performance (7 items) and project specific criteria (10 items). It is interesting to observe that out of 28 only 2 criteria, i.e. C9 and E8 in ANOVA test and D1 and E6 in Kruskal-Wallis test, are different and the rest are identical in both tests. It exhibits that there is very little or no effect of the power of statistical procedures on the final results.

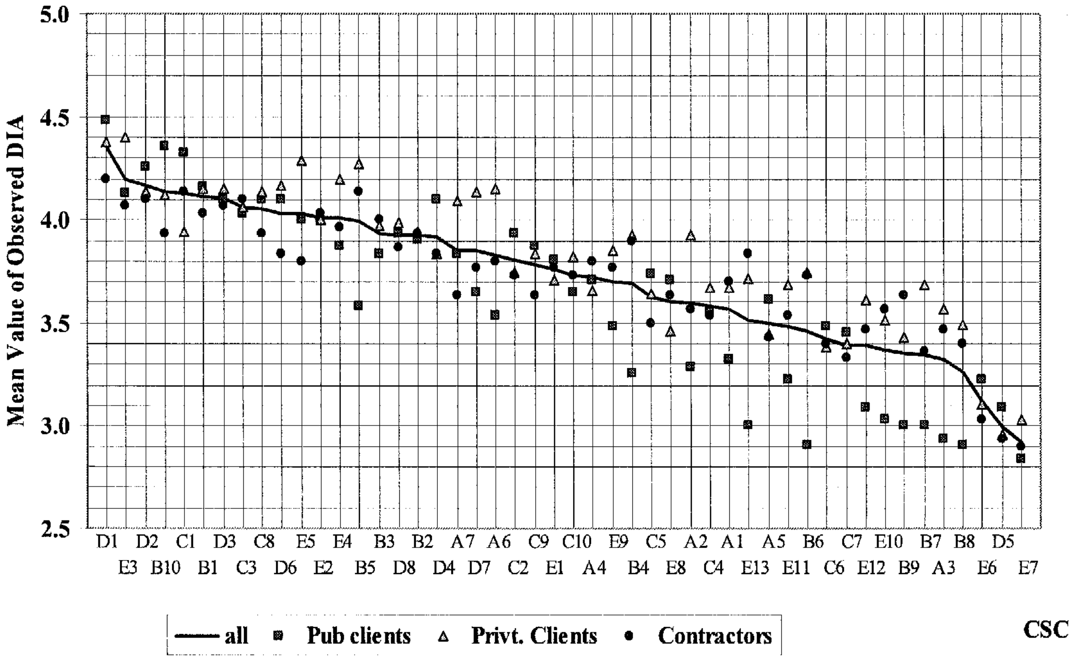


Figure 4.1 Comparison of Mean Observed DIA across Respondent Types

Therefore, in order to identify where the statistical differences amongst respondent groups exist multiple comparison procedure is applied. A number of multiple comparison procedures are available for pair-wise comparisons among means when the population variances are homogeneous or heterogeneous (Kirk, 1995: pp 158). Some researchers have their favorite which others argue are not good choice. The homogeneity of variance test has revealed that there is a significant departure from the equal variance assumption. Therefore, *Dunnett's T3* post hoc method, which is suitable when populations variances are heterogeneous and sample sizes are equal/unequal (Ibid.) as is the case, is conducted on the data to investigate the true differences across the respondent groups. An adjusted significance level of 0.017 was used as a measure of strength to distinguish the significant differences among the three respondent groups (For details, please refer to Rosenthal and Rosnow 1991: p 329; Norusis 1993: p 273; and Bryman and Cramer 2001: p 156). The results of *Dunnett's T3* test are presented in Table C3 (Refer to Appendix C). The detailed analysis of the result reveals that there is only one criterion, namely 'A2: Familiarity with regulating authorities' that is significantly different to all the three respondent groups.

With an aim to check the effect of test procedure on the analysis results the *Bonferroni* post hoc procedure is also performed on the data. The *Bonferroni* procedure is used when populations variances are homogeneous and samples sizes are equal/unequal (Kirk, 1995: pp 158). The results of the *Bonferroni* test are presented in Table C4 (Refer to Appendix C). Table 4.11 shows a summary of the results of the *Bonferroni* and *Dunnett's T3* tests. The results from the test confirms the same result, i.e. there is only a single criterion, viz., 'A2: Familiarity with regulating authorities' that is significantly different to all the three respondent groups, and all other criteria on which at least one pair of the respondent groups is statistically different, are same in both tests. It again confirms that there is very little or no effect of the power of statistical procedures on the final results.

The study of the multiple comparisons results in Table 4.11 (and Table C3 and C4) in light of the finding in Table 4.4 shows that private clients attached more importance value to the criterion '*A2: Familiarity with regulating authorities*' as compared to other respondent groups. One possible explanation could be that a good relationship with regulating authorities is always important to facilitate smooth implementation of the project by avoiding confusion and misunderstanding throughout the project. The results also show that there are 10 criteria which pubic clients viewed differently from both private clients and contractors, 5 criteria which private clients did not rate in the same way as the two other respondent groups, and 7 criteria which at least one sample group viewed differently from either of the remaining two groups.

Table 4.10 Summary of the Results of Parametric and Non-Parametric Tests

All tests are significant at the 0.05 level; ^ All CSC are numbered in the sequence as cited in Table 4.4.

ANOVA						Kruskal-Wallis		
CSC^		**Sum of Squares**	**Mean square**	**F**	**Sig.**	**Criteria**	**Chi-Square**	**Sig.**
A2	Between groups Within groups	61.262 514.170	30.631 1.125	27.225	0.000	A2	53.785	0.000
A3	Between groups Within groups	50.429 556.571	25.215 1.218	20.704	0.000	A3	42.344	0.000
A6	Between groups Within groups	33.850 376.011	16.925 0.823	20.571	0.000	A6	36.224	0.000
A7	Between groups Within groups	14.957 423.554	7.479 0.927	8.069	0.000	A7	9.376	0.009
B4	Between groups Within groups	35.068 437.669	17.534 0.958	18.038	0.000	B4	31.219	0.000
B5	Between groups Within groups	37.555 321.791	18.778 0.704	26.668	0.000	B5	36.093	0.000
B6	Between groups Within groups	69.795 415.551	34.897 0.909	38.378	0.000	B6	61.364	0.000
B7	Between groups Within groups	45.616 429.330	22.808 0.939	24.278	0.000	B7	37.837	0.000
B8	Between groups Within groups	38.879 489.719	19.440 1.072	18.141	0.000	B8	28.292	0.000
B9	Between groups Within groups	50.016 574.845	25.008 1.258	19.881	0.000	B9	32.037	0.000
B10	Between groups Within groups	10.273 341.988	5.137 0.748	6.864	0.001	B10	10.860	0.004
C1	Between groups Within groups	7.123 268.309	3.562 0.587	6.066	0.003	C1	11.037	0.004
C8	Between groups Within groups	4.490 277.171	2.245 0.607	3.701	0.025	C8	9.642	0.008
C9	Between groups Within groups	4.684 312.662	2.342 0.684	3.423	0.033	D1	9.276	0.010
D4	Between groups Within groups	4.634 240.363	2.317 0.526	4.406	0.013	D4	8.958	0.011
D6	Between groups Within groups	11.694 292.254	5.847 0.640	9.143	0.000	D6	16.704	0.000
D7	Between groups Within groups	24.410 284.483	12.205 0.623	19.606	0.000	D7	40.338	0.000
D8	Between groups Within groups	4.733 256.160	2.367 0.561	4.222	0.015	D8	9.429	0.000
E3	Between groups Within groups	10.636 243.145	5.318 0.532	9.995	0.000	E3	16.597	0.000
E4	Between groups Within groups	12.863 227.824	6.432 0.499	12.901	0.000	E4	26.190	0.000
E5	Between groups Within groups	22.028 243.067	11.014 0.532	20.738	0.000	E5	39.166	0.000
E7	Between groups Within groups	5.369 370.074	2.685 0.810	3.315	0.037	E6	7.134	0.028
E8	Between groups Within groups	5.440 407.725	2.720 0.892	3.049	0.048	E7	9.488	0.009
E9	Between groups Within groups	14.831 340.769	7.416 0.746	9.945	0.000	E9	21.958	0.000
E10	Between groups Within groups	22.518 495.124	11.259 1.083	10.392	0.000	E10	11.929	0.003
E11	Between groups Within groups	15.026 401.607	7.513 0.879	8.549	0.000	E11	24.332	0.000
E12	Between groups Within groups	19.915 546.596	9.957 1.196	8.325	0.000	E12	8.686	0.013
E13	Between groups Within groups	66.871 464.109	33.436 1.016	32.923	0.000	E13	48.205	0.000

Table 4.11 Summary of Post-hoc Multiple Comparisons in CSC among Respondent Types

CSC^	*Post hoc* method	Public-Private Client			Public Client-Contractor			Private Client-Contractor		
		MD	SE	Sig.	MD	SE	Sig.	MD	SE	Sig.
A2	Bonferroni	-.90*	.124	.000	-.47*	.145	.004	.43*	.121	.001
	Dunnett T3	-.90*	.136	.000	-.47*	.154	.008	.43*	.116	.001
A3	Bonferroni	-.83*	.130	.000	-.68*	.151	.000	.14	.126	.774
	Dunnett T3	-.83*	.127	.000	-.68*	.155	.000	.14	.131	.622
A6	Bonferroni	-.66*	.106	.000	-.31	.124	.037	.35*	.104	.002
	Dunnett T3	-.66*	.112	.000	-.31	.141	.081	.35*	.111	.005
A7	Bonferroni	-.18	.113	.342	.26	.132	.144	.44*	.110	.000
	Dunnett T3	-.18	.103	.231	.26	.148	.220	.44*	.130	.003
B4	Bonferroni	-.67*	.115	.000	-.64*	.134	.000	.04	.112	1.000
	Dunnett T3	-.67*	.134	.000	-.64*	.152	.000	.04	.106	.978
B5	Bonferroni	-.72*	.098	.000	-.56*	.115	.000	.16	.098	.315
	Dunnett T3	-.72*	.117	.000	-.56*	.139	.000	.16	.096	.290
B6	Bonferroni	-.93*	.112	.000	-.95*	.130	.000	-.02	.109	1.000
	Dunnett T3	-.93*	.125	.000	-.95*	.139	.000	-.02	.101	.997
B7	Bonferroni	-.79*	.114	.000	-.49*	.133	.001	.30	.111	.021
	Dunnett T3	-.79*	.129	.000	-.49*	.153	.005	.30	.111	.022
B8	Bonferroni	-.72*	.121	.000	-.64*	.142	.000	.08	.118	1.000
	Dunnett T3	-.72*	.138	.000	-.64*	.158	.000	.08	.114	.875
B9	Bonferroni	-.75*	.132	.000	-.86*	.153	.000	-.10	.128	1.000
	Dunnett T3	-.75*	.143	.000	-.86*	.157	.000	-.10	.120	.768
B10	Bonferroni	.20	.102	.164	.44*	.118	.001	.24	.099	.046
	Dunnett T3	.20	.091	.096	.44*	.133	.004	.24	.118	.121
C1	Bonferroni	.30*	.090	.002	.14	.105	.513	-.16	.088	.204
	Dunnett T3	.30*	.086	.002	.14	.096	.357	-.16	.085	.172
D4	Bonferroni	.18	.085	.101	.29*	.099	.011	.11	.083	.558
	Dunnett T3	.18	.084	.090	.29*	.092	.006	.11	.080	.425
D6	Bonferroni	-.10	.094	.874	.29	.109	.024	.39*	.091	.000
	Dunnett T3	-.10	.090	.615	.29	.113	.032	.39*	.097	.000
D7	Bonferroni	-.51*	.093	.000	-.10	.108	1.000	.41*	.090	.000
	Dunnett T3	-.51*	.077	.000	-.10	.113	.749	.41*	.106	.001
E3	Bonferroni	-.27*	.086	.005	.06	.100	1.000	.33*	.083	.000
	Dunnett T3	-.27*	.086	.006	.06	.112	.939	.33*	.091	.001
E4	Bonferroni	-.37*	.083	.000	-.07	.097	1.000	.30*	.081	.001
	Dunnett T3	-.37*	.080	.000	-.07	.098	.859	.30*	.085	.002
E5	Bonferroni	-.35*	.086	.000	.15	.100	.382	.50*	.083	.000
	Dunnett T3	-.35*	.087	.000	.15	.103	.364	.50*	.084	.000
E9	Bonferroni	-.45*	.101	.000	-.34*	.118	.011	.11	.099	.837
	Dunnett T3	-.45*	.098	.000	-.34*	.113	.008	.11	.098	.621
E10	Bonferroni	-.50*	.122	.000	-.58*	.142	.000	-.09	.119	1.000
	Dunnett T3	-.50*	.147	.003	-.58*	.156	.001	-.09	.102	.788
E11	Bonferroni	-.45*	.110	.000	-.32	.128	.043	.14	.107	.579
	Dunnett T3	-.45*	.104	.000	-.32	.128	.044	.14	.113	.521
E12	Bonferroni	-.51*	.128	.000	-.24	.150	.339	.27	.125	.094
	Dunnett T3	-.51*	.156	.004	-.24	.173	.430	.27	.113	.052
E13	Bonferroni	-.85*	.118	.000	-1.01*	.138	.000	-.15	.115	.555
	Dunnett T3	-.85*	.140	.000	-1.01*	.158	.000	-.15	.108	.402

^ All CSC are numbered in the sequence as cited in Table 4.4.
MD= Mean Difference (I-J)
SE=Standard Error
*MD is significant at the 0.017 level

Among the CSC pertaining to the contracting company attributes, there is a clear variation in DIA attached to the criterion '*A6: Post-business attitude*' among the respondent groups. One possible reason why private clients attached more weight to the criterion compared to other respondent groups could be that it can result into a good or improved relationship between the client and the contractor benefiting the selection of the contractor, for example, reduction in transaction costs, for future projects through selective tendering or negotiation which is the most common type of tendering procedure used by Singapore private clients. The results also highlight the apparent variation in DIA of CSC related to past performance of the contractor among the respondent groups- particularly, public clients viewed those CSC significantly different from the other two respondent groups. Public clients viewed those CSC reflecting relationship with past project owners, suppliers, subcontractors and regulating authorities significantly different from private clients and contractors who attached more priority to them. A good relationship among team players is always important as it creates conducive working environment resulting in effective communication flow and less chances of misunderstanding and disputes. The significantly different views of public clients on these CSC can in the author's opinion be attributed to individual perception and the environment in which the contract decisions are made.

One interesting finding from the study is that all the three respondent groups showed consensus on DIA of all CSC measuring the financial capability of the contractors, except the significantly different views of public and private clients on the criterion 'C1', which in the author's opinion could be attributed to their perceptions. Among CSC measuring performance potential of candidate contractors, private clients viewed the criterion '*D7: Quality control and assurance program*' significantly different from public clients and contractors. There are three CSC, viz., '*E3: Qualification and experience level of project manager*', '*E4: Qualification and experience of professional technical staffs*' and '*E5: Experience level of project team on similar type of project*' where private clients perceived DIA are significantly different from those of the other two respondent groups. These CSC were rated highly by private clients. Public clients placed less emphasis and viewed '*E9: The contractor's time and cost saving consideration*', '*E10: Risk sharing level of project owner*', '*E11: Reputation of the subcontractor to be used for the project*', '*E12: Type of* *performance bond*' and '*E13: Cash-out/payment schedule*' significantly different from both private clients and/or contractors. One interesting finding is that there is no CSC on which this sample of contractors surveyed is significantly different from both client types.

4.4.3 Selection Criteria Preferences

In order to get some insights into construction practitioners' selection criteria preferences, the section 4 of the questionnaire asked the respondents to assign the weight on a scale of 0 to 100 (0 being irrelevant and 100 being most important) to main CSC including tender price according to their importance in assessing the attributes of candidate contractors during contractor selection. The respondents are also encouraged to suggest any other major CSC which they generally consider to be important. Figure 4.2 highlights the preferences of CSC by Singapore construction clients and contractors based on the mean weights observed through the questionnaire survey as shown in Table 4.12.

Table 4.12 Observed Mean Weights of CSC

Respondents	**Normalized Value of Observed Mean Weights of CSC (%)**					
	A	**B**	**C**	**D**	**E**	**F**
Public Clients	12.35	17.76	16.11	14.51	13.73	25.55
Privt. Clients	11.14	15.11	17.75	13.02	9.05	33.93
Contractors	12.20	14.08	18.93	13.77	10.43	30.54

The results of ANOVA and Kruskul-Wallis tests in Table 4.13 show a high degree of consensus on the importance value of CSC among these samples of the respondent groups. However, there is a significant difference in perception regarding the importance value of 'project specific criteria' among the respondent groups. The results of Post hoc multiple comparison in Table 4.14 highlight that private sector clients viewed 'project specific criteria' significantly different from their counterparts in public sector. This significant difference in opinions between public and private clients can in the author's opinion be

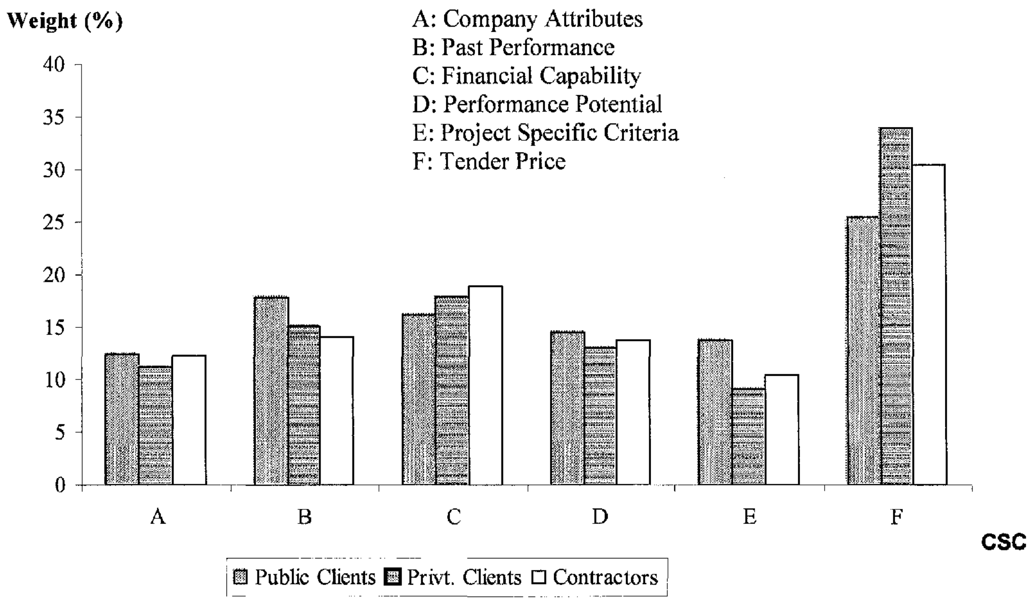


Figure 4.2 Selection Criteria Preferences of Singapore Construction Practitioners

Table 4.13 Results of Parametric and Non-Parametric Tests on Observed Weights of CSC

ANOVA						Kruskal-Wallis		
CSC		Sum of Squares	Mean square	F	Sig.	Criteria	Chi-Square	Sig.
A	Between groups Within groups	66.440 6973.175	33.220 55.785	27.225	.593	A	2.009	.366
B	Between groups Within groups	175.467 7818.851	87.733 62.551	1.403	.250	B	3.860	.145
C	Between groups Within groups	99.549 9879.848	49.775 79.039	.630	.534	C	.727	.695
D	Between groups Within groups	55.942 5695.593	27.986 45.565	.614	.543	D	1.444	.486
E	Between groups Within groups	459.646 4605.803	229.823 36.846	6.237	.003	E	12.619	.002
F	Between groups Within groups	1424.009 38086.674	712.004 304.693	2.337	.101	F	4.287	.117

All tests are significant at the 0.05 level

Table 4.14 Post-hoc Multiple Comparisons in Observed Weights of CSC among Respondent Types

CSC	*Post hoc* method	Public-Private Client			Public Client-Contractor			Private Client-Contractor		
		MD	SE	Sig.	MD	SE	Sig.	MD	SE	Sig.
A	Bonferroni	.99	1.622	1.000	-.74	1.913	1.000	-1.72	1.641	.866
	Dunnett T3	.99	1.714	.917	-.736	1.936	.974	-1.72	1.559	.614
B	Bonferroni	2.28	1.718	.563	3.25	2.026	.334	.97	1.737	1.000
	Dunnett T3	2.28	1.756	.483	3.25	1.677	.163	.97	1.452	.878
C	Bonferroni	-1.74	1.931	1.000	-2.43	2.277	.865	-.68	1.953	1.000
	Dunnett T3	-1.74	1.649	.644	-2.42	2.228	.623	-.68	2.172	.985
D	Bonferroni	1.23	1.466	1.000	-.16	1.729	1.000	-1.41	1.483	1.000
	Dunnett T3	1.23	1.527	.805	-.18	1.613	.999	-1.41	1.334	.646
E	Bonferroni	4.23*	1.319	.005	1.02	1.555	1.000	-3.21	1.333	.052
	Dunnett T3	4.23*	1.350	.008	1.02	1.542	.882	-3.21	1.293	.046
F	Bonferroni	-8.20	3.792	.098	-5.56	4.470	.647	2.63	3.835	1.000
	Dunnett T3	-8.20	3.523	.067	-5.56	4.164	.458	2.63	3.890	.874

MD= Mean Difference (I-J)
SE=Standard Error
*MD is significant at the 0.017 level

attributed to individual perceptions resulting from the types of the tendering procedure and complexity of the projects they have been associated with. Low significance level observed for 'past perform' criterion reinforces the finding in the previous section that the differences in the respondents' perceptions on DIA of CSC are more significant for 'project specific criteria' and 'past performance'. One interesting finding, which is inconsistent with general perception, is that the public clients attached less weight (25.55%) to the price criterion as compared to their counterparts in private sector (33.93%) and contractors (30.54%). Though the samples of respondents surveyed prefer the price criterion over other CSC, which is also consistent with the finding from the study of the UK construction industry by Wong *et al.* (2001), a good representation of proper balance between price and non-price criteria is a reflection of Singapore construction practitioners' realization of the importance of multiple criteria selection approach.

4.4.4 General Comments by Respondents

The questionnaire also encourages the respondents to provide comments on additional decision criteria which they usually consider during the contractor selection process. Some respondents from all the sample groups make some valuable comments and suggestions in relation to CSC as well as some points for consideration during selection process. Some of the additional criteria suggested by respondents from public client organizations include

- Registration with BCA;
- Conformance to specifications;
- Responsiveness;
- Bad debts or number of court summons; and
- It is not appropriate to generalize the importance value of evaluation criteria for all kinds of construction projects.

Comments suggested by some respondents from private sector client organizations include

- Quality assurance plan for the project;
- Additional value added to the project should be considered;
- Should look for proper balance between price and performance;
- It is not appropriate to generalize the importance value of evaluation criteria for all kinds of construction projects; and
- In certain projects 'reputation of sub-contractors' should be considered as a main criterion rather than as a sub-criterion.

Suggestions from the contractors group include

- Registration with BCA;
- Conformance to specifications;
- Bad debts;
- Safe work methods;

- The client should establish two independent estimates and the award should go to the contractor whose proposal is the closest to the average of the two;
- Should thoroughly check cash flow position of the contractor as cash flow is life blood of the project; and
- It is not appropriate to generalize the importance value of decision criteria for all kinds of construction projects.

The most common suggestion from all the three respondent groups- three from public clients, five from private clients and three from contractors, is the inappropriateness of the generalization of the importance value of decision criteria. It may be because of one-off nature of construction projects. This important aspect of any contractor selection system is rightly pointed out by Ng *et al.* (1999) that though a single system for contractor selection should be developed, the establishment of flexible weighting schemes to accommodate different emphases as per the requirements of clients and project is desirable.

In the author's opinion, registration with BCA, responsiveness and conformance to specifications are mandatory requirements which need to be checked before the actual evaluation process begins and should not be considered as evaluation criteria. The number of court summons simply means claims and disputes history of the candidate contractor. The recommendation that would be sought from previous clients of the past projects to assess the candidate contractor's attributes on the criteria 'A6' and 'A7' would reflect this point and in the author's opinion, the contractor alone should not be held solely responsible for the disputes leading to litigation because overall project success is a function of the performance of each participant of the project (Liu and Walker, 1998). In general, the tone of the comments suggest that the construction industry is becoming more aware of the importance of awarding a contract based on value-based approach, i.e. a proper balance between economic and non-economic parameters rather than just on the basis of price-related attributes.

4.5 Establishing Weights for Criteria

The normalized value of weights for criteria are established by using the equation

$$w_j = X_j / \sum X_j, \forall j \qquad \text{........................ (4.3)}$$

where, w_j and X_j are the normalized weight of criterion j and the observed mean DIA of criterion j obtained through the questionnaire survey, respectively. After establishing the weights the construction practitioners who participated in the interview were contacted for their opinions on the findings of the study. Based on their input and comments, all criteria except '*E10: Risk sharing level of project owner*' are removed from the list and the weights are recalculated for group E. All other CSC and their established weights are selected for inclusion in the proposed contractor selection system. Table C8 in Appendix C shows the normalized weights established for each of main CSC and sub-criteria under each criteria group.

4.6 Conclusion

The primary purpose of the questionnaire survey is to investigate contractor selection preferences in the Singapore construction industry and to make full use of the information obtained from the industry in developing a multiple criteria decision system for contractor selection. Findings from the study highlight that the CSC selected for the study are relevant and important from the viewpoints of all the respondents surveyed. The study highlights that the criteria pertinent to the contractor's ability to troubleshoot a wide range of construction problems, for example, depth of experience on similar type of project, qualification and experience level of project manager, qualification and experience of management staffs, type and scale of project completed in past 3 years, qualification and experience of technical staffs, are considered (very) important for assessing the capabilities of candidate contractors. The low DIA attached to the CSC pertaining to health and safety is an indication of a substantial lack of awareness of the importance of health and safety at worksites despite the various initiatives taken by the public bodies to improve the awareness of the importance of health and safety at all level of the construction industry. Criteria relating to the assessment of quality performance of contractors are also not highly ranked in the overall ranking.

Even though the overall ranking of CSC based on observed DIA are highly correlated, the detailed statistical analyses show significant differences in opinions across the respondent groups regarding the importance of those CSC for assessing the attributes of contractors during selection process. It reflects that though the respondents share some degree of commonality with respect to relevance of CSC, their decision-making preferences during the selection process are context specific, i.e. they assign varying level of importance to CSC depending upon the specific requirements of the project, their personal experience and preferences during the decision-making process. Findings, based on the samples of respondents surveyed, indicate that though there may be a possibility to identify a universal set of CSC to be used for assessing the capabilities of the candidate contractors during the selection process, the establishment of generalized weight or DIA for those CSC seems to be difficult as well as inappropriate.

Overall, the findings suggest that despite the dominance of the price criterion over any single non-price criteria, clients in Singapore want the best value from a contract, who demonstrates a proper balance between price and non-price attributes, which in turn reflects a strong indication of a shift in contractor selection preference i.e. from solely price-based selection practice to value-based selection approach.

Chapter 5
Development of Fuzzy MCDM Contractor Selection System

5.1 Chapter Overview

Contractor selection is the process of selecting the most appropriate contractor to deliver the project as specified so that the achievement of the best value for money is ensured. Construction clients are becoming more aware of the fact that selection of a contractor based on tender price alone is quite risky and may lead to the failure of the project in terms of time delay, cost overrun and poor quality standards. Evaluation of contractors based on multiple criteria is, therefore, becoming more popular. Contractor selection in multi-criteria environment is largely dependent on the uncertainty inherent in the nature of construction projects and surrounding the subjective nature of decision-making. This chapter presents the concept of the proposed contractor selection system based on fuzzy MCDM method. The notion of Shapley value is used to determine the overall importance value of criterion in accomplishing the overall objective of the decision-making process. An illustration with a hypothetical tender evaluation exercise considering a lesser number of CSC is presented to demonstrate the data requirements and the mechanics of the fuzzy MCDM method in selecting the most appropriate contractor for the project.

5.2 Introduction

The construction industry is characterized by cost and duration overruns, serious problems in quality standards and safety measures, and an increasing number of claims, counter-claims and litigations. To minimize or optimize all these risks, selection of an appropriate contractor to deliver the project as per requirements is the most crucial challenge faced by any construction client.

The previous works by Helmer and Taylor (1977), Samelson and Levitt (1982), Moore (1985a, b), Holt *et al.* (1995a), Kumaraswamy (1996), and Hatush and Skitmore (1997) show that despite a considerable increase in the complexity of projects and client's needs in the last three decades, along with an associated increase in alternative forms of project delivery system, CSC themselves mostly remain unchanged. These criteria can, in general, be summarized as tender cost, track record, performance potential with respect to financial, technical, and managerial capability, quality standards, and health and safety records. Fong and Choi (2000), after review of attitudes cited by researchers since 1967 concerning the influence of the tender price on the final selection of a contractor, summarized: (i). apart from the acceptance of the lowest tender price, there should be a trade-off between cost, time and quality in the final selection of contractor; (ii). however, in public projects, tender price still dominates over other criteria in tender evaluation exercise.

The extensive review of literature relating to contractor selection has, however, shown some indication of paradigm shift in contractor selection process, that is, from 'lowest-price' approach to 'multiple criteria' approach of construction clients in awarding the contracts. This point is also supported by the findings from the current questionnaire survey, discussed in Chapter 4, conducted to investigate the contractor selection preferences of construction clients. Because of substantial increase in clients' demand and complexity of the project, the clients are becoming more aware of the fact that the awarding of contract solely based on the price criterion is the root cause of almost all the problems related to project failure resulting from selecting a contractor not properly equipped, in terms of performance and capability, for the project.

According to Hipel *et al.* (1993), a decision problem is said to be complex and difficult, if there exist:

- multiple criteria-both qualitative and quantitative in nature;
- multiple decision makers;
- uncertainty and risk;
- incomplete information, imprecise data and vagueness surrounding the decision-making.

Russell and Skibniewski (1988) pointed out that contractor selection is a decision-making process that involves the development and consideration of a wide range of necessary and sufficient decision criteria as well as the participation of many decision-making parties. Therefore, contractor selection is, in practice, a complex MCDM problem and the choice of appropriate decision method for the selection process is very important in making an effective and meaningful appraisal of contractors.

5.3 Contractor Selection Models Using MCDM Methods

Construction researchers and practitioners have proposed different methods or procedures for contractor selection. To name a few of them: a multi-attribute utility model by Diekmann (1981); a discounted cash flow model by Hardy *et al.* (1981); a fuzzy bid evaluation model by Nguyen (1985); a statistical model by Jaselskis (1988); a multi-dimensional weighting method by Russell and Jaselskis (1991); multiple regression model by Hatush (1995); a utility model by Hatush and Skitmore (1998) and AHP contractor selection system by Fong and Choi (2000). Most of these researchers have incorporated multi-criteria decision analysis methods in their models/methodologies. However, their models or methodologies are generally based on single principal decision criterion such as time or quality, in addition to the price criterion, to evaluate the capabilities of contractors and on the assumption that the decision is made by a single person rather than multiple DMs or heavy reliance on historical data in case of neural network models (for e.g., Khosrowshahi, 1999). Lam *et al.* (2001) proposed a fuzzy neural network model for pre-qualification of contractors. Although, because of its ability to learn from experience the artificial neural network has found widespread application in many decision processes, it is, however, not a perfect method for a contractor selection problem which is dynamic in nature. Major disadvantages of artificial neural network models are their inability to deal with the risks associated with prediction based on historic data and their limited flexibility in adapting dynamic and complex variables of the construction industry. Hatush (1995) proposed a pre-qualification model based on multiple regression technique. As his multiple regression model was also developed based on historical data of pre-qualification cases, it also has the drawbacks of the neural network models.

5.3.1 AHP Models

Fong and Choi (2000) using eight major decision criteria demonstrated the applicability of AHP for contractor selection. Later, Mahdi *et al.* (2002) proposed a model based on AHP method considering the multi-criteria approach. AHP is very useful for dealing with complex and unstructured decision-making process in a multiple criteria environment. Many decision models have developed based on the concept of AHP. The underlying concept of AHP method is to rank alternatives based on the DMs' preferences concerning the importance of criteria and the degree to which they are met by each alternative. But, these models have some shortcomings that are associated with the AHP method:

- It does not take into account the uncertainty associated with the mapping of one's judgment to a number;

- If there were a large number of decision criteria, usually the case for contractor selection, making pairwise comparison of criteria puts cognitive burden on DMs as well as being time consuming;

- The judgment and preferences of DMs have great influence on the final decision based on the AHP method;

- It is mainly used in nearly crisp decision applications and hence contractor selection is not a perfect case for its application.

5.3.2 MAUT Models

The multi-attributes utility technique uses utility curves to represent the relationship between the specific capability of an alternative and the value of that capability in different choices of situations such as risky and less risky. Pongpeng and Liston (2003a) proposed a contractor selection model using a combination of utility function and social welfare function. Their model can be represented as

$$U^{CA} = \sum_{i=1}^{m}\sum_{j=1}^{n} w_{ij} u_{ij}$$

$$U^{BP} = \sum_{i=1}^{m} w_i' u_i'$$

where U^{CA} is the utility value of *contractor ability*, w_{ij} and u_{ij} are the normalized weight and utility value of the contractor's capability on the *j*th criterion assigned by the *i*th DM respectively, *m* is number of DMs, *n* is number of criteria, U^{BP} is the utility value of *bid price*, w_i' and u_i' are normalized weight and utility value of bid price assigned by the *i*th DM. The overall social welfare utility value (U^T) of a contractor is then given by

$$U^T = U^{CA} + U^{BP}$$

Candidate contractors are ranked based on their overall social welfare utility value and the contractor with the highest utility value is selected for the project. There are some disadvantages associated with MAUT:

- It requires the DMs to give a crisp utility value of a particular criterion to be used in a utility function so it does not take into account the uncertainty associated with mapping of one's judgment to a crisp value;

- It places burden on DMs by asking a large number of hypothetical lottery-type questions for establishing utility function which could be time consuming if there are a large number decision criteria to be considered;

- The utility approach assumes that DMs are well versed with the concept of the probability theory, which may not be the case in reality.

Therefore, in order to overcome all these shortcomings, a meticulous consideration is given to the selection of an appropriate decision-making method for the proposed contractor selection model.

5.4 Selection of Modeling Technique

Much of the decision-making in the real world takes place in an environment in which the goals, the constraints and the consequences of possible actions are not known precisely (Bellman and Zadeh, 1970). Hence, one of the most important characteristics of a useful and effective decision model is to provide the ability to deal with imprecise and vague information.

Selection of the most appropriate contractor is a decision-making process in which a group of DMs assesses the capabilities of the contractor to execute the project against a set of multiple criteria, which *may* vary between projects and clients. *Therefore, a contractor selection model must be capable of handling multiple decision makers and multiple decision criteria simultaneously.*

Moreover, this assessment is usually based on the past experience and subjective judgment of the DMs. Hence, the risks associated with the uncertainty and vagueness surrounding the decision-making process cannot be avoided. *Therefore, a contractor selection model must be capable of dealing with the uncertainty and vagueness inherent in the nature of decision-making regarding selection process.*

Furthermore, in certain situations the DMs may well be confronted with the difficulty in making quantitative assessment of the contractor performance on some of the attributes which by their nature require qualitative assessment. Hence, in such a situation it is easier for DMs to express their opinions in qualitative or linguistic terms as they *might* be less reluctant to handle the uncertainty associated with decision-making using linguistic terms rather than the crisp values, which cannot be defined with a reasonable degree of accuracy. *Therefore, a contractor selection model must be capable of handling both qualitative and quantitative assessments.*

In addition, as depicted in Figure 2.3 there are various routes to the final selection of the contractor for a construction project. Based on the objectives of the client's organization and the specific requirements of the project under consideration, the client will select a most appropriate route for selecting the final contractor for the project. *Therefore, a contractor selection model must also be able to carry out the selection process at different levels of details as per the requirements.*

Each construction project has its own distinct characteristics and requirements and hence no two projects are identical in respect to site conditions, design and resource requirements. This peculiarity of construction poses the problem of non-generalizability of selection criteria specific to the construction project. *Therefore, a contractor selection model must be flexible enough to adapt the varying requirements, such as decision criteria, of construction projects to reflect the project individuality.*

Taking all these important points into consideration, the technique, selected for modeling contractor selection system, must reflect the following characteristics:

- Capability to handle multiple decision criteria and multiple DMs simultaneously;
- Ability to deal with uncertainty surrounding the nature of decision-making;
- Capability to handle both qualitative and quantitative assessments;
- Ability to carry out the selection process at different levels of details;
- Flexibility to adapt and reflect the individuality of construction projects.

From the discussion of decision-making methods potentially useful for contractor selection process in section 2.6.2, only Goal Programming Method, Multi-Attribute Utility Method, AHP Method and Fuzzy MCDM Method seem to be promising and potential candidates for modeling for contractor selection system. Table 5.1 shows the comparison of these methods in terms of their relative robustness in handing the decision-making problems regarding contractor selection. The suitability of these methods is assessed in light of the above-mentioned characteristics which are essential for a contractor selection model. Column 4 of Table 5.1 shows the ability of different methods in handling both qualitative and quantitative assessment. For instance, 'No' means that particular method, for example, Goal Programming, is not capable of handling both quantitative and qualitative assessments. Column 7 shows the cognitive burden each method puts on the decision makers. For example, AHP places 'High' cognitive burden on the DMs as it requires all criteria to be compared pairwise in order to establish their importance for achieving overall goal and alternatives are then compared pairwise in order to determine the degree to which they meet those criteria in achieving overall goal, which is time consuming as well as demands cognitive effort on the part of DMs.

From Table 5.1 it is clear that MAUT, AHP and Fuzzy MCDM methods are almost equally promising for contractor selection process. However, in view of its high capability in dealing with uncertainty and vagueness and low demand of cognitive burden on DMs, one important feature of any decision model, fuzzy MCDM method- a combination of fuzzy set theory and MCDM method, is preferred to other methods and selected as decision-making method to be used for the proposed contractor selection system.

The main concern in all real-world decision problems like contractor selection is handling multiple, usually conflicting, criteria and uncertainty. Probability theory and/or fuzzy set theory have been used by researchers to model the decision-making problems under uncertainty or in real-world situations. The former takes into account the stochastic nature of decision analysis whereas the latter captures the subjective nature of human judgment. Efstathiou (1979) and Dubois and Prade (1985) suggested that a probabilistic decision analysis method such as statistical decision analysis does not measure the imprecision in

Table 5.1 Comparison of MCDM Methods Potentially Useful for Contractor Selection

(1) Method	(2) C-1	(3) C-2	(4) C-3	(5) C-4	(6) C-5	(7) C-6
Goal Programming	Yes	Low	No	Low	Low	Low
Multi-Attribute Utility Theory	Yes	Medium	Yes	Medium	Low	Medium
Analytic Hierarchy Process	Yes	Medium	Yes	High	High	High
Fuzzy MCDM	Yes	High	Yes	High	High	Low

C-1: Ability to handle multi-criteria and multi-decision makers simultaneously
C-2: Capability to deal with uncertainty and vagueness associated with decision-making
C-3: Ability to handle both qualitative and quantitative assessments
C-4: Capability to carry out the selection process at different levels of details
C-5: Flexibility to adapt and reflect the project individuality
C-6: Cognitive burden on decision makers

human behavior; rather, this method is a way to model incomplete knowledge about the external environment surrounding human beings. Fuzzy set theory, on the other hand, is a better way for modeling uncertainty (or imprecision) arising from mental phenomena which are neither random nor stochastic in nature. However, fuzzy set theory does not replace probability theory but rather provides solution to problems that lack the mathematical rigor required by probability theory (Nguyen, 1985).

5.4.1 Concept of Fuzzy Set Theory

Lukasiewicz in the early 1920s first proposed the concept of fuzzy set (Rescher, 1969) by developing systems which were able to represent a range of truth values covering all real numbers from 0 to 1. According to him, a given real number in this range is able to represent the possibility of any given statement being true or false. By extending the work on the possibility theory, Zadeh (1965) introduced the concept of fuzzy set theory. A fuzzy set can be defined mathematically by assigning to each possible individual in the universe of discourse a value representing its grade of membership in the fuzzy set. This grade represents the degree to which that individual is similar or compatible with the concept represented by the fuzzy set. Thus, an individual may belong in the fuzzy set to a greater or lesser degree as indicated by a larger or smaller membership grade. These membership grades are very often represented by real-number values ranging in the closed interval between 0 and 1.

Fuzzy set theory has been used to deal with ill-defined and complex problems due to incomplete and imprecise information that characterized the real-world systems. It uses linguistic variables to model vagueness intrinsic to human cognitive process. Zadeh (1973) stated that ".... as the complexity of a system increases, human ability to make precise yet significant statement about its behaviors diminishes until a threshold is reached beyond which precision and significance become mutually exclusive". Membership function, linguistic variables, natural language computation, linguistic approximation, fuzzy integrals, and fuzzy weighted sum are main concepts of fuzzy set theory applied to approximate characterization and decision-making. A linguistic variable is a variable whose values are linguistic terms. It differs from numerical variable in that its values are not numbers but words or sentences in a natural or artificial language. Linguistic variables such as 'poor management', 'good performance' and 'moderate risk' describe the vague concept (Refer to Zadeh, 1965; Schmucker, 1984; Klir and Folger, 1988 for more details).

5.4.1.1 Fuzzy Membership Function

Membership function of an element represents a degree to which the element belongs to a set. Let a_i be a fuzzy number such that $\forall a_i \in \mathbb{R}$ (set of real numbers) and considered in the form of

$$a_i = \{x_1, x_2, x_3, x_4\}, \quad \text{for } i = 1, 2, \ldots\ldots\ldots, m$$

where $x_1 < x_2 < x_3 < x_4$ is the scale of preference structure to be used by DMs and m is the number of fuzzy number to be used in the analysis. Figure 5.1 and 5.2 show the graphical representation of trapezoidal and triangular membership function μ(x) respectively.

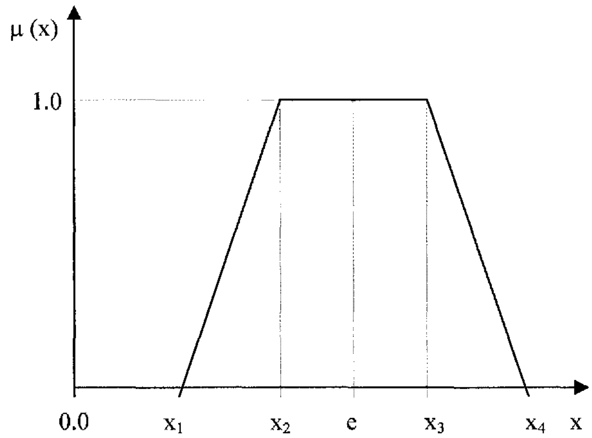


Figure 5.1 Graphical Representation of Trapezoidal Membership Function

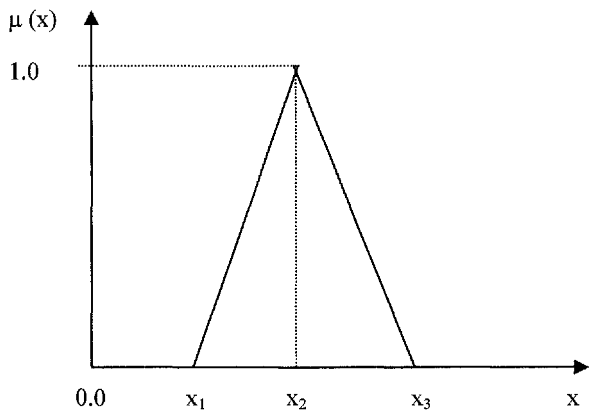


Figure 5.2 Graphical Representation of Triangular Membership Function

The normalized membership function of an alternative a_i can be expressed in the form of

$$\mu_{ai}(x) = \begin{cases} 0, & x < x_1 \\ (x - x_1) / (x_2 - x_1), & x_1 < x < x_2 \\ 1, & x_2 < x < x_3 \\ (x_4 - x) / (x_4 - x_3), & x_3 < x < x_4 \\ 0, & x > x_4 \end{cases}$$

5.4.1.2 Operations on Fuzzy Numbers

Let A = (a_1, a_2, a_3, a_4) and B = (b_1, b_2, b_3, b_4) be any two positive trapezoidal fuzzy numbers. Then the operations [+, –, ×, ÷] are expressed as (Kaufmann and Gupta, 1991):

$$A \oplus B = (a_1, a_2, a_3, a_4) \oplus (b_1, b_2, b_3, b_4) = (a_1+b_1, a_2+b_2, a_3+b_3, a_4+b_4),$$

$$A \ominus B = (a_1, a_2, a_3, a_4) \ominus (b_1, b_2, b_3, b_4) = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1),$$

$$A \otimes B = (a_1, a_2, a_3, a_4) \otimes (b_1, b_2, b_3, b_4) = (a_1b_1, a_2b_2, a_3b_3, a_4b_4),$$

$$A \odot B = (a_1, a_2, a_3, a_4) \odot (b_1, b_2, b_3, b_4) = (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1),$$

where, $\oplus$, $\ominus$, $\otimes$, $\odot$ represent the fuzzy addition, subtraction, multiplication and division respectively. Let a_{ij}^k be the fuzzy number (weight) assigned to an alternative A_i by DM_j for criterion C_k, then the average of fuzzy numbers across all the DMs can be expressed as:

$$A_{ij}^k = (1/p) \otimes (a_{i1}^k \oplus a_{i2}^k \oplus \ldots\ldots\ldots\ldots \oplus a_{ip}^k), \text{ for } j = 1, 2, \ldots, p \qquad \ldots\ldots\ldots.(5.1)$$

where p is the numbers of DMs involved in the evaluation process.

5.4.1.3 Defuzzification

Defuzzification is an operation that produces a nonfuzzy or crisp value that adequately represents the degree of satisfaction of the aggregated fuzzy number. For the proposed system, trapezoidal and triangular fuzzy numbers are used to represent the DMs' opinions. Let a trapezoidal fuzzy number be parameterized by x_1, x_2, x_3, x_4 as shown in Figure 5.1, then its defuzzified value 'e' is given by the following equation (Ibid.),

$$e = (x_1 + x_2 + x_3 + x_4) / 4 \qquad \text{.........(5.2)}$$

Similarly, for triangular fuzzy number as represented in Figure 5.2, 'e' is given by as,

$$e = (x_1 + 2x_2 + x_3) / 4 \qquad \text{........(5.3)}$$

A detailed discussion of different types of fuzzy numbers, membership functions, aggregation and defuzzification methods can be found in Zimmerman (1985), Klir and Folger (1988) and Kaufmann and Gupta (1991).

5.4.2 Multi-Criteria Decision Making

Multi-criteria decision making problems are characterized by the need to evaluate a finite set of alternatives with respect to a set of multiple criteria. A multi-criteria decision-making problem can generally be represented in a matrix format as:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccc} \mathbf{c_1} & \mathbf{c_2} \cdots\cdots & \mathbf{c_n} \end{array} \\ \begin{bmatrix} x_{11} & x_{12} \cdots\cdots & x_{1n} \\ x_{21} & x_{22} \cdots\cdots & x_{2n} \\ \vdots & \vdots & \vdots \\ x_{m1} & x_{n2} \cdots\cdots & x_{mn} \end{bmatrix} \end{array} \quad \begin{array}{c} \mathbf{W} \\ \begin{Bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{Bmatrix} \end{array}$$

where A_1, A_2,.., A_m are alternatives, c_1, c_2,.., c_n are criteria with which performances of alternatives are measured, x_{ij} is the rating or score of alternative A_i on criterion c_j, and w_j is the normalized weight of c_j, D is the decision matrix and W is normalized criterion weight vector. The main purpose in MCDM problem is to assess the overall importance values of the alternatives on some permissible scale. Alternatives are generally first evaluated explicitly with respect to each of the criteria to obtain some sort of criterion specific priority scores which are then aggregated into overall performance values.

5.5 Multi-Person Multi-Criteria Contractor Selection Framework

In contractor selection process, DMs assess the capability of a contractor to deliver the project on time, within budget and as specified against a number of important decision criteria. Hence, contractor selection is a complex decision-making process involving the development and consideration of a large number of sufficient and necessary decision criteria as well as the participation of many decision-making parties. Therefore, contractor selection is a multi-person multi-criteria decision-making process. Figure 5.3 shows an example multi-person multi-criteria (MPMC) contractor selection framework based on four decision criteria and four DMs.

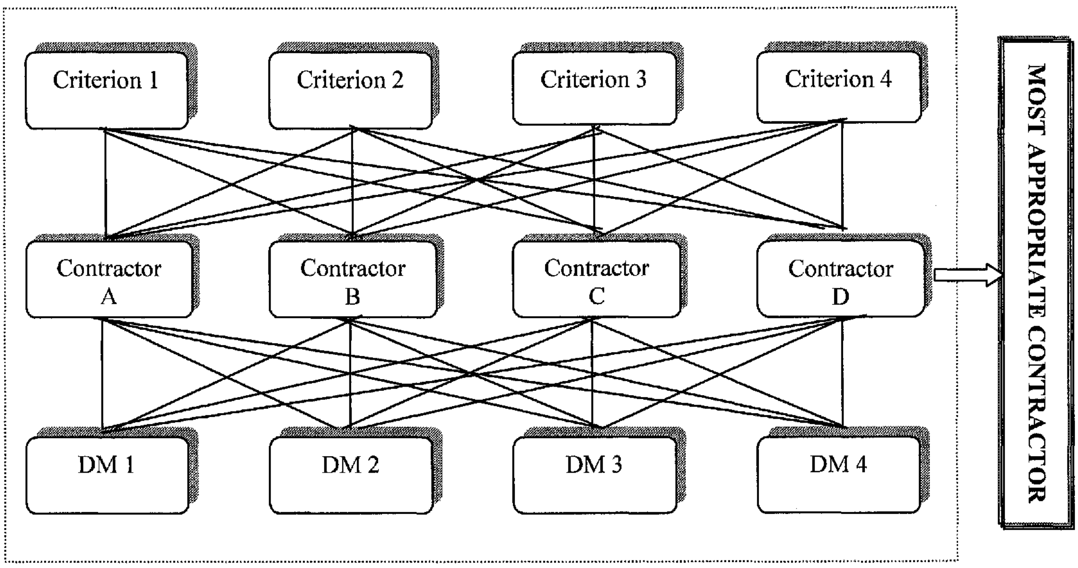


Figure 5.3 Example Multi-DM Multi-Criteria Contractor Selection Framework

5.6 Conceptual Contractor Selection System

Based on the theoretical knowledge base developed through knowledge acquisition process in Chapter 2 and some fundamental knowledge obtained through the questionnaire survey in Chapter 4, a conceptual model for contractor selection process is proposed. Figure 5.4 portrays the flow chart of the proposed conceptual framework for contractor selection. The proposed system can perform P&P qualification only or P&P qualification plus tender evaluation, based on the nature of the project under consideration. For P&P qualification plus tender evaluation process, the system envisages that the candidate contractors are required to submit all information regarding their P&P parameters as well as tender proposal at the same time. C&C (Completeness and Conformance) screen checks the specific requirements such as completeness and thoroughness of submission and information supplied and conformance to the specifications such as mandatory requirements. This step is to ensure that only those candidate contractors, who satisfy all mandatory requirements, are passed through for further evaluation process. The overall scores for candidate contractors are calculated across all decision makers.

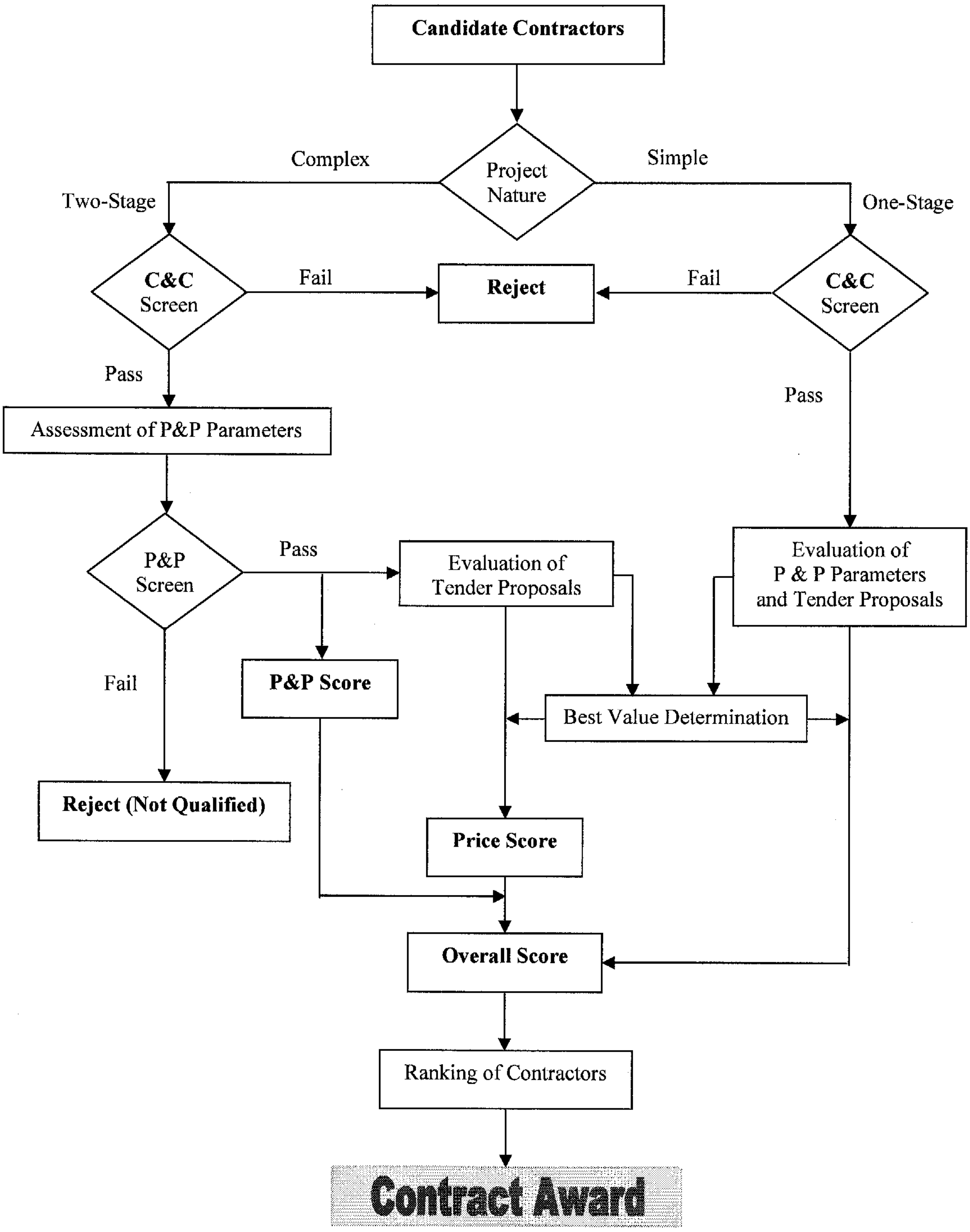
For complex projects which require prequalification, the system envisages that interested contractors are required to submit detailed information regarding their P&P parameters, such as company's attributes, past performance, financial, technical and managerial capabilities and resource availability. At P&P screen, the appraisal of the performance and potential parameters of candidate contractors, who passed through the C&C screen, to perform the project with respect to the specific requirements of the project under consideration is carried out. The aim of this process is to filter out those candidate contractors who do not satisfy the performance and potential requirements specified for the project. P&P scores for all contractors who passed through P&P screening test are calculated and selected contractors (generally 3-5 top-ranked contractors depending upon the nature of the project) are asked to submit tender proposals for the second stage of the selection process.

At the second stage of the selection process, tender proposals submitted by the pre-qualified contractors are evaluated and price scores are determined to establish the overall scores of the contractors. This evaluation process incorporates, in addition to tender price, 'best value' consideration depending upon the nature and complexity of the project. For complex projects with longer duration, consideration of life cycle cost analysis and value engineering analysis will be taken into account while evaluating the attractiveness of tender proposal. Corcoran and McLean (1998) described, based on their study to determine the meaning of 'value for money' as a procurement principle for public sector decision-makers, 'value for money' as the principle concerned with balancing conflicting elements, such as time, cost, quality and in some instances risk, for the purpose of obtaining best deal for the procuring department. Since it is rare for all the three to be satisfied, the purpose of best value determination should be the optimization of this cost-time-quality triangle, which requires the construction clients to make fine adjustments of these elements based on their subjective judgments such as Is added value necessary and useful? How much more should be paid for the added value? Does the added value justify the additional price? All these fine adjustments are to be made before scoring the tender proposals. Combined scores for the contractors are calculated by aggregating P&P scores and price scores across all DMs. Ranking of contractors is to be done on the basis of overall scores and the contractor with highest overall score should be considered as the most appropriate contractor for the project as he demonstrates the best balance between the performance and potential parameters and price criterion.

5.7 Fuzzy Multi-Person Multi-Criteria Decision Making

A fuzzy decision-making framework generally consists of the following steps:

- Defining and specifying the types of fuzzy numbers and their membership functions to be used by DMs;
- Establishing the scale of preference structure to be used by DMs;
- Assigning the fuzzy values to attributes based on their performance on the decision criteria;



P&P: Performance and Potential
C&C: Completeness and Conformance

Figure 5.4 Proposed Framework for Contractor Selection

- Aggregating fuzzy numbers across the DMs;
- Defuzzification;
- Determination of global or overall importance value of each decision criteria; and
- Ranking of alternatives based on overall score.

In fuzzy MPMC problems, the ranking of alternatives must take into account their fuzzy scores on all criteria, the weight assigned to each criterion, the possible difficulties of comparing two alternatives when one is significantly better than the other on a subset of criteria, but much worse on at least one criterion from the complementary subset of criteria, and the DMs' attitude towards the risk associated with evaluation. Therefore, the relationships among criteria are crucial for adequate treatment of fuzzy decision-making because they reflect the structure of interaction among the criteria and represent DMs' preferences of criteria. Thus, the overall importance of a particular criterion should not solely be determined by the importance of that criterion, but also by the value of all other criteria considered in the evaluation process. Shapley (1953) proposed a method to determine the expected marginal contribution of a particular criterion (player) to overall goal. Let us consider a set of decision criteria as $C = \{c_1, c_2, \ldots\ldots, c_n\}$ and μ be a fuzzy measure on $C = \{c_1, c_2, \ldots\ldots, c_n\}$ such that:

$$\mu(C) = \sum_{i=1}^{n} \mu_i(c_i) \text{ for i=1,2,\ldots.., n.}$$

$$\mu(\phi) = 0 \text{ and } \mu(C) = 1$$

where ϕ is null set and $\mu(c_i)$ is the weight or the importance value of the criterion c_i. The importance index or Shapley value of criterion c_i with respect to μ is defined as (Ibid.):

$$\mu(c_i) = \sum \frac{(N-A)!(A-1)!}{N!}[\mu(A) - \mu(A - c_i)] \qquad \ldots\ldots\ldots\ldots(5.4)$$

where, N is number of decision criteria, A is any combination of decision criteria containing criterion c_i and $0! = 1$, as usual. Thus, in addition to the usual weights on criteria taken separately, weights on any combination of criteria must also be defined in MCDM problems. The reason for inclusion of the concept of overall importance value of criteria is to elicit the DMs' evaluation criteria preferences that depict the trade-off the DMs are willing to accept between decision criteria. In order to demonstrate the data requirements and the mechanics of the proposed decision-making method an illustrative example of hypothetical contractor selection exercise is presented in the next section.

5.8 Illustrative Example of Fuzzy MPMC Decision Making

An example is designed in a hypothetical manner to illustrative the application of the proposed evaluation technique. It involves the selection of the most appropriate contractor among four contractors (A, B, C and D) with respect to three main CSC, i.e., past performance (c_1), financial capability (c_2) and performance potential (c_3) of the contractors based on the information supplied by the four DMs- DM_1, DM_2, DM_3 and DM_4.

5.8.1 Establishing Fuzzy Numbers for Linguistic Variables

Table 5.2 shows the linguistic variables with their corresponding fuzzy numbers selected to be used for the linguistic assessment of the performances of contractors' attributes on CSC. These fuzzy numbers for linguistic variables may be established by the client or by the group consensus of the decision-making parties involved in the selection process. For the proposed contractor selection system only seven fuzzy numbers are chosen to describe the level of performance on decision criteria because it is generally difficult for an expert to distinguish subjectively between more than seven alternatives (Saaty 1977). Figure 5.5 shows the graphical representation of the fuzzy numbers for linguistic variables for the DMs to use in the assessment of contractors' attributes.

Table 5.2 Fuzzy Numbers for Linguistic Variables

Linguistic Variables	Fuzzy Number
VG (Very Good)	(0.8, 0.9, 1.0, 1.0)
G (Good)	(0.6, 0.7, 0.8, 0.9)
AA (Above Average)	(0.5, 0.6, 0.7, 0.8)
A (Average)	(0.4, 0.5, 0.5, 0.6)
BA (Below Average)	(0.2, 0.3, 0.4, 0.5)
P (Poor)	(0.1, 0.2, 0.3, 0.4)
VP (Very Poor)	(0.0, 0.0, 0.1, 0.2)

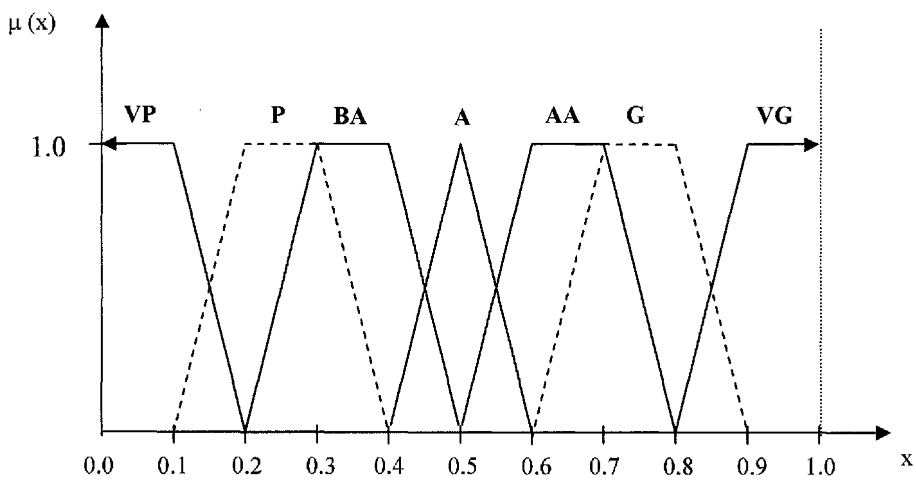


Figure 5.5 Graphical Representations of Fuzzy Numbers for Linguistic Variables

5.8.2 Establishing Weights for CSC

Table 5.3 shows the weights, on a scale of 1-100 (100 being the most important), assigned to each main CSC by DMs based on their experiential judgment.

Table 5.3 Assigned Weights for Sub-Criteria

Main CSC	**DM_1**	**DM_2**	**DM_3**	**DM_4**
Past Performance (c_1)	80	72	75	80
Financial Capability (c_2)	85	75	80	80
Performance Potential (c_3)	75	72	70	75

The normalized weight for each criterion can be obtained by dividing mean value of c_i by $\sum c_i$, as

$w(c_1) = 0.33$,

$w(c_2) = 0.35$,

$w(c_3) = 0.32$.

5.8.3 Establishing Overall Importance Values of Main CSC

Now, based on the weight established for main CSC DMs are required to assign weight to the combinations of CSC, for example, $w(c_2,c_3)$ represents the average weight assigned to the combination of criterion c_1 and c_2 ('Past Performance' and 'Financial Capability') and $w(\phi)$ is the weight to the null set of criteria. These three CSC, namely, Past Performance, Financial Capability and Performance Potential, do not compensate each other, that is, a bad score on one criterion cannot be adjusted by a good score on any other complementary criteria. However, in practice, these criteria generally, to some extent, corporate each other, i.e., an increase (or decrease) in the degree to which one criterion is satisfied often increases (or decreases) the degree to which another criterion is satisfied. Therefore, the weight assigned to the combination of any two criteria must be at least equal to the sum of their individual weight assigned separately (cf., Shapley, 1953), that is,

$$w(c_1,c_2) \geq w(c_1) + w(c_2) \quad \text{....(5.5)}$$

For example, if the maximum score that can be assigned to a contractor with performances on all CSC close to their maxima, i.e., as per or close to the expectation of DMs is 1, then what score they are willing to assign a contractor whose performances on any combination of CSC, say c_2 and c_3, are close to their maxima and very poor on the rest of CSC, provided equation (5.5) is satisfied. The same process is repeated for all possible combinations of CSC to get the importance values the DMs are willing to assign to all possible combinations of criteria. This process is, in fact, to elicit the DMs' preferences of CSC in the selection process and the relationship among them. Suppose the weights assigned by DMs to different combinations of criteria are as presented in Table 5.4.

Table 5.4 Weights Assigned by DMs to Different Combination of Sub-Criteria

Combination of Criteria	**DM_1**	**DM_2**	**DM_3**	**DM_4**
w (c_1,c_2)	0.88	0.82	0.85	0.85
w (c_1,c_3)	0.72	0.75	0.78	0.75
w (c_2,c_3)	0.92	0.88	0.90	0.90

The average weights assigned by the DMs to the combinations of CSC are calculated as follows:

$w(c_1,c_2) = 0.85$,

$w(c_1,c_3) = 0.75$,

$w(c_2,c_3) = 0.9$,

$w(c_1,c_2,c_3) = 1.0$,

$w(\phi) = 0$,

where, w (c_1) represents the average weight assigned to the criterion c_1, w (c_1, c_2) the weight to the combination of criteria c_1 and c_2 and w (ϕ) is the weight to the null set of criteria. Using equation (5.4),

$$\mu(c_i) = \sum_{i=1}^{n} [\{w(A) - w(A - c_i)\} \; \{(N - A)! \; (A - 1)!\} / N!]$$

where, N is the number of CSC, A is any combination of CSC containing criterion c_i, and 0! = 1, as usual.

- <u>when A is c_1 alone:</u>

$\mu(c_1)_1 = [\{w(c_1) - w(\phi)\} \; \{(3 - 1)! \; (1 - 1)!\} / 3!\}$

$= \{0.33 - 0.0\}\{2 \times 1\} / 6 = 0.11$

- <u>when A is the combination of c_1 and c_2:</u>

$\mu(c_1)_2 = [\{w(c_1, c_2) - w(c_2)\} \; \{(3 - 2)! \; (2 - 1)!\} / 3!\}$

$= \{0.85 - 0.35\} \; \{1 \times 1\} / 6 = 0.0833$

- <u>when A is the combination of c_1 and c_3:</u>

$\mu(c_1)_3 = [\{w(c_1, c_3) - w(c_3)\} \; \{(3 - 2)! \; (2 - 1)!\} / 3!\}$

$= \{0.75 - 0.32\}\{1 \times 1\} / 6 = 0.072$

- <u>when A is the combination of c_1, c_2 and c_3:</u>

$\mu(c_1)_4 = [\{w(c_1, c_2, c_3) - w(c_2, c_3)\} \; \{(3 - 3)! \; (3 - 1)!\} / 3!\}$

$= \{1.0 - 0.9\}\{1 \times 2\} / 6 = 0.0333$

Now,

$\mu(c_1) = \mu(c_1)_1 + \mu(c_1)_2 + \mu(c_1)_3 + \mu(c_1)_4$

$= 0.11 + 0.0833 + 0.072 + 0.0333 = 0.298$

Similarly, $\mu(c_2)$ and $\mu(c_3)$ can be calculated as 0.384 and 0.318. These values indicate the expected marginal contribution or global importance of each CSC to overall goal. It is convenient to scale these values by a factor N (in this example N = 3), so that an importance index greater than 1 indicates a criterion more important than the average. From the Table 5.5, it is clear that the DMs attach more weight to 'Financial Capability', as scaled Shapley value (Shapley value x 3) is greater than 1 for criterion c_2, than any other CSC, that is, the tendency of the DMs is such that they are likely to accept a contractor with good financial capability and high tender price than a contractor with low tender price and poor financial capability, all other CSC considered being equal.

5.8.4 Rating of Performance of Contractors

For simplicity, let us assume that the criterion c_3 (Performance Potential) consists of three sub-criteria, that is, resource availability (c_{31}), managerial capability (c_{32}) and technical competence (c_{33}) and their established weights are 0.35, 0.34 and 0.31 respectively. Now, contactors' performances on each of criteria are to be rated by DMs. Table 5.6 shows the linguistic assessment of the contractors' performances on the criterion (c_{31}) 'Resource Availability'.

Table 5.5 Overall Importance Value of CSC

Criteria	**Past Performance (c_1)**	**Financial Capability (c_2)**	**Performance Potential (c_3)**
Shapley Value, $\mu(c)$	0.298	0.384	0.318
Scaled Shapley Value [$\mu(c) \times 3$]	0.894	1.152	0.954

Table 5.6 Linguistic Assessment of Contractors' Performance on Criterion 'c_{31}'

Resource Availability (c_{31})	**DM_1**	**DM_2**	**DM_3**	**DM_4**
Contractor A	G	VG	G	G
Contractor B	G	G	G	AA
Contractor C	VG	VG	G	G
Contractor D	A	A	AA	AA

The fuzzy decision matrix for criterion c_{31} can be written as:

$$X_{C31} = \begin{array}{cccc} \textbf{DM}_1 & \textbf{DM}_2 & \textbf{DM}_3 & \textbf{DM}_4 \end{array}$$

$$X_{C31} = \begin{bmatrix} (0.6,0.7,0.8,0.9) & (0.8,0.9,1.0,1.0) & (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) \\ (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) \\ (0.8,0.9,1.0,1.0) & (0.8,0.9,1.0,1.0) & (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) \\ (0.4,0.5,0.5,0.6) & (0.4,0.5,0.5,0.6) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) \end{bmatrix}$$

Using equation (5.1) for aggregating and averaging the scores across all DMs as explained in section 5.4.1.2, the average fuzzy score matrix for the contractors is obtained as follow:

$$X_{C31} = \begin{bmatrix} (0.650,0.750,0.850,0.925) \\ (0.575,0.675,0.775,0.875) \\ (0.700,0.800,0.900,0.950) \\ (0.450,0.550,0.600,0.700) \end{bmatrix}$$

The crisp scores on criterion c_{31} are obtained using equation (5.2) as follow:

Contractor A = (0.650+0.750+0.850+0.925)/4 = 0.794
Contractor B = (0.700+0.800+0.900+0.950)/4 = 0.725
Contractor C = (0.375+0.450+0.525+0.625)/4 = 0.838
Contractor D = (0.450+0.550+0.600+0.700)/4 = 0.575

Similarly, scores for different contractors against criterion c_{32} and c_{33} are obtained as provided in Table 5.7. Using simple additive weighting method, score of each contractor on 'Performance Potential' criterion can be calculated as follow:

$$\text{Score} = \sum w_k x_k \quad \text{for } k = 1, 2, 3. \qquad \text{............(5.6)}$$

where, w_k is the normalized weight of sub-criterion k, and x_k is the aggregated score of the contractor on the sub-criterion k as shown in Table 5.7.

Table 5.7 Rating of Contractors' Performance on Criterion 'c_3'

Performance Potential (c_3)	**A**	**B**	**C**	**D**
Resource Availability (c_{31})	0.794	0.725	0.838	0.575
Managerial Capability (c_{32})	0.857	0.894	0.598	0.565
Technical Competence (c_{33})	0.879	0.864	0.725	0.625

In matrix form, they can be represented as:

$$\mathbf{TS} = \begin{matrix} \mathbf{A} \\ \mathbf{B} \\ \mathbf{C} \\ \mathbf{D} \end{matrix} \begin{bmatrix} 0.794 & 0.857 & 0.879 \\ 0.725 & 0.894 & 0.864 \\ 0.838 & 0.598 & 0.725 \\ 0.575 & 0.565 & 0.625 \end{bmatrix} \begin{bmatrix} 0.35 \\ 0.34 \\ 0.31 \end{bmatrix} \begin{matrix} \mathbf{c_{31}} \\ \mathbf{c_{32}} \\ \mathbf{c_{33}} \end{matrix}$$

Scores for contractor A on 'Performance Potential' criterion can be calculated as 0.842 (0.794x0.35+0.857x0.34+0.879x0.31). Hence, total scores for contractors on criterion 'Performance Potential' are:

Contractor A = 0.842

Contractor B = 0.826

Contractor C = 0.721

Contractor D = 0.587

Let us assume that scores of contractors on 'Past Performance' and 'Financial Capability' criteria are obtained as shown in Table 5.8.

Table 5.8 Score Matrix for Contractors

CSC	A	B	C	D
Past Performance (c_1)	0.921	0.860	0.845	0.725
Financial Capability (c_2)	0.725	0.836	0.706	0.656
Performance Potential (c_3)	0.842	0.826	0.721	0.587

The overall scores (OS) for contractor against decision criteria can be represented in the matrix form as

$$\mathbf{OS} = \begin{matrix} \mathbf{A} \\ \mathbf{B} \\ \mathbf{C} \\ \mathbf{D} \end{matrix} \begin{bmatrix} 0.921 & 0.725 & 0.842 \\ 0.860 & 0.836 & 0.826 \\ 0.845 & 0.706 & 0.721 \\ 0.725 & 0.656 & 0.587 \end{bmatrix} \begin{bmatrix} 0.298 \\ 0.384 \\ 0.318 \end{bmatrix} \begin{matrix} \mathbf{c_{31}} \\ \mathbf{c_{32}} \\ \mathbf{c_{33}} \end{matrix}$$

Using equation 5.6, overall score for each contractor can be calculated. For example, the overall score for Contractor A is 0.8263 (0.921x0.298 + 0.725x0.384 + 0.842x0.318). Hence, overall score for contractors and their ranking are as shown in Table 5.9. The selection system recommends Contractor B should be selected for the project based on the information provided by DMs.

Table 5.9 Overall Scores and Final Ranking of Contractors

Contractor	A	B	C	D
Overall Score	0.8263	0.8400	0.7522	0.6546
Rank	2	1	3	4

This simple illustrative example of P&P qualification is to only elaborate the mechanics and data requirements of the proposed evaluation technique. Evaluation of tender proposal and best value determination is also not considered in the example. For combining the P&P score and price score, the predetermined weights for P&P component and price component can be used to arrive at overall scores before ranking of the candidate contractors. A real case of contractor selection considering all these issues is presented in Chapter 7.

However, it is recommended that the final ranking of the contractors based on the overall values should be simply used as a guide for viewing the relative differences between candidate contractors. For in complex MPMC decision problems choosing an alternative just because it happens to be marginally better in overall score than another alternative is less meaningful as the variation in the weights of the decision criteria may change the final ranking. Hence, establishing the weight stability intervals, that is, the interval within which a weight can vary without changing the final results is always important to ensure that the ranking of alternatives obtained is stable to small weight variation. Sensitivity analysis of the developed system is always important to investigate the stability of the system prediction. In order to assist DMs in negotiation during criteria trade-off before final ranking, the proposed computer-interactive selection system will have the facility to provide them with the information such as how each candidate contractor is performing on each of CSC and how each contractor is rated by DMs . All these important considerations are taken into account while developing computer-interactive contractor selection system described in Chapter 7.

5.9 Conclusion

The success level of any construction project may well be argued to depend significantly on the basic philosophy of 'the right contractor for the right project'. Therefore, the selection of the most appropriate contractor for the project is a crucial challenge faced by every construction client to ensure the achievement of best value for money. In this chapter, a conceptual system for contractor selection in multi-criteria environment is presented. The proposed decision-making method allows DMs to express their opinions about the performances of attributes on decision criteria in more realistic manner as the use of fuzzy set theory facilitates assessment to be made in qualitative and linguistic or approximate terms which better correspond to real-world situations. In an actual contractor selection process, in addition to tender price, a large number of decision criteria and sub-criteria need to be considered simultaneously and in most cases the DMs are less reluctant to handle the uncertainty associated with decision-making directly in the scores of performance on particular criteria by using approximate values than by using crisp values and this makes the use of fuzzy linguistic variables for the proposed contractor selection system more appropriate.

In developing the system, it is assumed that the performances of attributes on decision criteria are fuzzy whereas the performances of the DMs are not. Hence, the importance weights for CSC are established using numerical scale values and the assessment of performances of contractors' attributes on CSC are carried out using fuzzy linguistic variables. The interaction among the CSC is taken into consideration for adequate treatment of fuzzy decision-making. In order to avoid the overestimation of the importance of a particular criterion, the overall importance of a particular criterion is not solely determined by the importance of that criterion, but also by the value of all other criteria considered in the evaluation process. For this purpose, the marginal contribution of each of the decision criteria to overall goal is determined by using the concept of the Shapley value. Using this concept, the method presented produces such an evaluation that reflects the relationships among the decision criteria and DMs' preferences and concerns in decision-making process.

The challenges in using the proposed system would be defining and specifying the types of fuzzy numbers for linguistic variables and establishing the scale of preference structure to be used in the evaluation process. When there are many stakeholders with different interests in the outcomes of the project, it would be more difficult and complicated to establish the scale of preference structure as each of them may have different idea about the importance of decision criteria and how they should be evaluated making group decision-making much more complicated and fuzzier. One of the simple and effective ways to address this issue is the approach to arriving at it by ensuring the group (of DMs) consensus, reflecting the pooled risk-bearing attitude of the group. Another useful method would be the use of fuzzy Delphi method (Kaufmann and Gupta 1988) to achieve a group consensus. In this method, a number of industry experts are first asked to express their opinions about the fuzzy numbers for linguistic variables and scale of preference structure for them and results are then aggregated. These aggregated results are sent back to them so that they can change their opinions based on the aggregated results. This process continues until a level of general agreement is achieved. One major weakness of the proposed method is that the exhaustive establishment of weights for different combinations of criteria for determination of overall importance values, if there are many, puts burden on DMs and is also time consuming. The major advantage of the proposed method is that it makes the selection process more systematic and realistic as the use of fuzzy set theory allows the DMs to express their assessment of contractors' performance on CSC in linguistic terms rather than as crisp values.

With an aim to strengthen the proposed contractor selection system, an effort is also made to establish the evaluation system for financial soundness of contractors during selection process, which is described in the next chapter.

Chapter 6

Evaluation Model for Financial Health of Construction Firms

6.1 Chapter Overview

Economic slowdown in recent years has led many construction firms to pull out of business as a result of deep financial problems. Consequently, construction clients face the risk of project failure in terms of time, cost, quality and annoyance. To reduce such a risk, construction clients need to evaluate the financial soundness of the contractors before awarding the contract. This chapter describes a method using financial ratios to investigate the changes in the financial health of candidate contractors for comparing their financial soundness during tender evaluation process. The concept of entropy method is employed to calculate the objective weights of financial ratios and MCDM method is used to produce an overall performance score for the contractors. A real case study of the assessment of financial soundness of contractors during a contractor selection exercise is carried out to illustrate the application of the method. The evaluation results obtained from the method shows that the approach can well be used to assist construction clients in assessing the financial capability of the contractor to execute the project under consideration.

6.2 Introduction

In Singapore, the low volume of construction demand as a consequence of economic depression in recent years has increased the number of construction companies experiencing financial difficulties or cash-flow problems and heading to insolvency. Furthermore, the fierce competition as a result of low construction demand has caused more cash-flow problems in the construction industry in recent years. For example, from Jan 2002 to Mar 2003, 26 Singapore construction companies were declared insolvent as a result of their cash flow squeeze (Cheong and Tan, 2003). In such a harsh economic environment construction clients need to be more careful in selecting the construction company whose services they engage for the execution of construction projects.

Financial ratios are used to generate the information that in itself is not clearly identifiable from financial statements (McNamee, 1985). Many researchers have developed financial ratio models to predict the failure or bankruptcy of non-construction companies (Beaver, 1966; Altman, 1968; Edmister, 1972; Blum, 1974; Ohlson, 1980; Altman, 1983; Taffler, 1983; Keasey and Watson, 1986) and for construction companies (Mason and Harris, 1979; Kangari, 1988; Abidali, 1990; Russell and Jaselskis, 1992b; Ramsey-Dawber, 1993) as well. In general, these models use different financial ratios selected by the developer of the model, after multiple discriminant analysis of financial ratios of past failure and non-failure companies, on the basis of their discriminating power in predicting the failure of the company. In general, the application of these financial models essentially consists of calculating ratios for an individual company, comparing these with some industry average to predict the impending financial failure of the company or with ratios for competing companies to make inter-company comparison, for example, in contractor selection by clients.

Mason and Harris (1979) using discriminant analysis for 20 failed and 20 non-failed construction companies in the UK proposed a ratio model which can be used to assist construction clients in contractor selection to identify the financial health of the construction companies and to avoid awarding the contract to a contractor with impending financial distress signals. They used multiple regression approach to establish their six-variable model which calculated a combined Z-score for an individual construction company. A positive score was considered as an indication of the long-term solvency of the construction companies whereas companies with negative scores were regarded as potentially insolvent. Edum-Fotwe *et al.* (1996) highlighted the inconsistency and redundancy of variables used in the model of Mason and Harris. Kangari (1988) proposed a model, which considered five external or macroeconomic factors and statistics, to predict changes in the business failure rate in the construction industry. According to him, the use of this model can assist the companies in determining when failure rates will be high, so that the management decisions can be made to lower the chance of business failure.

Abidali (1990) also developed a seven-variable model which can be used to assist construction clients in predicting the long-term solvency of the construction companies during tender evaluation process. However, Edum-Fotwe *et al.* (1996) also pointed out the inconsistency of Abidali's model. Russell and Jaselskis (1992b) using logistic regression approach proposed a contractor failure predictive model. Like Kangari's (1988) model, their model also used variables other than ratios derived from the financial statements and did not consider the financial soundness for predicting the failure of the contractor.

Among the four models discussed above, which were fundamentally developed in the context of the construction industry, Mason and Harris (1979) and Abidali (1990) can well be used to assist construction clients in evaluating or predicting the financial stability of contractors during tender evaluation. Their models considered only those variables which showed the greatest predictive ability with respect to a given event or the power of discrimination between failure and non-failure companies. However, both these models are only applicable in the specific industry environment, i.e. developed from the data collected from the UK construction industry and cut-off for the models were determined at the time when the models were developed. Furthermore, most of the variables used in the models are only spot values so that they only measure the financial status of a company at a specific point in time and do not reflect the managerial actions in formulating alternative strategies in response to the dynamism of market forces and business environment. In addition, some financial ratios change over time due to changes in inflation, interest rates or effect of phases of business cycles and this instability of ratios will have significant effect on the predictive ability of the models using cut-off points the values of which might also have changed between the development and prediction periods. Therefore, it is always important that the technique used to evaluate the financial health of a company must consider all those financial ratios which can be interrelated to map a comprehensive profile of company financial characteristics and data instability over time. This chapter presents a method for assessing the financial health of construction companies capable of reflecting all these considerations in the evaluation outcomes.

6.3 Selection of Financial Ratios

Karels and Prakash (1987) summarized a set of bankruptcy or failure definitions, from a financial perceptive, used by researchers in their empirical study of bankruptcy. They include negative net worth, non-payment of creditors, bond defaults, inability to pay debts, overdrawn bank accounts, omission of preferred dividends, receivership and so on. In the short run, a company can continue its operation even though it exhibits these characteristics, which illustrates the point that failure does not amount to bankruptcy. The ability of a company to avoid these failures or to pay its financial obligations when they become due is largely dependent on the amount of financial obligations to meet, the liquid assets of the company, the profit generating ability of the company, and the possibility of getting outside financing and managerial actions to improve the financial status of the company. Therefore, the financial ratios selected for the study of a company's financial health must reflect consideration for all these characteristics in the assessment.

Russell (1990) suggested that key financial ratios addressing solvency, efficiency, and profitability of candidate contractors should be properly analyzed during the evaluation process. Hatush and Skitmore (1997) also highlighted that the analysis of the financial statement should include evaluating three important areas covering liquidity, efficiency and profitability performance the contractor.

Selection of financial ratios for a particular study has always been contentious (for e.g., Edum-Fotwe *et al.*, 1996) because of information overlaps. If all ratios were selected, the assessment result would contain redundant information. On the other hand, if only fully independent ratios were selected, some information would be missed out in the analysis. The credibility of financial ratios is governed to a large extent by corporate reporting behavior in disclosing relevant and accurate information. It is therefore always vital to select a set of financial ratios, which are well responsive to the elements that cause changes to a company's financial health, for the analysis of financial soundness so that all the relevant aspects of the company are taken into consideration. In fact, financial aspects of a company's operation can be represented by its short-term liquidity, cash position, long-term solvency, profit generating ability and managerial efficiency in utilizing the resources as shown in Figure 6.1. Selecting one or two ratios from each classification for the study of the assessment of a company's financial health would account for consideration of all aspects of financial characteristics of the company. One important criterion in selecting the financial ratios for the study of the financial soundness of a company is that they should not move in the same direction. Taking into account all these considerations, five ratios-one from each classification are selected for the study and they are:

1. Working capital to current liabilities (Short-term liquidity)
2. Cash flow to current liabilities (Cash position)
3. Net worth to total liabilities (Long-term solvency)
4. Return on total assets (Profit generating ability)
5. Revenue to total assets (Managerial performance)

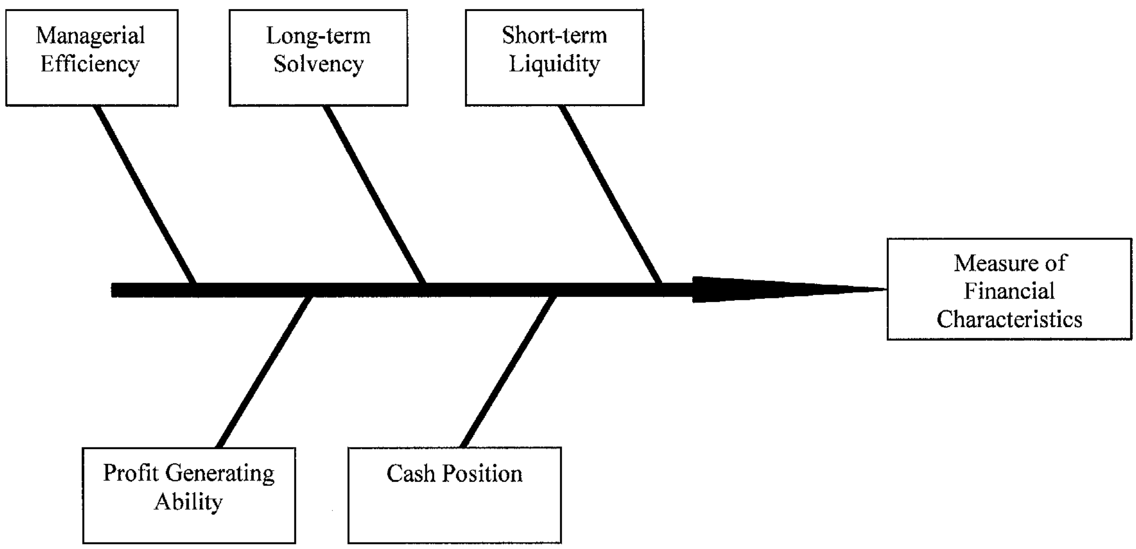


Figure 6.1 Aspects of Financial Characteristics of a Company

6.3.1 Working Capital to Current Liability (WC/CL)

The liquidity of a company is an important aspect of its financial capability, which is an important criterion to be competitive. Working capital (WC), the difference between total current assets and total current liabilities (CL), is an important value representing the amount of day-to-day operating liquidity available to a business. Working capital to current liabilities ratio measures the company's potential cash reservoir to meet its current liabilities (short-term liquidity) when they mature. Instead of current ratio, i.e., current assets to current liabilities, which is a more popular financial ratio used for assessing a company's ability to meet its short-term financial obligations, the net working capital ratio is selected to assess the company's ability to meet its short-term liabilities. The reason for selecting this ratio is because of its responsiveness to the changes in working capital, for example, when the net working capital halves, net working capital ratio also halves whereas the current ratio would only fall, for example, from 2:1 to 1.5:1. Therefore, the current ratio is less responsive to changes in the company's working capital, which represents the cushion available to the business for carrying receivables and for financing day-to-day operation. However, working capital can be maintained by borrowings. If a company increases borrowings to maintain its working capital, the profit will record a fall as a result of additional finance expenses whereas the company's current ratio will record an increase which, however, does not necessarily mean that the company's current liquidity status is healthy. Furthermore, other ratios such as profitability ratios will also record a fall. The static nature of current ratio when computed from balance sheet information at a point in time highlights vulnerability of this ratio to window dressing, that is, the alteration of financial statements at the time of publication to give an artificially improved appearance to the company financial status.

6.3.2 Cash Flow to Current Liabilities (CF/CL)

Cash flow, as net income plus non-working capital expenses such as depreciation and amortization, serves as a useful indicator of the likelihood of financial distress. This ratio-cash flow (CF) to current liabilities (CL), free from manipulation through window dressing, can be viewed as a liquid asset flow ratio and is also a good indicator of a company's ability to meet its short-term maturing obligations without liquidating its non-liquid assets. To ensure survival in difficult phases of business cycles, management should attempt to maximize the company's main source of secure funding- its internal cash generation. Deterioration of a company's cash flow is a key indicator of impending problems leading to insolvency. Construction's reliance on a cash-flow cycle for each project, with negative cash flows occurring at the start of most projects, makes the management of cash flow a prime concern. Having insufficient cash flow on hand is always a major reason for construction company bankruptcies.

6.3.3 Net Worth to Total Liabilities (NW/TL)

The ratio of net worth (NW) to total liabilities (TL) measures the company's ability to meet its long-term obligations when they become due. This ratio also indicates the extent to which a company is financed by liabilities. If this ratio is less than 1, it indicates that the creditors have a greater equity in the company's assets than do the owners- stockholders. Such top-heavy liabilities make the business extremely vulnerable to any unexpected contingencies and severely restrict the management's flexibility in business operation. It also indicates the possibility of obtaining more outside loan when it needs to gear the business which is one of the important considerations in assessing the contractor's financial capability while assessing the contractors on tender lists.

6.3.4 Return on Total Assets (EBIT/TA)

Return on total assets of a company is calculated by dividing the earning before interest and taxes (EBIT) by the average total assets (TA). It measures the return on investment in terms of all capital employed in the business- whether supplied in the form of equity or debt. This return, expressed as percentage, gives an indication of how much more or less the company is earning before interest and taxes, and of the efficiency of the company operating performance, that is, how efficiently and effectively the company is utilizing its resources to generate the profit. This ratio is important as it tells about the company's ability to generate the profit for the ability to generate an adequate profit is necessary for sustained growth. The company can expand the business by plowing back profits or by raising money in capital markets which consider the company's ability to generate adequate profit on capital employed. To successfully compete with all other companies in the capital markets, the company's return on total assets must be comparable favorably with the return for other companies.

6.3.5 Revenue to Total Assets (REV/TA)

The ratio of revenue (REV) to total assets is a measure of trading stability, that is, how efficiently the management is utilizing the resources at its disposal to generate respectable revenue. When a company increases its asset base it is looking for a corresponding increase in sales or revenue. If comparable sales increases have failed to accompany sizable investment in assets, then poor asset utilization is indicated. Continuous deterioration of this ratio indicates that the company is experiencing trading difficulties or indulging in overtrading. Higher ratio values indicate faster sale and effective contract winning strategy.

The credibility of financial ratios is governed to a large extent by corporate reporting behavior in disclosing relevant and accurate information. It is therefore always important to select a set of financial ratios for the analysis so that all the relevant aspects of the company are taken into consideration.

6.4 Proposed Financial Evaluation Model

Multiple criteria decision-making is widely used in ranking or selecting one or more alternatives from a set of available alternatives with respect to multiple usually conflicting decision criteria (Hwang and Yoon, 1981). The assessment of financial health and ranking of construction companies is a complex process and requires the simultaneous consideration of multiple financial ratios which are often highly correlated and conflicting in nature. Moreover, in general no one single contractor performs better than all of his competitors in all aspects of financial characteristics and this poses difficulty in decision-making regarding determination of overall performance and ranking of contractors. Hence, MCDM approach provides a perfect framework for the problem of evaluating the financial performance of construction companies.

In MCDM problems, the importance weight assigned to the decision criteria must reflect the subjectivity of DMs' preferences and the objective characteristics of the criteria themselves (Zeleny, 1982). Since the DMs may have different perceptions of the importance of different decision criteria used, it is always difficult to reach a consensus on the relative importance of criteria through subjective weighting method. If suitable DMs are not available, this problem becomes more difficult and complex. If, therefore, an unbiased ranking of construction companies, in respect of their financial strength, is desired, the relative importance of financial ratios have to be established through objective weighting process which is free from subjective preferences of DMs. "Attributes importance is as much a property of the attribute as it is of a decision maker" (Zeleny, 1982). It implies that attributes can be viewed as information sources and their relative importance reflects the amount of information contained in each of them. To handle such an evaluation situation, the objective weighting method of Zeleny (1982) that uses the entropy concept of Shannon (1949) can well be used to measure the relative importance of financial ratios from the amount of average intrinsic information that each financial ratio transmits to the DMs as the entropy measure clearly indicates the amount of decision information contained in each financial ratio (c.f., Hwang and Yoon, 1981).

Entropy can be defined as a numerical measure of the average amount of information contained in a set of criteria. If all alternatives have more distinct and differentiated values for a particular criterion, the criterion is more important or dominating in making a choice between alternatives. On the other hand, if all alternatives have much similar values for a criterion, the relative weight assigned to the criterion can be smaller. If all alternatives have similar value for a criterion, the criterion can be eliminated from the set of criteria as it transmits no information to the DMs (Zeleny, 1982). The main idea of entropy concept is that the importance relative to a criterion C_j, measured by the weight w_j, is a direct function of the information conveyed by the criterion relative to the whole set of alternatives. The amount of information contained in each criterion C_j can be measured by the entropy as:

$$E_j = -k \sum a_{ij} \log (a_{ij}) \qquad \text{..............(6.1)}$$

$$a_{ij} = x_{ij} \ / \ [\sum x_{ij}], \ \forall i \qquad \text{..............(6.2)}$$

$$k = 1/ \log (m) \qquad \text{..................(6.3)}$$

where, x_{ij} is performance rating of the *i*th alternative on criterion *j*, k is a constant which ensures $0 \leq Ej \leq 1$ for $\forall j$, and m is the number of alternatives. The measure of discriminating power is expressed as the 'measure of dispersion' or 'degree of divergence'

$$D_j = 1 - E_j \qquad \text{..............(6.4)}$$

The higher the value of D_j in the evaluation of the alternatives A_{ij} for j, the more important the criterion C_j for the given problem (Zeleny 1982, pp 190). In other words, the important criteria are those which have the greatest discriminating power between alternatives. If all a_{ij} against a particular criterion are the same, the criterion can be removed from the set of criteria for the given situation, as it transmits no information to the DMs (Ibid.). Finally, the normalized objective weight of each criterion can be calculated as

$$w_j = D_j / \sum D_j, \ \forall j \qquad \text{.................(6.5)}$$

The DMs' preferences can also be reflected in the importance values of the criteria by multiplying the weights w_j obtained by the entropy method by a factor (f_j) representing the DMs' preferences. Hence, the final weights for decision criteria will be:

$$w'_j = w_j f_j \qquad \text{...............(6.6)}$$

The simple additive weighting method is used to aggregate the performance ratings of alternatives on criteria to produce overall performance scores of alternatives. Though many other aggregation methods are available for the purpose, simple weighting additive method is preferred because of its simplicity and of the fact that it yields extremely close approximations to very much more complicated aggregation methods (Edwards, 1977). This aggregation process can be expressed as:

$$\text{Score} = \sum x_j w_j \qquad \text{.................(6.7)}$$

where, x_j is the rating of an alternative on criterion (financial ratio) j and w_j is the normalized weight of the criterion j. The higher the score, the better the financial health of the candidate company. In order to take into account the effect of data instability over time and the dynamism of managerial actions in formulating alternative strategies to improve the company's financial performance, analysis is done for a period of three consecutive years so that all aspects of company's operation performances and managerial effectiveness are reflected in the analysis results.

6.5 Illustrative Example

A real contractor selection case is considered to demonstrate the application of the method. There were three contractors vying for the project and their annual reports for three financial years (FYs) are thoroughly studied and performance ratings of each of the companies with respect to financial ratios selected for the analysis of financial performance are calculated and presented in Tables 6.1-6.3 (Financial figures are provided in Table C6-8 in Appendix C).

Table 6.1 Performance Matrix for FY- 2000

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA (%)	REV/TA
A	2.4802	-0.1802	4.7294	-1.2965	0.0315
B	-0.4780	0.0810	0.7712	2.5582	0.5379
C	0.8818	0.0289	1.6391	1.4067	0.8266

Table 6.2 Performance Matrix for FY- 2001

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA (%)	REV/TA
A	4.5507	-2.6652	6.8301	-30.0724	0.0055
B	-0.5865	0.0335	0.7888	5.2648	0.4426
C	0.5834	-1.9474	1.0281	-8.3359	0.8715

Table 6.3 Performance matrix for FY- 2002

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA (%)	REV/TA
A	3.7804	-0.6171	7.4533	-5.0779	0.0069
B	-0.4387	0.2578	1.0517	11.7743	0.6139
C	0.8606	0.0995	1.0373	11.3882	0.8345

Before the equation (6.2) can be used for normalization process, all the terms in the performance matrix in Tables 6.1-6.3 have to be transformed so that all elements in the tables, i.e., all $x_{ij} \geq 0$. This transformation is done by adding $\min_i(x_{ij})$ to all the terms of the respective column j. This transformation is obviously neutral in case of ordinal and cardinal utilities (Pomerol and Barba-Romero, 2000, pp. 54) which is the case for this study. The scaled or transformed performance ratings of contractors are shown in Tables 6.4-6.6.

Table 6.4 Scaled (Transformed) Performance Rating Matrix for FY-2000

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA (%)	REV/TA
A	2.9582	0	4.7294	0	0.0315
B	0	0.2612	0.7712	3.8547	0.5379
C	1.3598	0.2090	1.6391	2.7032	0.8266

Table 6.5 Scaled (Transformed) Performance Rating Matrix for FY-2001

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA (%)	REV/TA
A	5.1372	0	6.8301	0	0.0050
B	0	2.6987	0.7888	35.3372	0.4426
C	1.1699	0.7178	1.0281	21.7365	0.8715

Table 6.6 Scaled (Transformed) Performance Rating Matrix for FY-2002

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA (%)	REV/TA
A	4.2191	0	7.4533	0	0.0069
B	0	0.8749	1.0571	16.8522	0.6139
C	1.2993	0.7166	1.0373	16.4661	0.8345

Using equation (6.2), normalization of the ratings is performed and the normalized performance matrices are presented in Tables 6.7-6.9.

Table 6.7 Normalized Performance Matrix for FY- 2000

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA	REV/TA
A	0.6851	0	0.6624	0	0.0226
B	0	0.5554	0.1080	0.5878	0.3853
C	0.3149	0.4446	0.2296	0.4122	0.5921

Table 6.8 Normalized Performance Matrix for FY- 2001

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA	REV/TA
A	0.8145	0	0.7899	0	0.0038
B	0	0.7899	0.0912	0.6192	0.3355
C	0.1855	0.2101	0.1189	0.3808	0.6607

Table 6.9 Normalized Performance Matrix for FY- 2002

Contractor	WC/CL	CF/CL	NW/TL	EBIT/TA	REV/TA
A	0.7645	0	0.7811	0	0.0047
B	0	0.5497	0.1102	0.5058	0.4218
C	0.2355	0.4503	0.1087	0.4942	0.5734

The entropy and measure of dispersion of each financial ratios are calculated using equation (6.1), (6.3) and (6.4). Table 6.10 shows the calculated entropy and degree of divergence of each financial ratio. Then, normalized objective weights are obtained using equation (6.5) and presented in Table 6.11.

Table 6.10 Entropy and Divergence Matrix

	Entropy (E)			Divergence (D)		
	FY-2000	FY-2001	FY-2002	FY-2000	FY-2001	FY-2002
WC/CL	0.5671	0.4366	0.4968	0.4329	0.5634	0.5032
CF/CL	0.6254	0.4680	0.6276	0.3746	0.5320	0.3724
NW/TL	06354	0.5989	0.6165	0.3646	0.4011	0.3835
EBIT/TA	0.6169	0.6049	0.6309	0.3831	0.3951	0.3691
REV/TA	0.6949	0.6019	0.6447	0.3051	0.3981	0.3553

Table 6.11 Objective Weights of Selected Financial Ratios

	Weights (w_j)		
	FY-2000	FY-2001	FY-2002
WC/CL	0.233	0.246	0.254
CF/CL	0.201	0.232	0.188
NW/TL	0.196	0.175	0.193
EBIT/TA	0.206	0.173	0.186
REV/TA	0.164	0.174	0.179

The significant differences between the objective weights of financial ratios in Table 6.11 seem to suggest the capability of the entropy method in reflecting the contrast intensity of information emitted by the performance of the construction companies through a set of financial ratios. From the table, it is clear that the ratio of WC/CL has highest value of weights for all the three years indicating more discriminating power than the other financial ratios. It means that this ratio is more important in assessing the financial performance as the companies have more divergent performance ratings on these ratios and they contribute more towards the assessment outcomes. This is also in line with the real situation of the construction industry as well as the popular notion of corporate world that a company generally fails when it becomes incapable of meeting its current liabilities when they mature.

However, this contradicts the finding of Mason and Harris (1979) that short-term liquidity is less important in determining a company's solvency than a more fundamental aspect of its earning ability. But, in the author's opinion the liquidity status of a company is more important than its earning ability particularly in a time when the company is going through a difficult phase of economic slowdown and business conditions. In construction, debtors, work-in-progress, and retained money by the clients have to be carried by the contractor all along the project life and enough working capital is necessary to support them. However, it does not discount the importance of a company's ability of generating profit which is one of the most important criteria to remain in the business and grow. This is also evident from Tables 6.1-6.3 that even though contractor B has recorded negative working capital for all the three financial years it is still ranked first in preference order, as shown in Table 6.12, because of its higher scores on other financial ratios, particularly on profitability ratio, which is a reflection of its better performance on other operational aspects of the business. Therefore, a single financial ratio or function is not sufficient to assess the financial health of a company and a combination of key financial ratios or a number of analyses should be combined to discriminate between companies (Edmister, 1972)

After establishing the objective weights of financial ratios, the next step is to aggregate all performance ratings to produce overall performance scores of contractors. Equation (6.7) is used to calculate the overall performance scores for the contractors and the aggregated scores for FY 2000, 2001 and 2002 and total scores for three consecutive years are shown in Table 6.12.

Table 6.12 Financial Score Matrix and Ranking of Contractors

Contractor	Score (FY-2000)	Score (FY-2001)	Score (FY-2002)	Score (Total)	Rank
A	1.6203	2.4614	2.5126	6.5943	3
B	1.0858	6.9402	3.6136	11.6359	1
C	1.3720	4.5372	3.8784	9.7876	2

Figure 6.2 shows the graphical representation of the trend of performances of the companies over a period of three years. It indicates how the management is trying to improve the financial stability of the company and how well a company is performing relative to its competitors in the industry. It is clear from Figure 6.2 that had the evaluation been based on only one year spot values, for example, of FY-2002 contractor C, who scored well above the rest of the competitors, would have been ranked first in preference order. However, the evaluation outcomes would only shed light on the contractors' financial performance in the year of account or littler earlier.

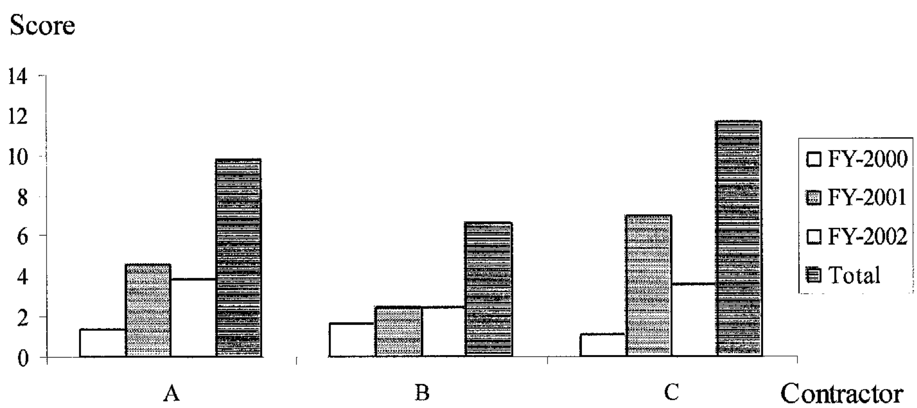


Figure 6.2 Graphical Representation of Financial Performance of Contractors

As pointed by Langford *et al.* (1993) that ratios are indicators of past performances and the trend may continue if the management of the company does nothing to change the situation. That is why it is always important to see the momentum of performance of the companies by observing the changes in the trend of important financial ratios over a period of time while assessing their financial health.

6.6 Conclusion

Selection of the right contractor for a construction project is the most important task faced by any construction clients. Since it takes more than just adequate financial resources to successfully execute a project, the capability of a contractor to execute a construction project is usually assessed against multiple decision criteria. Soundness of financial health is one of the important selection criteria used in the evaluation process. In practice, the prospective client wants to know, while assessing the contractor attributes to execute the project, whether the contractor will be able to finance the client's job in addition to keeping up his current commitments. The client also likes to see if the contractor has in progress one or more losing jobs that will drain off the progress payment money that the client pays to finance his own job.

This chapter discusses a quick and effective method of assessing financial stability of construction companies which can be used for evaluating financial capability of contractors on tender list. The method involves determination of the objective weights of multiple financial ratios based on the amount of information emitted by them. Each of the ratios in the study is included for its ability to reflect the changes in each aspect of a company's financial characteristics and when combined to produce an overall performance score, the method provides the inter-relationship among the ratios which is an advantage over the traditional ratio analysis, in which setting threshold values for financial ratios in order to make a meaningful comparison is always a difficult task for the DMs as these values are greatly influenced by phases of business cycle, changes in the competitive nature of the market, etc.

The use of objective weights for financial ratios based on the contrast intensity of information contained therein and the analysis of trend of performance over a number of year (three years in this case) take into account the data instability over time in evaluation process. The more the number of years studied in evaluation process, the more pronounced the performance trend would be and the better conclusion can be made based on the evaluation outcomes. It can be suggested that a significant drop in the overall performance scores for any two consecutive years should be considered as an indication of impending financial distress and a call for thorough inspection.

Some limitations of the proposed model include: (i) the financial ratios to be used in the study are derived from the published financial information which in many instances may reflect abrupt changes in the financial status of the company due to the effect of one-off events, for example, asset write-down, resulting from the volatile nature of construction. Hence, the entropy method, which derives the objective weights of criteria based on the discriminating power of criteria among alternatives, used in the model may attach undue larger weightings to the affected ratios as a result of such abrupt changes in the financial statement; (ii) because of differing international accounting practices and tax laws, published information on the financial position of companies, and financial ratios derived therefrom do not provide an equitable international basis for assessing the financial health of companies for evaluation purposes. The proposed model does not also take into account the discrepancies arising from the effect of different accounting standards. Hence, it is recommended that all these points be taken into consideration while performing the financial evaluation of candidate contractors.

Since the effort the management and the stakeholders may take to improve or strengthen the company's performance are not predictable, it is recommended that the evaluation outcomes be used only as a guideline for measuring changes in the financial health of construction companies while comparing their financial capability during tender evaluation process and the final decision regarding the financial soundness of candidate contractors should be made on engineering judgment of the DMs considering all other factors such as bank status, bond status, work-in-progress, financial credit ratings and the uncertainty and risk associated with the decision.

With little modification the method can also be used to help the management identify the movement in the individual ratio scores relative to its competitors' or the industry's average so that alternative strategies can be formulated for corrective action. Hence, the use of this technique can no doubt be beneficial to the prospective construction clients in assessing the financial soundness of the potential contractors and to the management in identifying the aspect of a company's financial performance that needs thorough inspection.

Chapter 7
Developing Computer Application for the Selection System

7.1 Chapter Overview

Based on the concept of fuzzy set theory and MCDM method, and the findings observed through the questionnaire survey of the industry, a more realistic computer-interactive decision system for contractor selection is developed. This chapter includes the detailed discussion of major processes involved in the computer-based contractor selection system and elaboration on the logical structure of the system. A step-by-step illustration of the mechanics of the system is presented with the aid of some screen shots from an actual contractor selection case. It also illustrates the application of the evaluation model for financial stability of contractors on tender list. The chapter concludes with discussion of limitations, some suggestions and points for consideration.

7.2 Introduction

The findings from the investigation of preferences of construction practitioners regarding contractor selection in chapter 4, the theoretical concept of fuzzy set theory and MCDM method discussed in chapter 5 and the entropy method for establishing objective weights of decision criteria in chapter 6 form the very basis on which the computer application for the proposed contractor selection system is structured. The computer-based contractor selection system can be used for P&P qualification process (Type I) and P&P qualification plus tender evaluation process (Type II). Due to the uniqueness of construction, it is not appropriate to generalize selection criteria and their weights for all kinds of construction projects. Therefore, in order to enhance the flexibility and applicability of the system to selection of contractors for a wide range of construction projects, the system has a feature that allows the users to adapt the selection process in terms of selection criteria and weights as per the specific requirements of the project under consideration. The model for evaluating the financial soundness of contractors is developed as a sub-model of the selection system. The use of this model in the selection process is optional and can be bypassed if the detailed analysis of financial soundness of candidate contractors is not warranted for a particular selection process.

User interaction and data analysis are mostly two main features of any computer-interactive system. Microsoft Visual Basic is used to develop user-friendly interfaces to provide the users an easy access to data analysis. Microsoft Excel, which is a powerful tool for data mapping and computation, is used for computational task and as database for storing and retrieving data.

7.3 Structure of the Contractor Selection System

In order to elaborate on the logical sequence of the system process, a flow diagram is developed as shown in Figure 7.1. The whole structure of the system is broadly divided into seven main processes as discussed below:

7.3.1 Recording Basic Information for Selection Process

At the start of the evaluation process, the computer-interactive system requires the users (DMs) to provide the project information such as type of project, location of project and project identification (ID) for data keeping in database for future reference, the number of DMs participating in the selection exercise and the number of candidate contractors on the tender list such as name and ID number for referencing purpose, for developing templates for interfacing activities and for allocating storage space in database. For contractor selection process considering both P&P qualification and tender evaluation, weights for P&P criteria ($W_{P\&P}$) and Price criteria (W_{Price}) have to be provided for balancing P&P score and price score to establish overall score for candidate contractors.

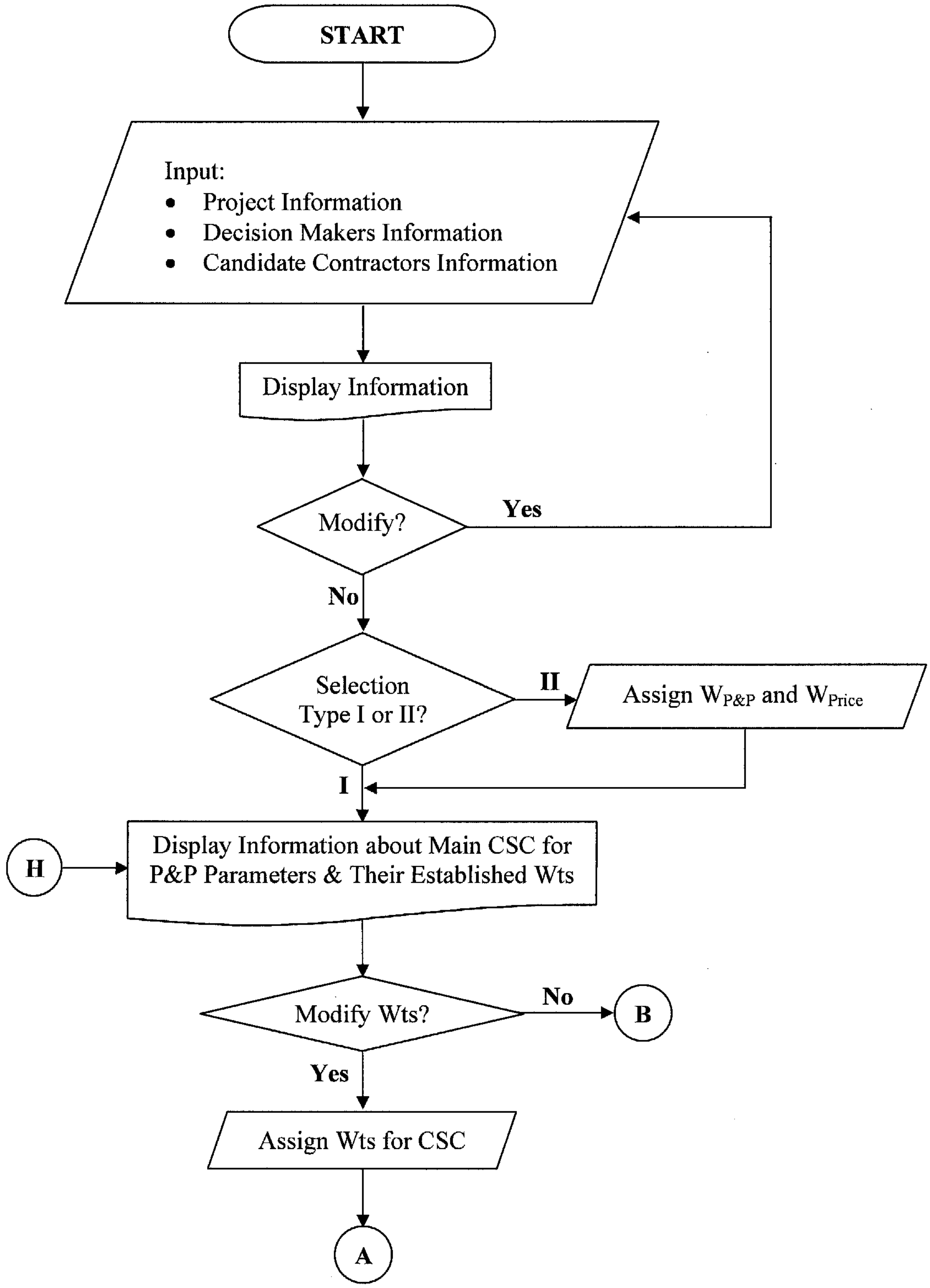


Figure 7.1 Flow Diagram Showing the Logical Sequence of the System Process

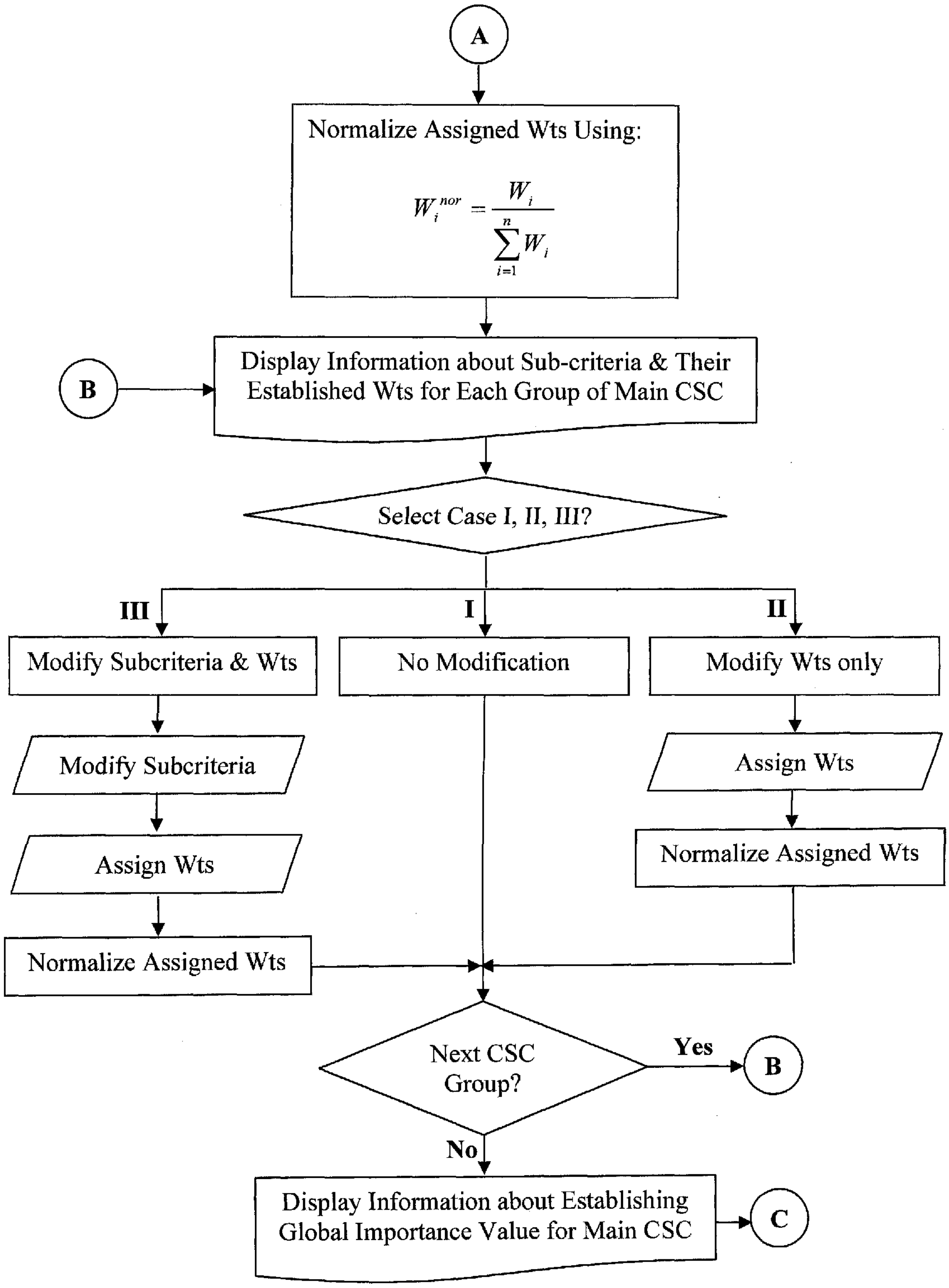


Figure 7.1 (Continued)

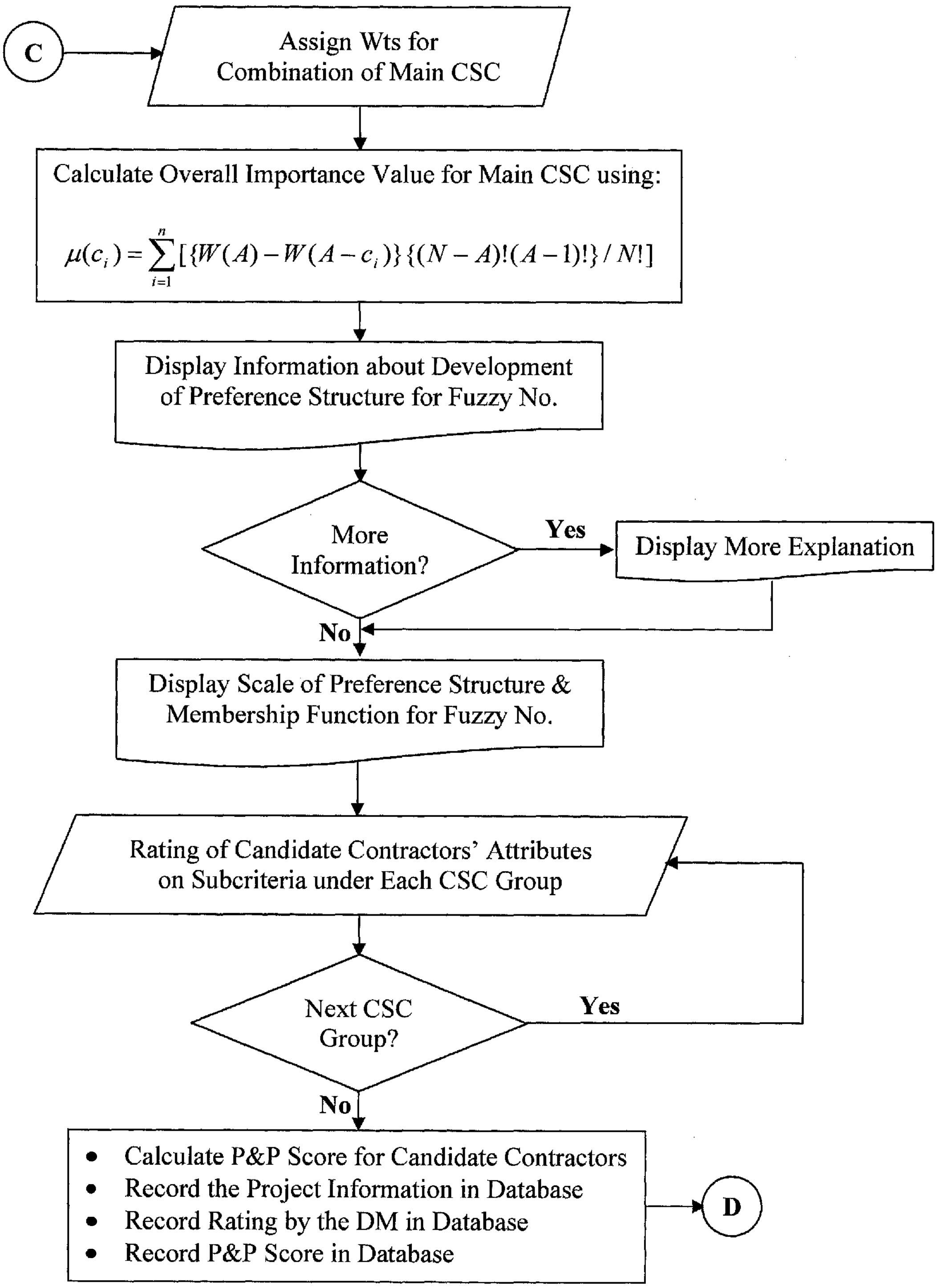


Figure 7.1 (Continued)

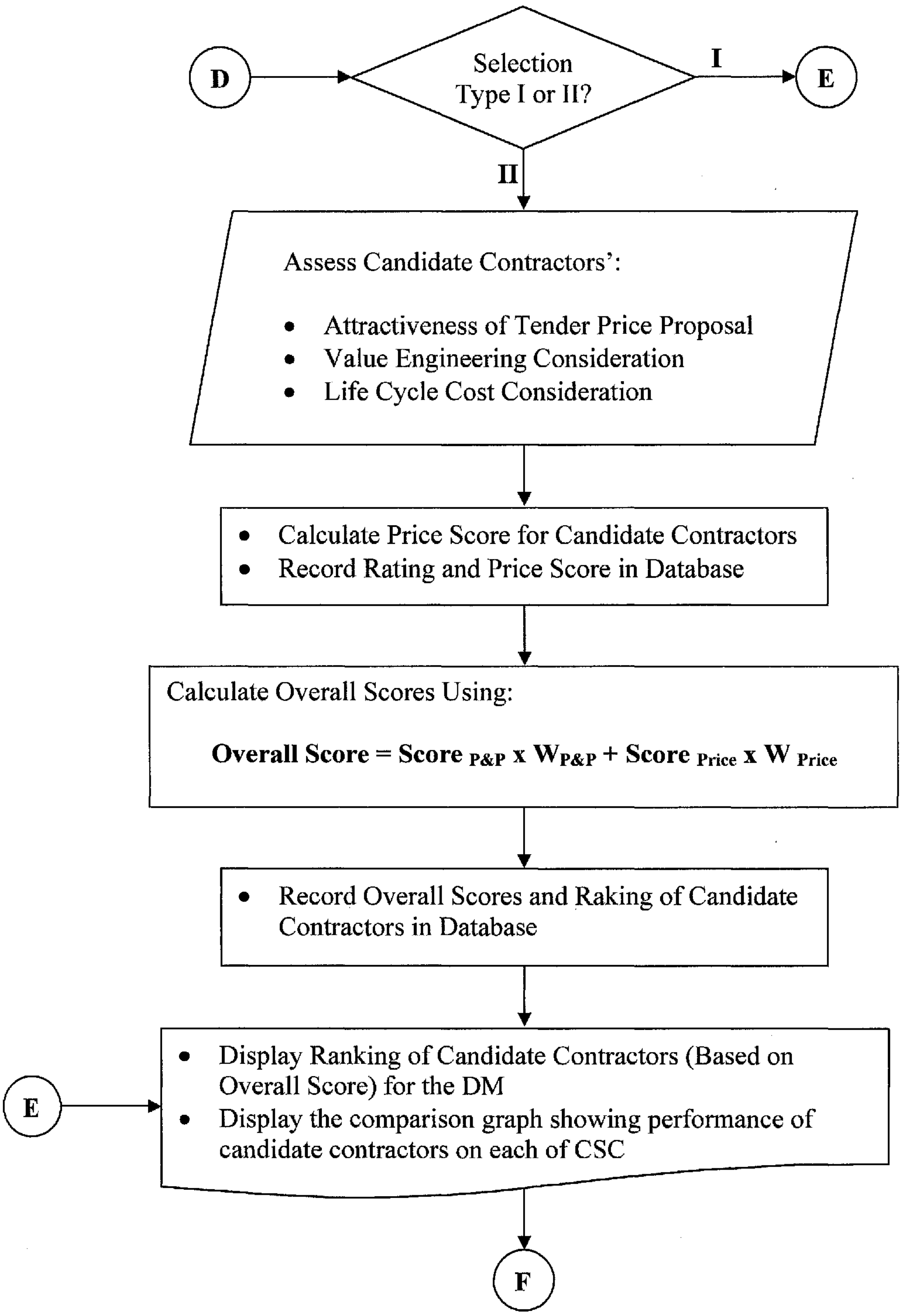


Figure 7.1 (Continued)

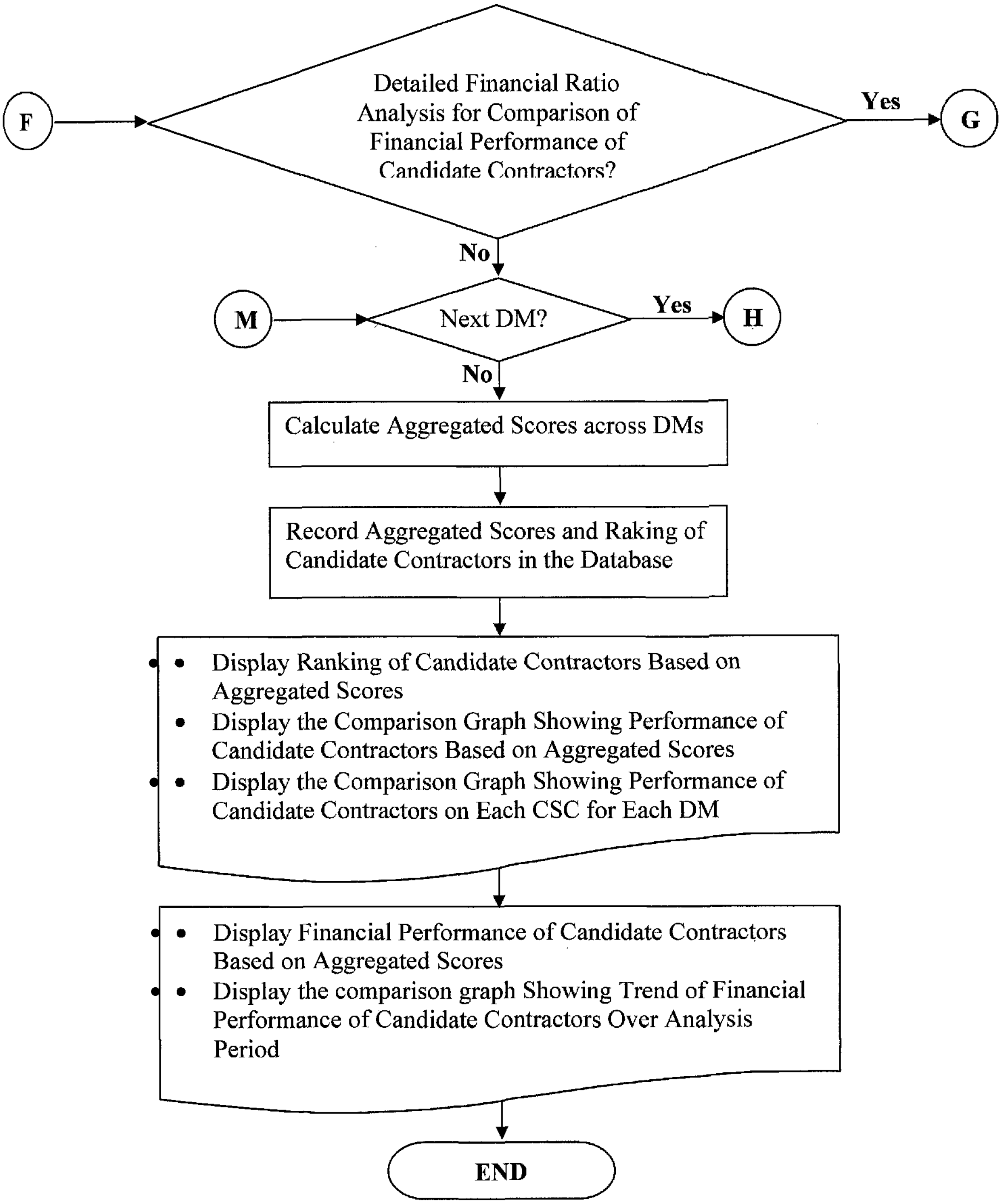


Figure 7.1 (Continued)

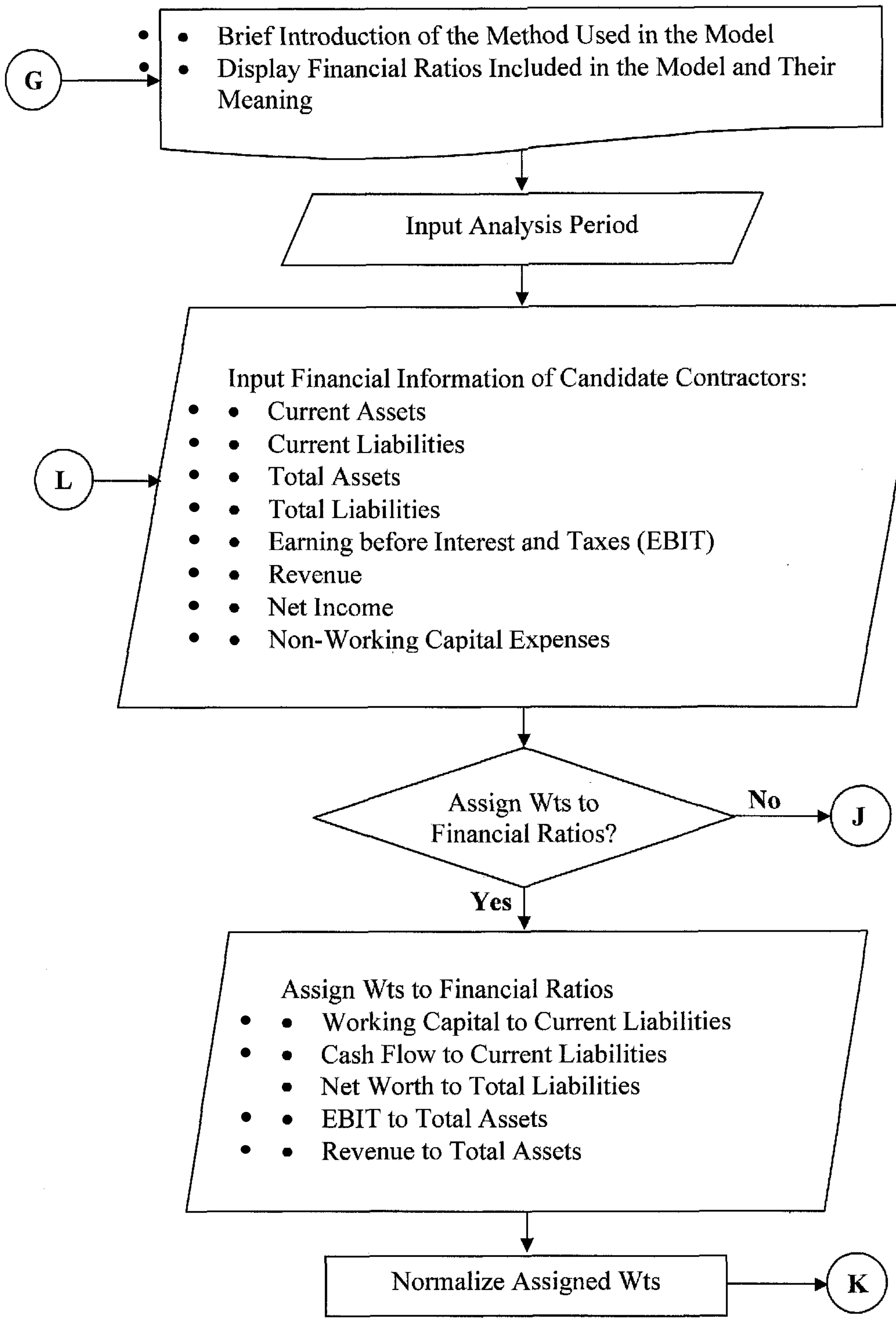


Figure 7.1 (Continued)

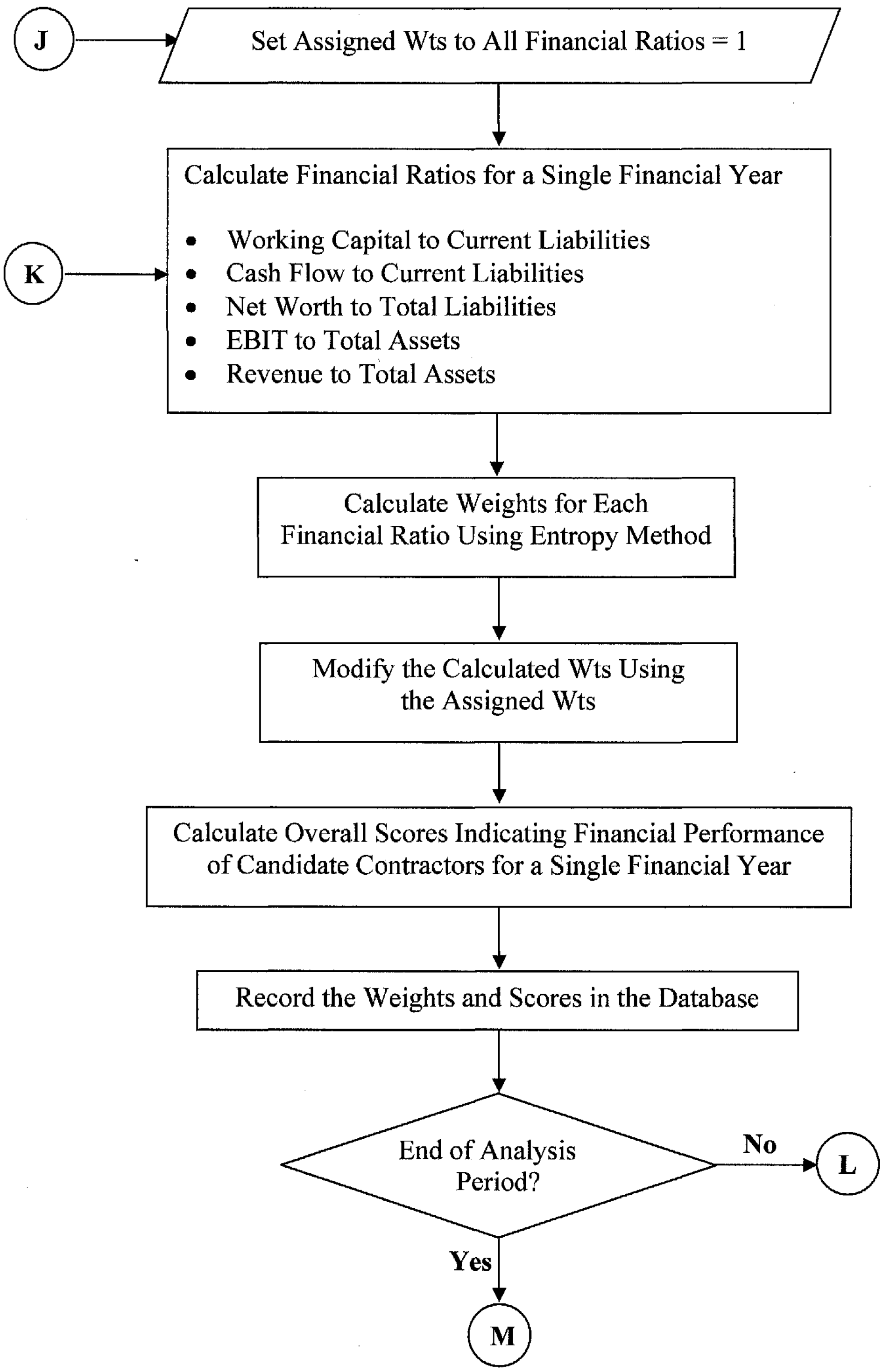


Figure 7.1 (Continued)

7.3.2 Selecting Criteria and Establishing Weights

Based on the findings from the review of literature and from the investigation of the industry, criteria selected for inclusion in the system are categorized under five main CSC groups. The weights for main CSC are also established on the basis of their observed DIA through the questionnaire survey of the industry. Table 7.1 shows main CSC considered in the system and their corresponding normalized value of established weights (in percent). These weights are provided to DMs as default weights by the system. However, users can change the relative weights depending upon the specific requirements of the project under consideration. A number of sub-criteria or factors are considered, on the basis of their relative importance derived from the survey, for measuring the performance of candidate contractors on main CSC. The computer-based selection system allows users to add or remove sub-criteria from the list and also modify their established weights, if they deem necessary in light of the requirements of the project under consideration.

Table 7.1 Main CSC and Their Established Weights

Group ID	Main CSC	Established Weights
A	Contracting Company's Attributes	17.0
B	Past Performance of the Contractor	22.3
C	Financial Capability of the Contractor	25.2
D	Performance Potential of the Contractor	19.7
E	Project Specific Criteria	15.8

At this stage the users have three options:

- **Option I: No modification**

  In this case, the user accepts all sub-criteria or factors selected to measure candidate contractors' attributes on main CSC and their established weights.

- **Option II: Modify weights**

  This option allows the users to change the weights of sub-criteria established. Choosing this option by the users signify that the sub-criteria selected are relevant and important for assessing candidate contractors' attributes on CSC, but the established weights need to be modified according to the specific requirements of the project under consideration.

- **Option III: Modify criteria and weights**

  In this case, both criteria and their established weights can be modified. The users can add or remove one or more criteria from the list and assign weight to the selected criteria accordingly.

7.3.3 Establishing Overall Importance Value of Main CSC

The main purpose of this process that is designed on the concept of Shapley value (Shapley, 1953) is to elicit the DMs' preferences of criteria and relationship among them. Users are required to express the weight they are willing to assign to a combination of criteria when a candidate contractor's performance on the combination of criteria is close to maxima, i.e. as per or close to their expectation and very poor on the rest of the criteria. As in contractor selection process a bad score on one criterion cannot be adjusted by a good score on any other complementary criteria, the weight assigned to the combination of any criteria must be at least equal to the sum of their individual weight assigned separately, that is

$$W(A,B) \geq W(A) + W(B)$$

where, $W(A)$ and $W(B)$ are the weights of criterion A and B and $W(A, B)$ is the weight assigned to the combination of criterion A and B. From the weights assigned to all possible combination of criteria overall importance value of each CSC is calculated using equation 5.4 in Section 5.7.

7.3.4 Rating Candidate Contractors' Attributes on Criteria

This process consists of

- rating candidate contractors' performance and potential attributes on the selected criteria using linguistic variables shown in table 5.2 in Section 5.8.1.
- aggregation of fuzzy scores using equation 5.1 in Section 5.4.1.2.
- converting aggregated fuzzy scores to crisp value using equation 5.2 and 5.3 in Section 5.4.1.3.
- calculating P&P score for each candidate contractor using equation 5.6 in Section 5.8.4.
- ranking of candidate contractors based on overall P&P score, if the type of selection process is Type I, i.e. to evaluate P&P qualification of candidate contractors only.

7.3.5 Evaluating Tender Proposal

This process involves

- evaluating the attractiveness of tender price proposals.
- assessing value engineering consideration by candidate contractors.
- assessing of life cycle cost consideration by candidate contractors.
- aggregation of fuzzy scores.
- converting aggregated fuzzy scores to crisp values.
- calculating Price score for each candidate contractor as explained in the previous section.
- ranking of candidate contractors based on overall score determined using equation

$$\textbf{Overall Score} = \textbf{Score}_{P\&P} \times \textbf{W}_{P\&P} + \textbf{Score}_{Price} \times \textbf{W}_{Price}$$

For selection process considering only P&P qualification this process is not required and can be bypassed. Finally, project information, ratings by the users and scores for all candidate contractors are to be recorded in database for future reference.

7.3.6 Investigating Financial Soundness

The evaluation model for financial health of candidate contractors, which is discussed in chapter 6, is designed as a sub-model of the selection system. If users want to assess the financial stability of candidate contractors on the tender list, this sub-model helps users to have a quick analysis of the trend of financial performance of a candidate contractor with respect to his competitors in the industry and/or the industry's average. The use of the sub-model in the evaluation process is optional. The users can bypass this process if they deem that the detailed analysis of financial soundness of candidate contractors is not warranted for a particular case of contractor selection.

This process consists of

- specifying the analysis period.
- expressing candidate contractors' financial information for each year of analysis period.
- deriving financial ratios from the information provided.
- calculating weights of financial ratios using equations 6.1-6.5 in Section 6.4.
- assigning weights to financial ratios by DMs.
- modifying the calculated weights of financial ratios by multiplying the assigned weights using equation 6.6 in Section 6.4.
- calculating score for each candidate contractor using equation 6.7 in Section 6.4.
- displaying the trend of financial performance of candidate contractors over the analysis period.

7.3.7 Reporting Results

The final outcomes of the results are presented both in tabular format and graphs. It includes the results showing ranking of contractors based on overall aggregated scores, how each candidate contractor is performing on each CSC and how each DM has rated contractors, and a comparison of financial performance of contractors showing a trend over the analysis period.

7.4 Mechanics of the Contractor Selection System

As explained in the previous sections, the entire structure of the contractor selection system can be broadly divided into seven main processes. Because of its capability to design user-friendly dialog or windows or template for entering/presenting data and graphs Microsoft Visual Basic (Dietel *et al.*, 1999) is selected as a programming language to manage interfacing between the user and data analysis part of the computer program and task replication in the process. The following sections present a step-by-step demonstration of the mechanics of the contractor selection system with the aid of screen shots from one of the actual contractor selection cases used for validation of the system in the next chapter.

7.4.1 Entering Basic Information

In this step, the basic information such as type of project, number of decision makers, number of contractors etc. need to be provided. Figure 7.2 shows a dialog for entering basic information for the selection process. This information is necessary for indexing purpose, for controlling repetitive activities in the process and for storing and retrieving data for future reference. Figure 7.3 shows dialog for recording DMs' name and their ID number and candidate contractors' name. It is important for identification purpose in the post-mortem analysis of the final outcomes of the selection system to observe how each DM has rated each of candidate contractors. Actual names of contractors are not used with an aim to avoid favoritism and bias in the selection process.

Figure 7.4 shows dialog for choosing type of selection process, i.e. whether P&P qualification of contractors only or P&P qualification plus tender evaluation. If the process is Type II selection, then weights to P&P criteria and price criteria have to be provided at this stage. Figure 7.5 shows dialog for assigning weights to P&P criteria and price criteria. "Previous" button is to go back to the previous window. When "Continue" button is clicked the system normalizes the assigned weights and stores them in memory for future use in balancing P&P scores and price scores.

7.4.2 Selecting Criteria and Establishing Weights

Figure 7.6 shows five main CSC with brief definition and their weights (all weights expressed as %) established through the questionnaire survey. The users can accept the established weights or modify according to the requirements of the project under consideration. If "Modify Weights" option is selected, the users can assign weights to criteria on a scale of 1-100, 100 being most important, as shown in Figure 7.7. The users can then compare the assigned weights with the established weights by clicking "Show Normalized Weights" option as in Figure 7.8. (The sum of the normalized weights is not exactly equal to 100 due to truncation effect.) If the users are not satisfied with the assigned weight they can change them by selecting "Modify" option and repeating the steps till they are satisfied with the assigned weights.

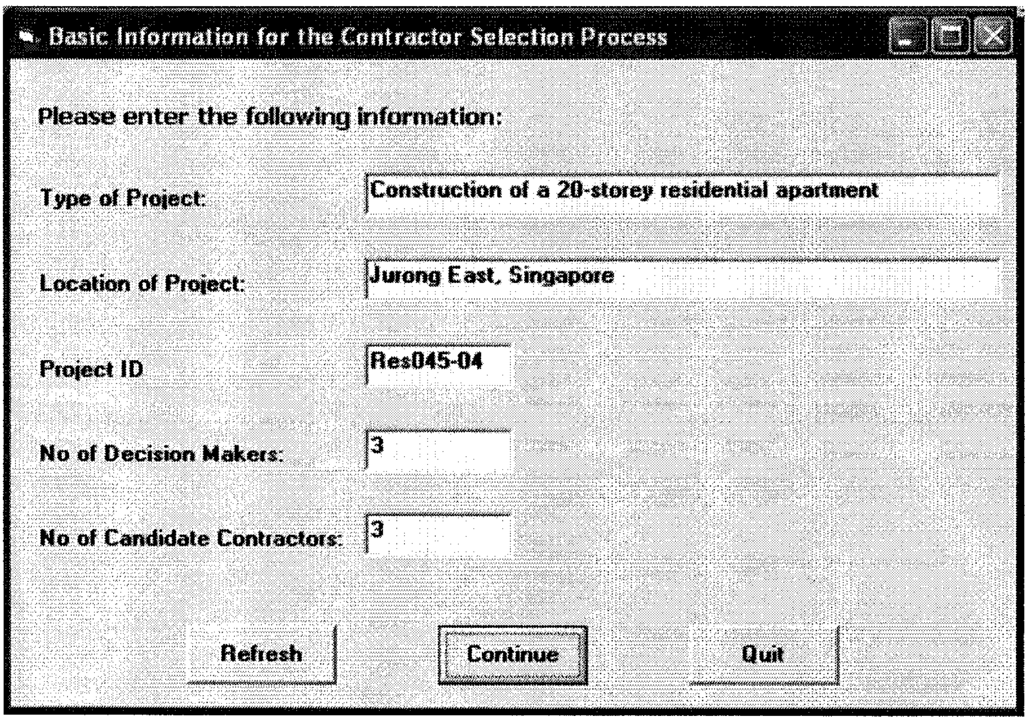


Figure 7.2 Basic Information Dialog

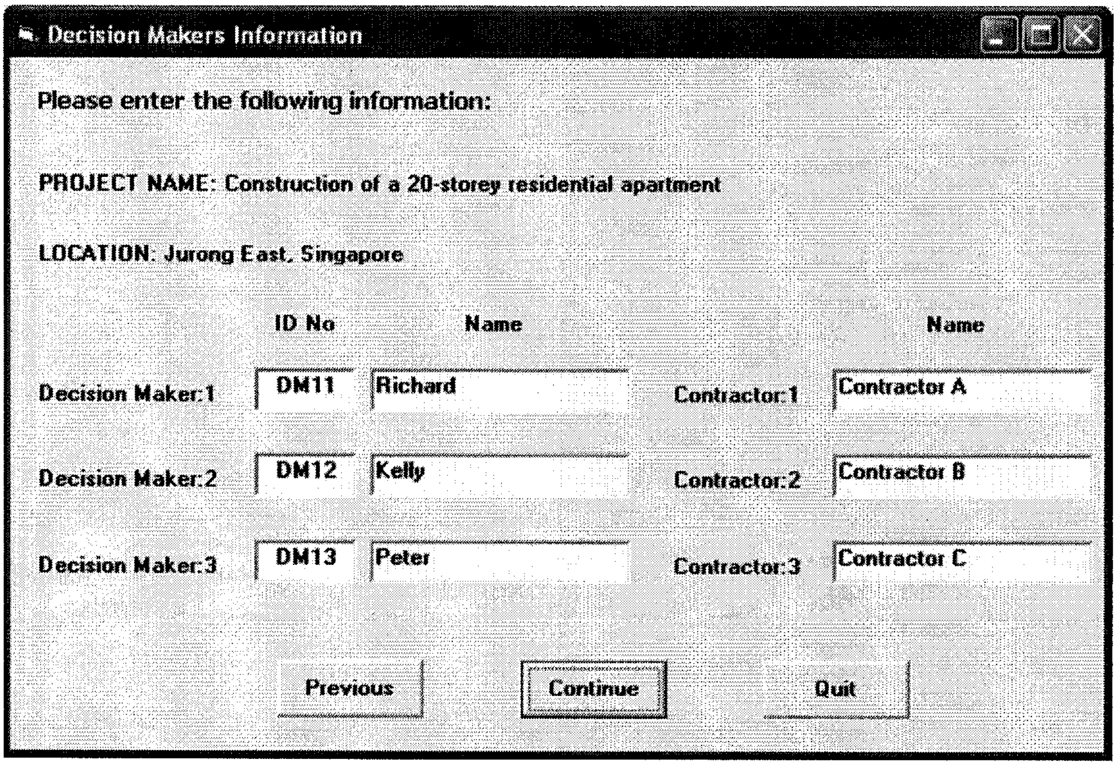


Figure 7.3 Decision Makers and Contractors Identification Dialog

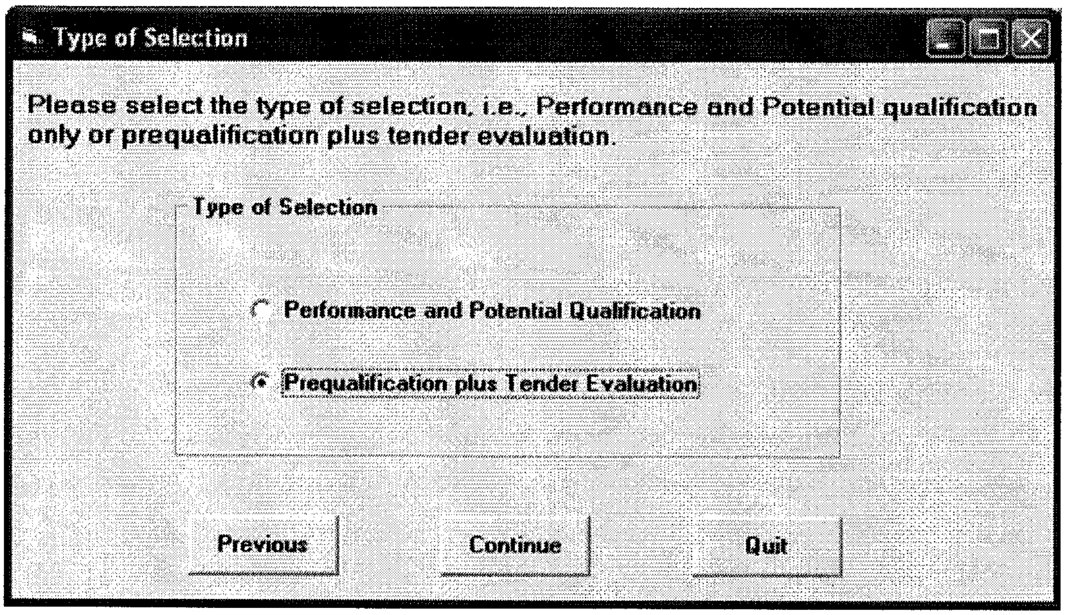


Figure 7.4 Selection Type Dialog

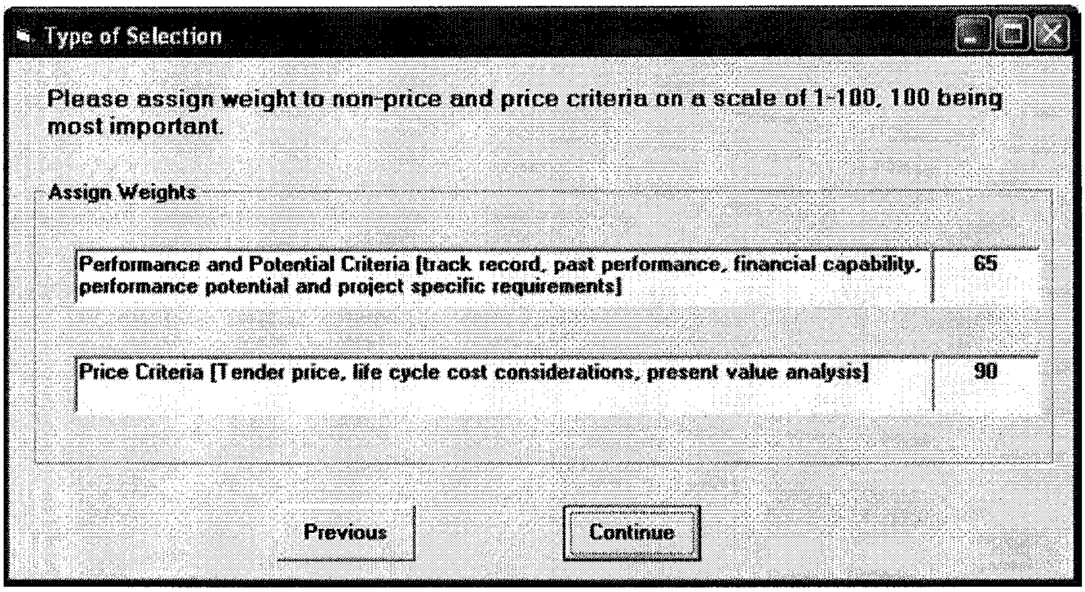


Figure 7.5 Dialog for Assigning Weights to P&P Criteria and Price Criteria

Next step is to select sub-criteria or factors to gauge candidate contractors' attributes on main CSC. Figure 7.9 shows the list of sub-criteria selected under CSC group A. The users have three options.

- Modify Weights: Accept the suggest criteria but want to change the established weights of some or all criteria in the list as shown in Figure 7.10. Figure 7.11 shows the normalized value of the assigned weights which can be modified by clicking "Modify" option if the users wish so.

- Modify Weights and Criteria: This option allows the users to change both criteria and their weights. Figure 7.12 shows the template to add or remove criteria. The user has removed one criterion from the suggest criteria list and assigned weights to remaining criteria as in Figure 7.13. Figure 7.14 shows the normalized value of weights assigned to the criteria, which can still be modified if the user wishes so.

- No Modification: means accept the selected criteria and their weights. Selecting this option will lead to next CSC group.

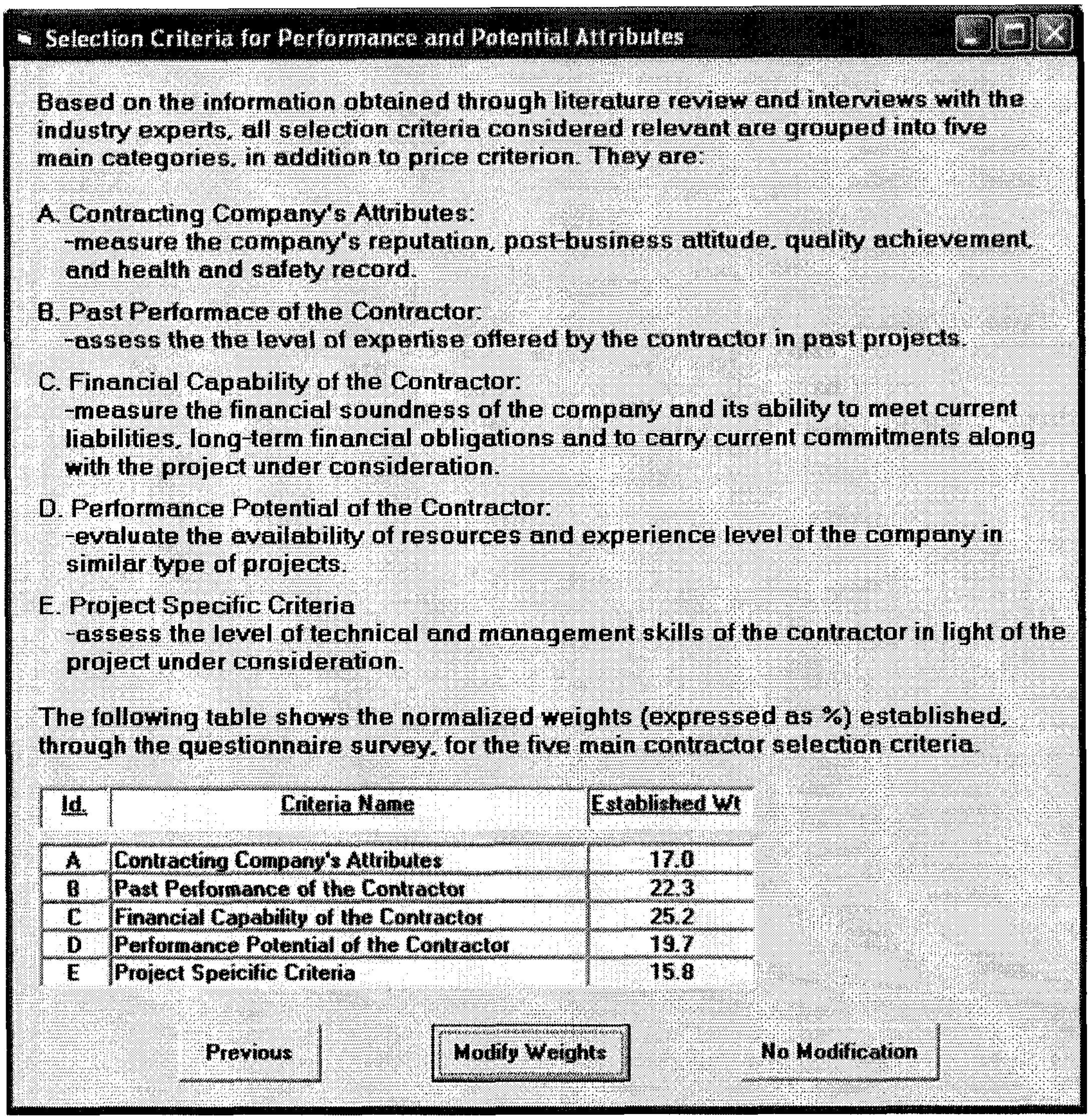


Figure 7.6 Five Main CSC and Their Established Weights

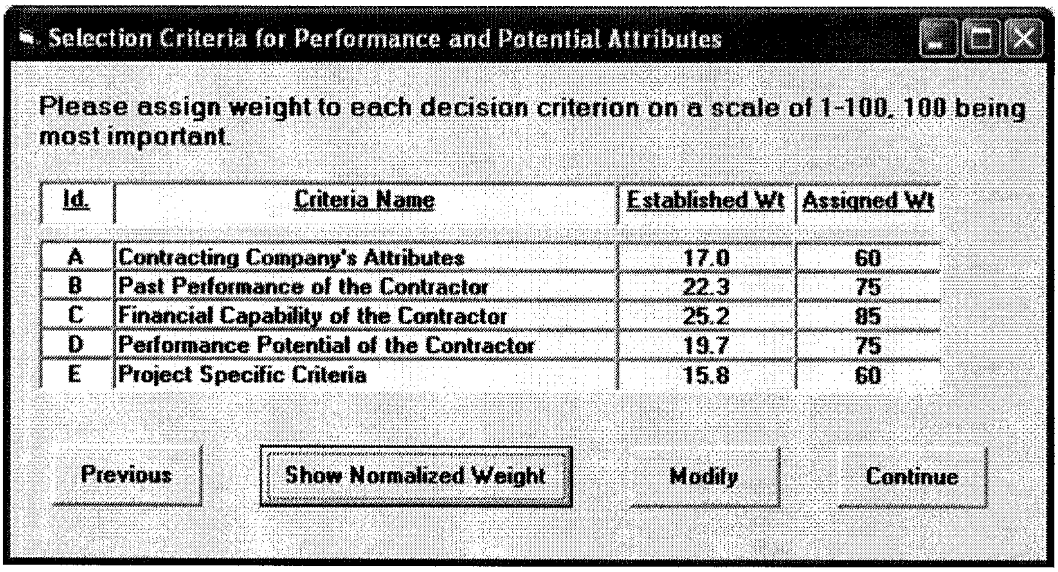


Figure 7.7 Template for Modifying the Established Weights for Main CSC

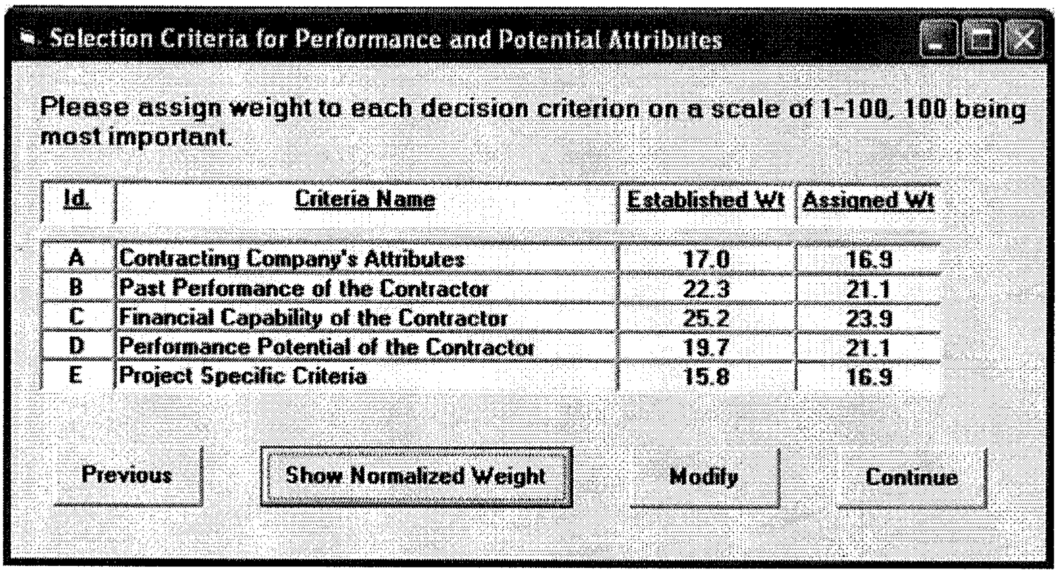
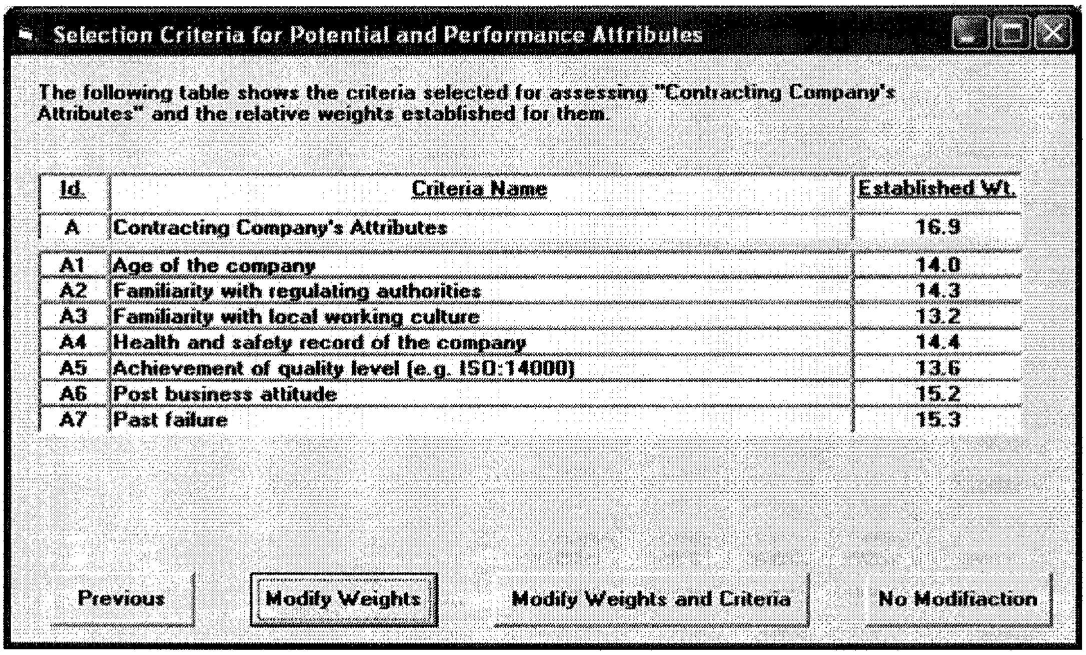
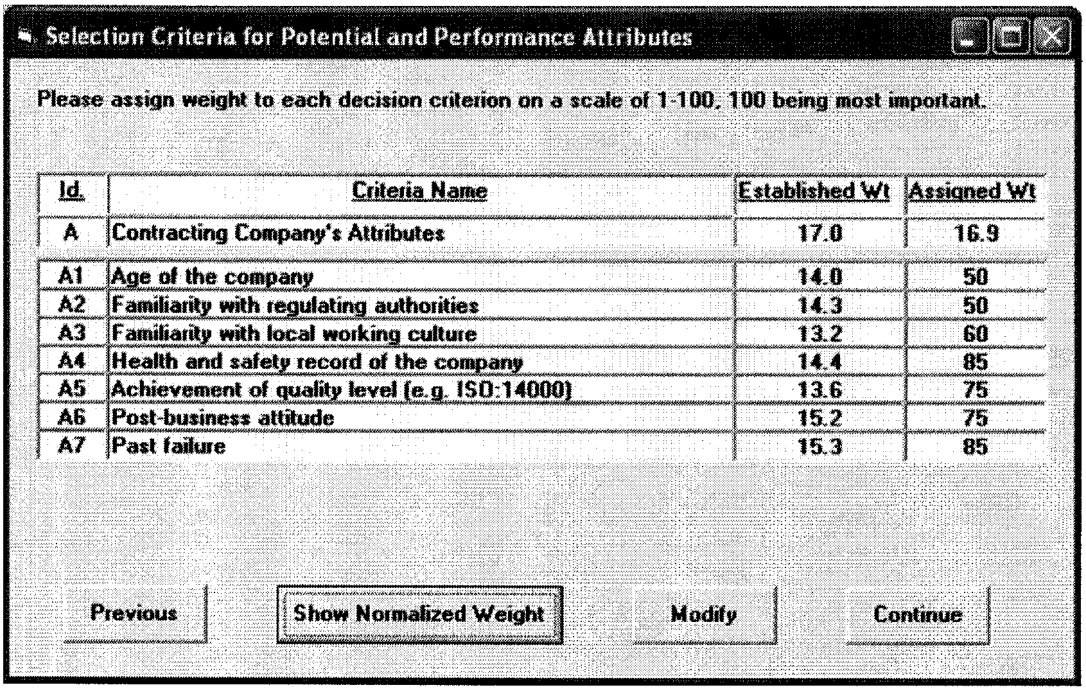


Figure 7.8 Normalized Weights (%) Assigned to Main CSC



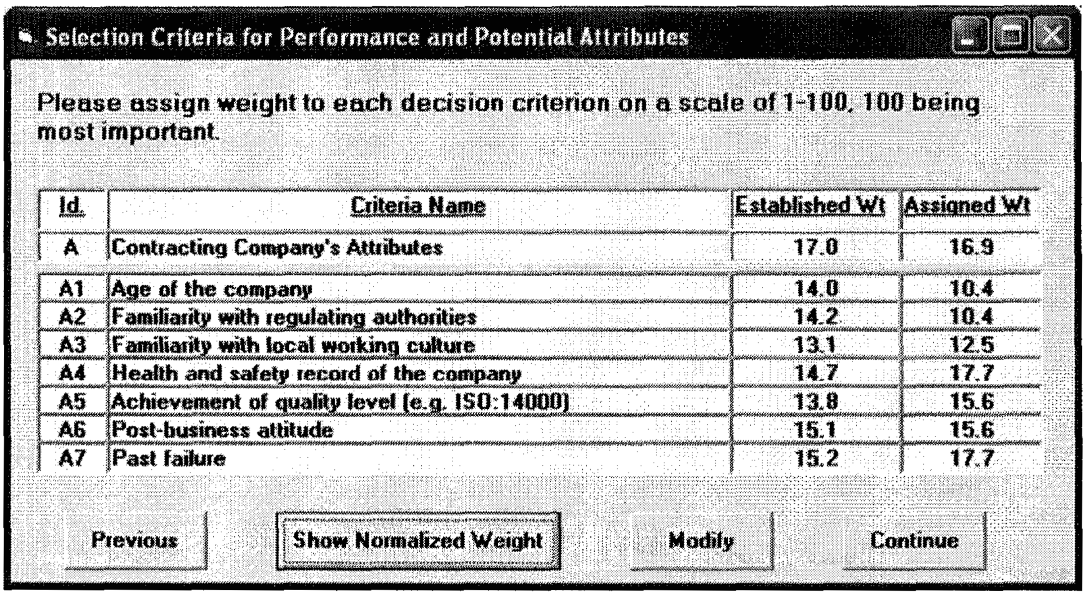
Id.	Criteria Name	Established Wt.
A	Contracting Company's Attributes	16.9
A1	Age of the company	14.0
A2	Familiarity with regulating authorities	14.3
A3	Familiarity with local working culture	13.2
A4	Health and safety record of the company	14.4
A5	Achievement of quality level (e.g. ISO:14000)	13.6
A6	Post business attitude	15.2
A7	Past failure	15.3

Figure 7.9 Weights Established for Sub-Criteria under Group A



Id.	Criteria Name	Established Wt	Assigned Wt
A	Contracting Company's Attributes	17.0	16.9
A1	Age of the company	14.0	50
A2	Familiarity with regulating authorities	14.3	50
A3	Familiarity with local working culture	13.2	60
A4	Health and safety record of the company	14.4	85
A5	Achievement of quality level (e.g. ISO:14000)	13.6	75
A6	Post-business attitude	15.2	75
A7	Past failure	15.3	85

Figure 7.10 Template for Modifying Established Weights

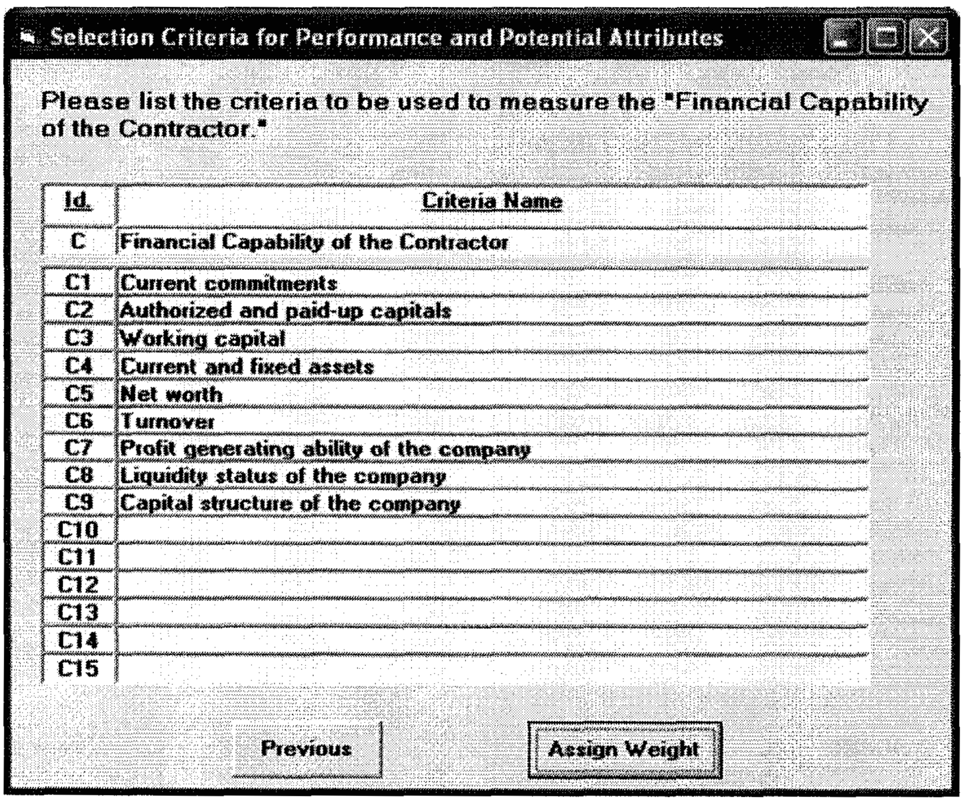

Selection Criteria for Performance and Potential Attributes

Please assign weight to each decision criterion on a scale of 1-100, 100 being most important.

Id.	Criteria Name	Established Wt	Assigned Wt
A	Contracting Company's Attributes	17.0	16.9
A1	Age of the company	14.0	10.4
A2	Familiarity with regulating authorities	14.2	10.4
A3	Familiarity with local working culture	13.1	12.5
A4	Health and safety record of the company	14.7	17.7
A5	Achievement of quality level (e.g. ISO:14000)	13.8	15.6
A6	Post-business attitude	15.1	15.6
A7	Past failure	15.2	17.7

Previous | Show Normalized Weight | Modify | Continue

Figure 7.11 Normalized Weights (%) Assigned to Sub-Criteria under Group A

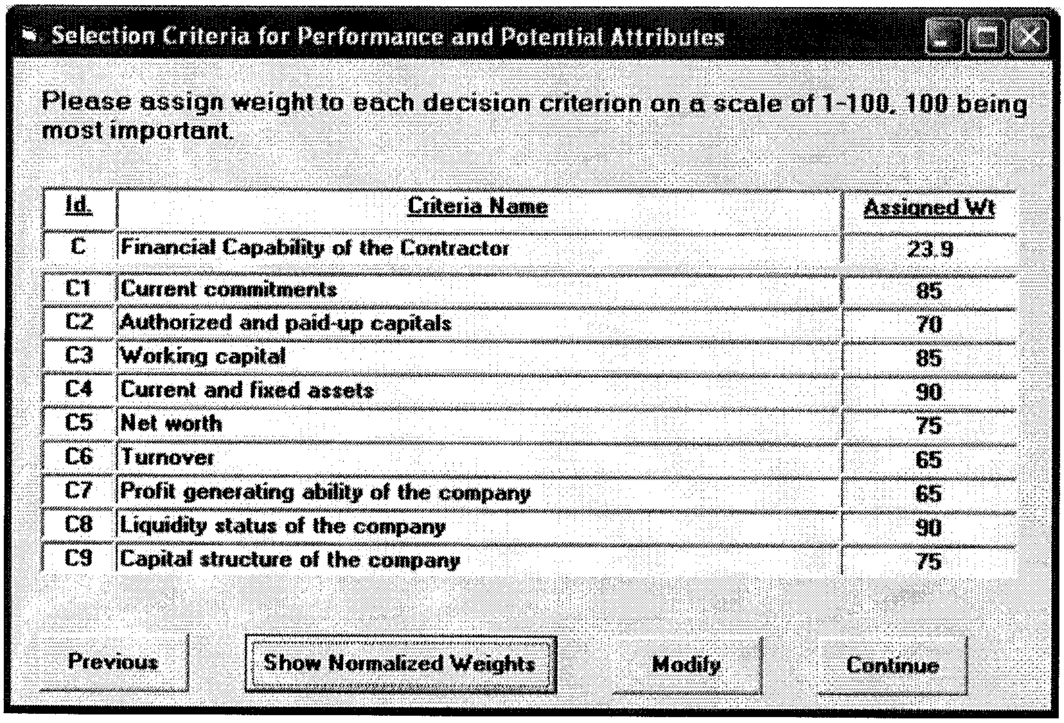

Selection Criteria for Performance and Potential Attributes

Please list the criteria to be used to measure the "Financial Capability of the Contractor."

Id.	Criteria Name
C	Financial Capability of the Contractor
C1	Current commitments
C2	Authorized and paid-up capitals
C3	Working capital
C4	Current and fixed assets
C5	Net worth
C6	Turnover
C7	Profit generating ability of the company
C8	Liquidity status of the company
C9	Capital structure of the company
C10	
C11	
C12	
C13	
C14	
C15	

Previous | Assign Weight

Figure 7.12 Template for Changing Selected Sub-Criteria



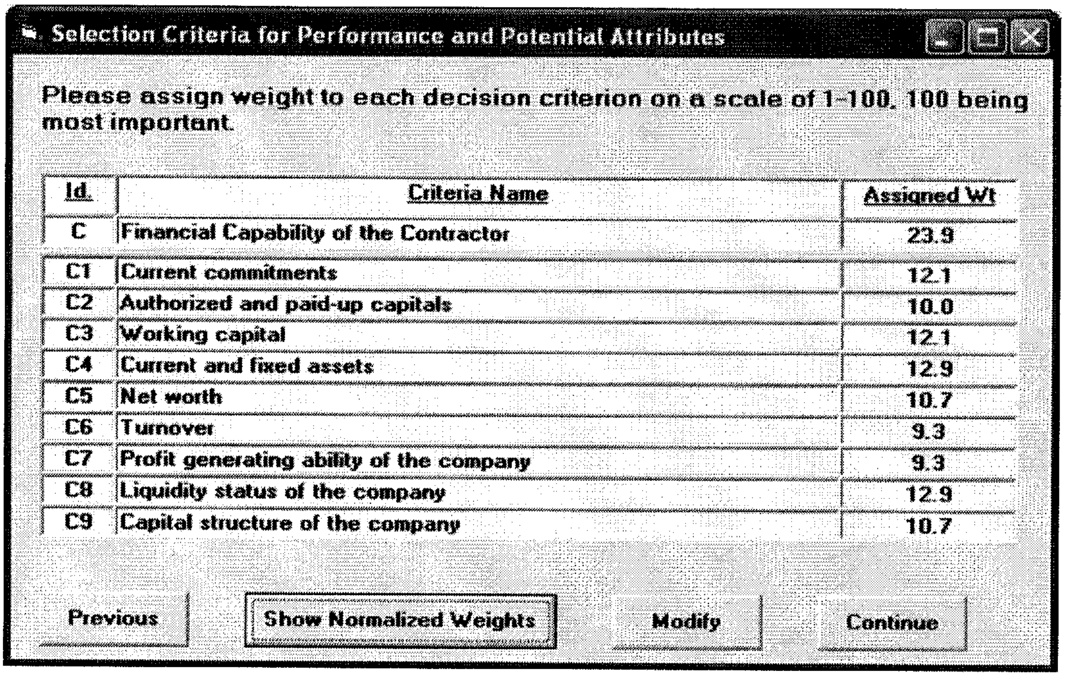
Selection Criteria for Performance and Potential Attributes

Please assign weight to each decision criterion on a scale of 1-100, 100 being most important.

Id.	Criteria Name	Assigned Wt
C	Financial Capability of the Contractor	23.9
C1	Current commitments	85
C2	Authorized and paid-up capitals	70
C3	Working capital	85
C4	Current and fixed assets	90
C5	Net worth	75
C6	Turnover	65
C7	Profit generating ability of the company	65
C8	Liquidity status of the company	90
C9	Capital structure of the company	75

Previous | Show Normalized Weights | Modify | Continue

Figure 7.13 Template for Assigning Weights to Sub-Criteria



Selection Criteria for Performance and Potential Attributes

Please assign weight to each decision criterion on a scale of 1-100, 100 being most important.

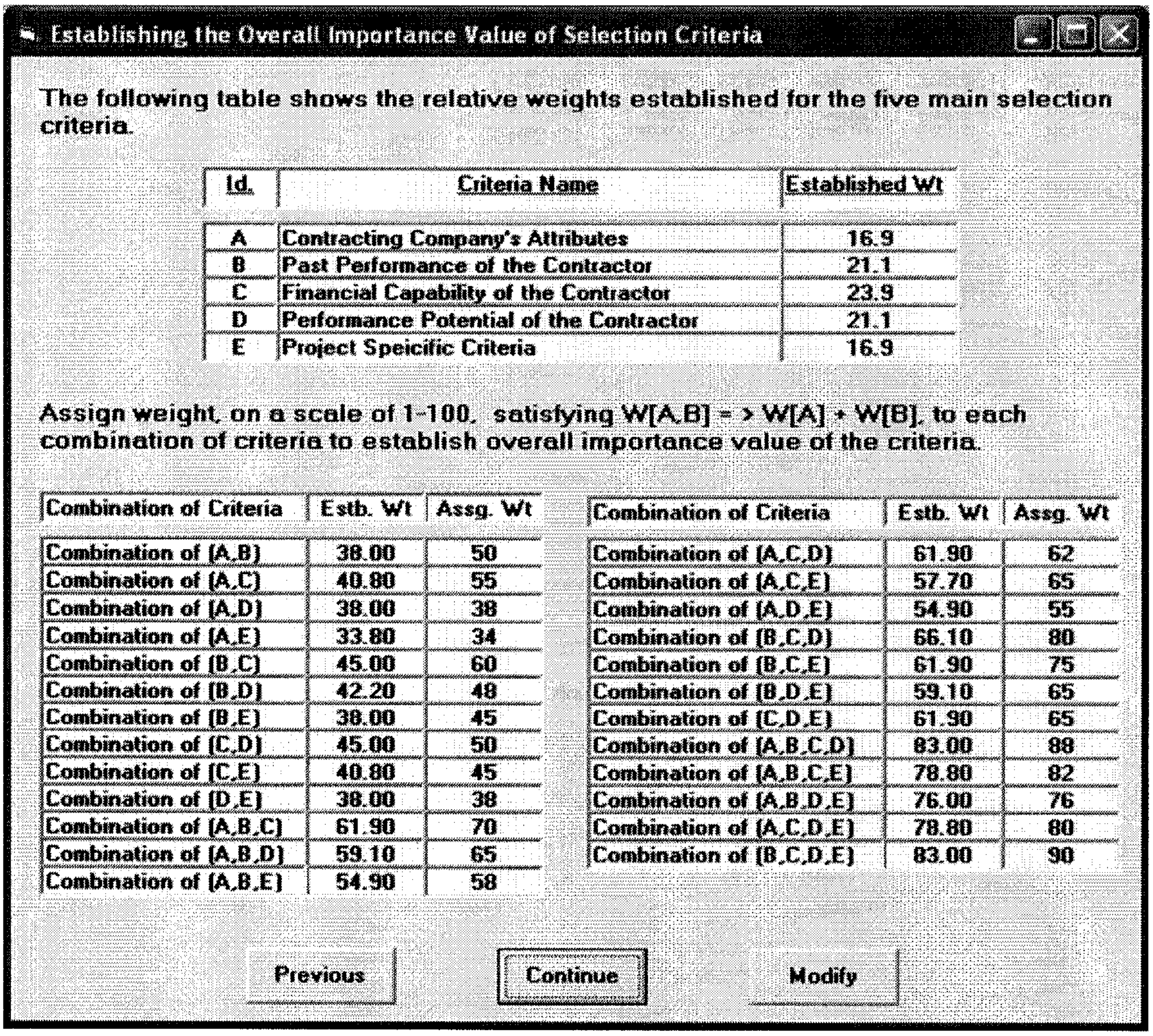
Id.	Criteria Name	Assigned Wt
C	Financial Capability of the Contractor	23.9
C1	Current commitments	12.1
C2	Authorized and paid-up capitals	10.0
C3	Working capital	12.1
C4	Current and fixed assets	12.9
C5	Net worth	10.7
C6	Turnover	9.3
C7	Profit generating ability of the company	9.3
C8	Liquidity status of the company	12.9
C9	Capital structure of the company	10.7

Previous | Show Normalized Weights | Modify | Continue

Figure 7.14 Normalized Weights (%) Assigned to Sub-Criteria under Group C

7.4.3 Establishing Overall Importance Value

Figure 7.15 shows template for expressing appropriate weights to combinations of criteria to establish overall importance value or global importance value as explained in Section 5.8.4. If the users want to modify the assigned weights, they can click "Modify" option button. Figure 7.16 shows the overall importance value of main CSC. From the overall importance value of CSC established it is apparent that this DM is more willing to select a contractor with better financial soundness and past performance record.



Id.	Criteria Name	Established Wt
A	Contracting Company's Attributes	16.9
B	Past Performance of the Contractor	21.1
C	Financial Capability of the Contractor	23.9
D	Performance Potential of the Contractor	21.1
E	Project Speicific Criteria	16.9

Combination of Criteria	Estb. Wt	Assg. Wt
Combination of [A,B]	38.00	50
Combination of [A,C]	40.80	55
Combination of [A,D]	38.00	38
Combination of [A,E]	33.80	34
Combination of [B,C]	45.00	60
Combination of [B,D]	42.20	48
Combination of [B,E]	38.00	45
Combination of [C,D]	45.00	50
Combination of [C,E]	40.80	45
Combination of [D,E]	38.00	38
Combination of [A,B,C]	61.90	70
Combination of [A,B,D]	59.10	65
Combination of [A,B,E]	54.90	58

Combination of Criteria	Estb. Wt	Assg. Wt
Combination of [A,C,D]	61.90	62
Combination of [A,C,E]	57.70	65
Combination of [A,D,E]	54.90	55
Combination of [B,C,D]	66.10	80
Combination of [B,C,E]	61.90	75
Combination of [B,D,E]	59.10	65
Combination of [C,D,E]	61.90	65
Combination of [A,B,C,D]	83.00	88
Combination of [A,B,C,E]	78.80	82
Combination of [A,B,D,E]	76.00	76
Combination of [A,C,D,E]	78.80	80
Combination of [B,C,D,E]	83.00	90

Figure 7.15 Template for Expressing Appropriate Weights for Combinations of Main CSC

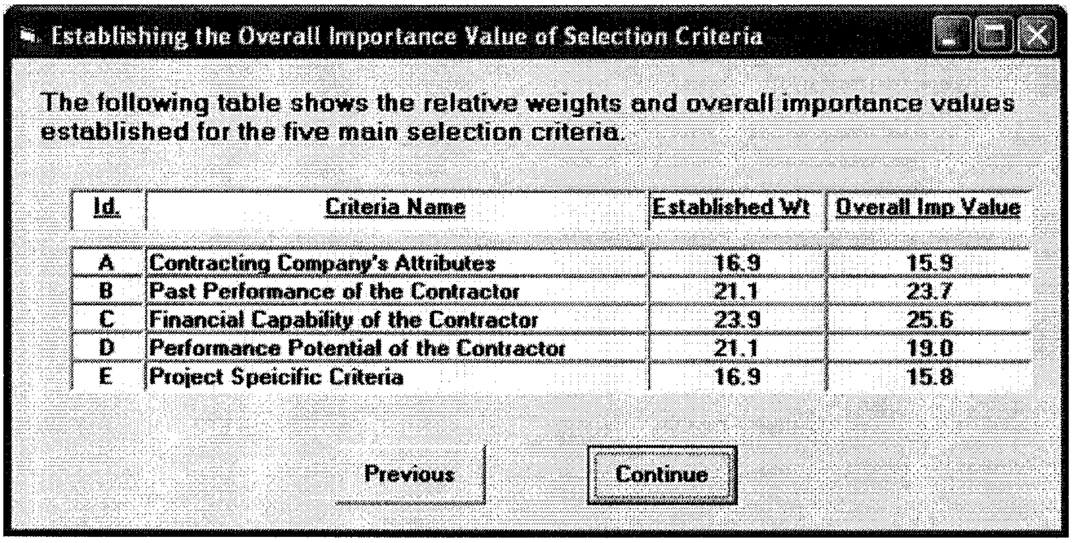


Figure 7.16 Overall Importance Value Established for Main CSC

If the users are not satisfied with the overall importance value, they can choose "Previous" option to go back to the template shown in Figure 7.15 and reassign weights to combinations of criteria.

7.4.4 Evaluating Performance and Potential Attributes

After selection of criteria and establishment of their weights, next step is to evaluate candidate contractors' attributes on each group of CSC. Figure 7.17 highlights the linguistic variables, corresponding fuzzy numbers and their membership functions. Linguistic variable "VG (Very Good)" means the candidate contractor's attribute on a particular criterion is very good. If the users need more explanation on fuzzy numbers and membership functions, they can click "Show More Explanation" button. Some highlights of the concept of fuzzy set theory discussed in Section 5.4 will pop up. Figure 7.18 shows dialog for scoring contractors' performance on CSC group B "Past Performance" and ratings by one of the DMs (participating construction professionals). The user can modify the ratings by clicking the "Modify" button. If the "Continue" button is clicked, ratings will be stored in memory and a new window for scoring contractors' performance on next

CSC group will pop up. When candidate contractors' attributes have been assessed on all CSC, weights assigned to criteria, ratings by the DM and the calculated scores for P&P for each candidate contractor will be recorded in the database.

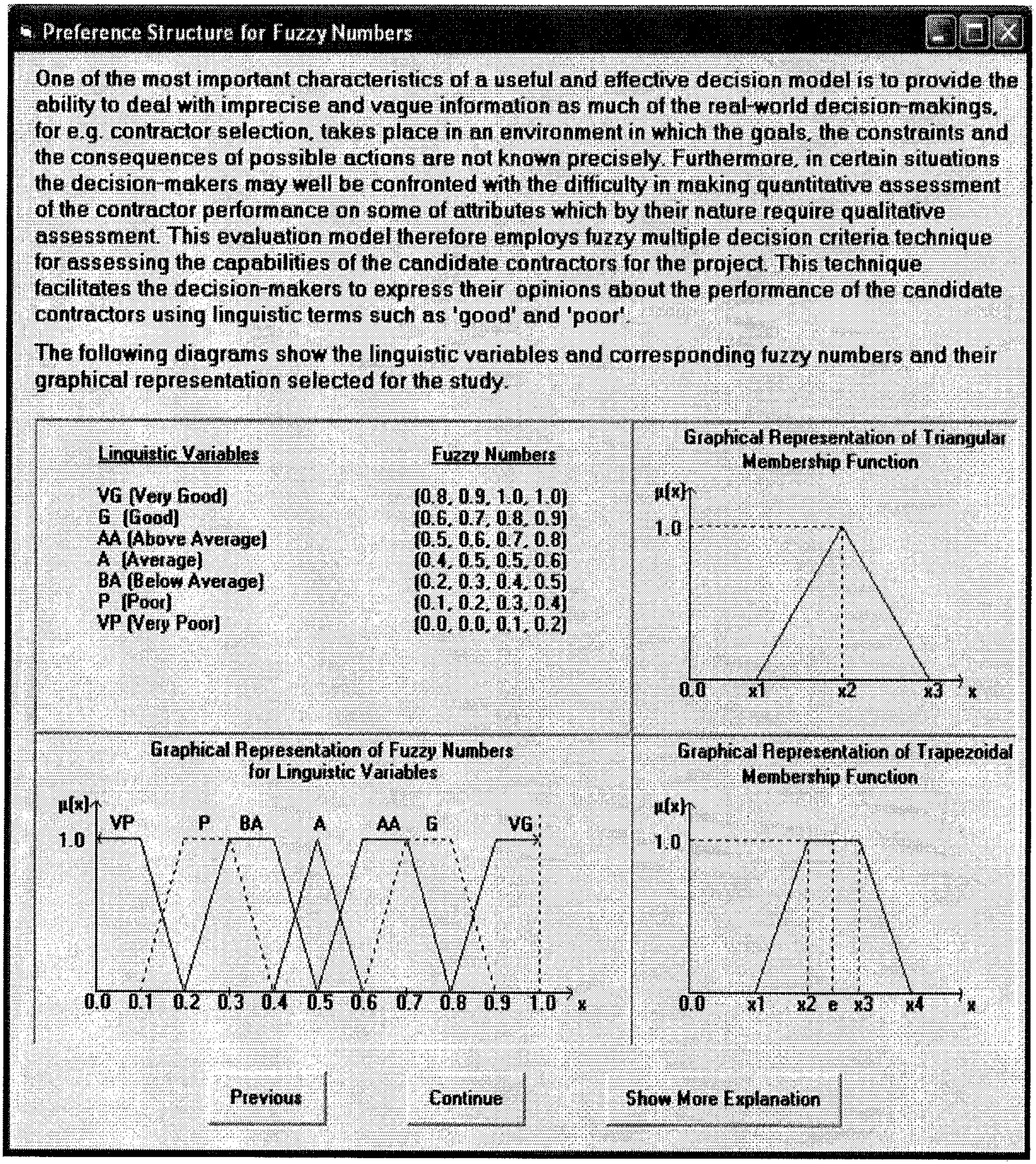
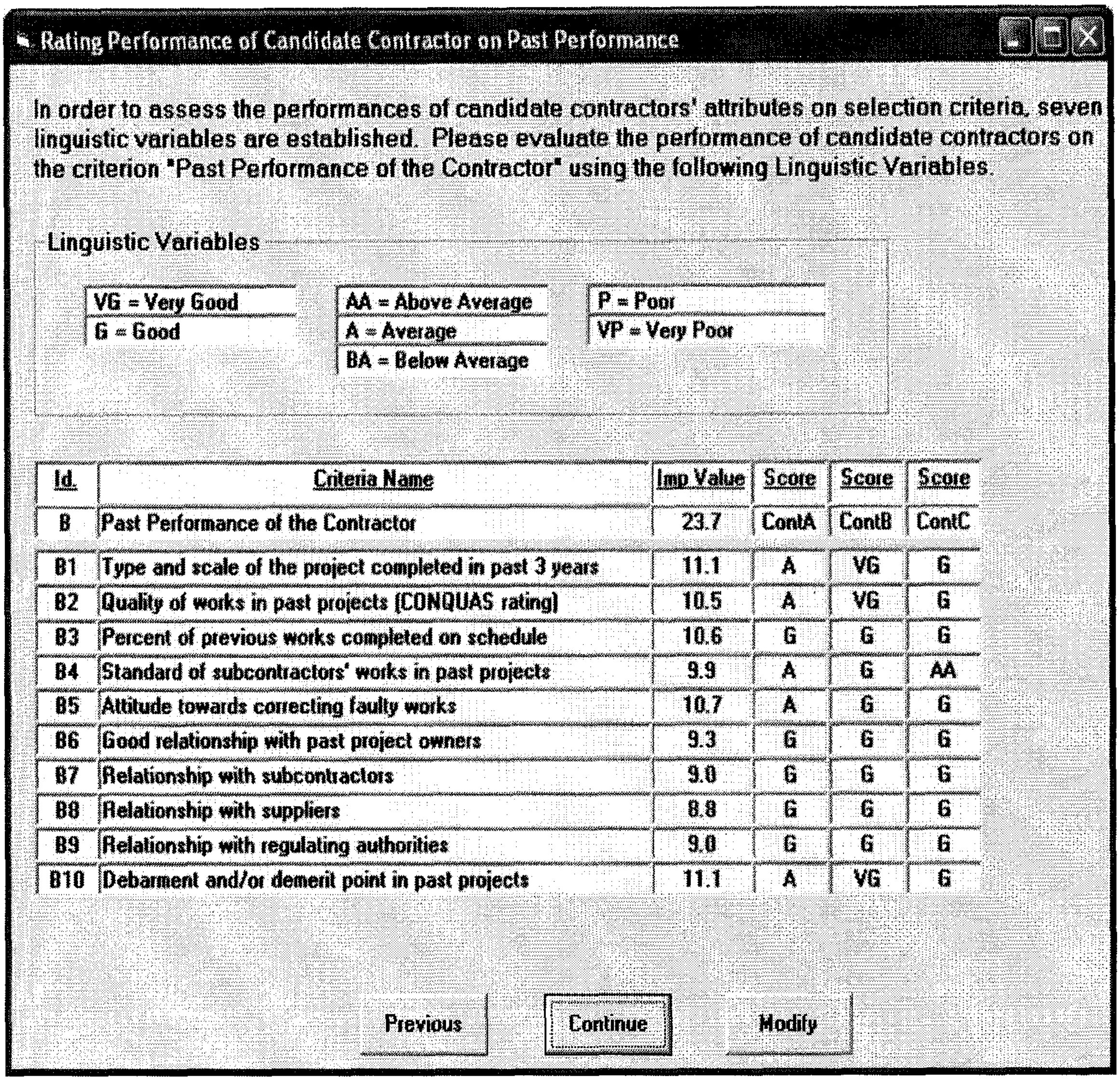


Figure 7.17 Linguistic Variables, Fuzzy Numbers and Their Graphical Representation



Rating Performance of Candidate Contractor on Past Performance

In order to assess the performances of candidate contractors' attributes on selection criteria, seven linguistic variables are established. Please evaluate the performance of candidate contractors on the criterion "Past Performance of the Contractor" using the following Linguistic Variables.

Linguistic Variables

VG = Very Good
G = Good
AA = Above Average
A = Average
BA = Below Average
P = Poor
VP = Very Poor

Id.	Criteria Name	Imp Value	Score	Score	Score
B	Past Performance of the Contractor	23.7	ContA	ContB	ContC
B1	Type and scale of the project completed in past 3 years	11.1	A	VG	G
B2	Quality of works in past projects (CONQUAS rating)	10.5	A	VG	G
B3	Percent of previous works completed on schedule	10.6	G	G	G
B4	Standard of subcontractors' works in past projects	9.9	A	G	AA
B5	Attitude towards correcting faulty works	10.7	A	G	G
B6	Good relationship with past project owners	9.3	G	G	G
B7	Relationship with subcontractors	9.0	G	G	G
B8	Relationship with suppliers	8.8	G	G	G
B9	Relationship with regulating authorities	9.0	G	G	G
B10	Debarment and/or demerit point in past projects	11.1	A	VG	G

Previous Continue Modify

Figure 7.18 Template for Scoring Candidate Contractors' Performance on CSC "Past Performance"

7.4.5 Scoring Tender Proposal

If the selection process involves both P&P qualification and tender evaluation, the DMs need to score the tender price proposals. Dialog used for scoring of tender price proposal is shown in Figure 7.19. Price proposals are evaluated, in this case, using three criteria-attractiveness of tender price, value engineering consideration and life cycle cost consideration. The user can add two more criteria to the list for evaluating the tender price proposal. When the "Continue" button is clicked, ratings by the DM and calculated scores for Price criteria are recorded in database and the ranking of candidate contractors based on overall scores by the DM is presented as shown in Figure 7.20. Once a DM has rated contractors on all CSC, he or she cannot go back to previous windows. This restriction is to prevent the users from manipulating ratings in order to get the results of their choice. By clicking the "Detailed Financial Ratio Analysis" button, the users can perform financial ratio analysis to investigate the financial stability of the candidate contractors.

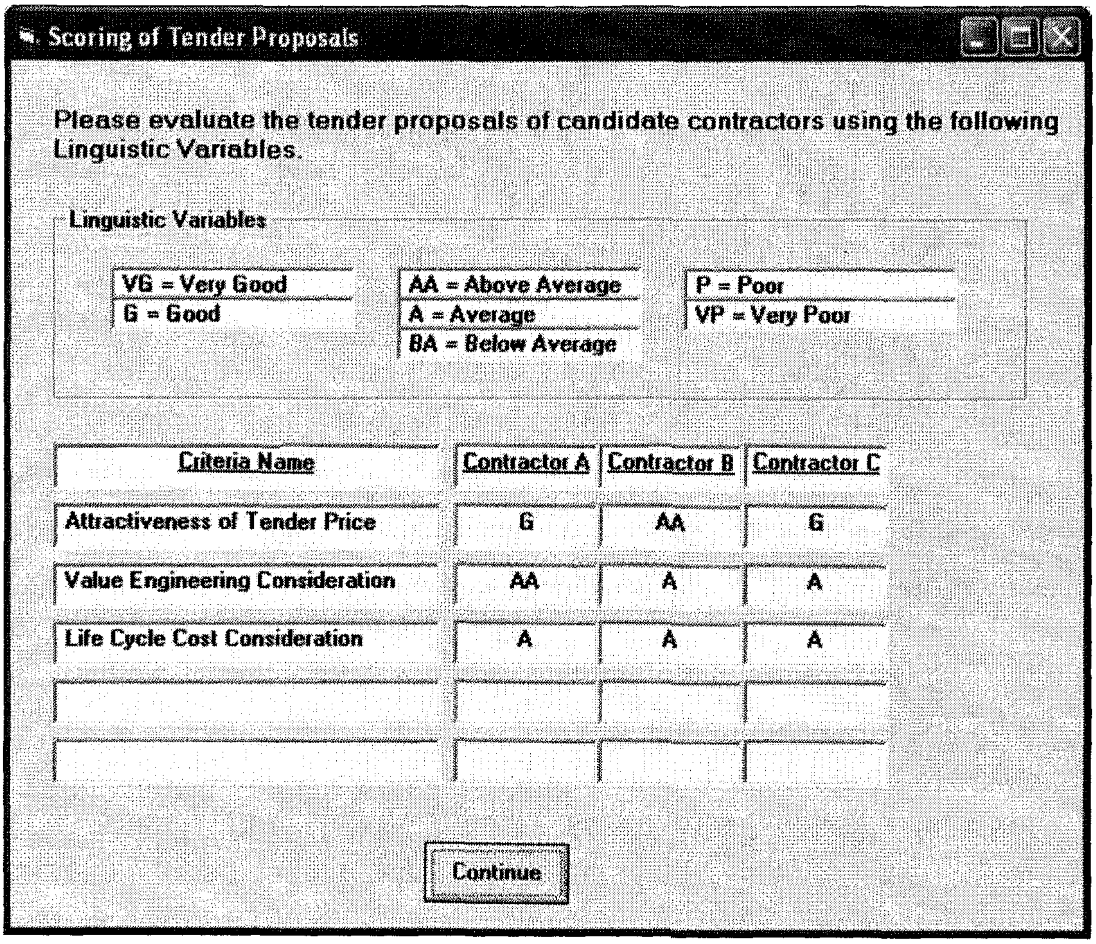
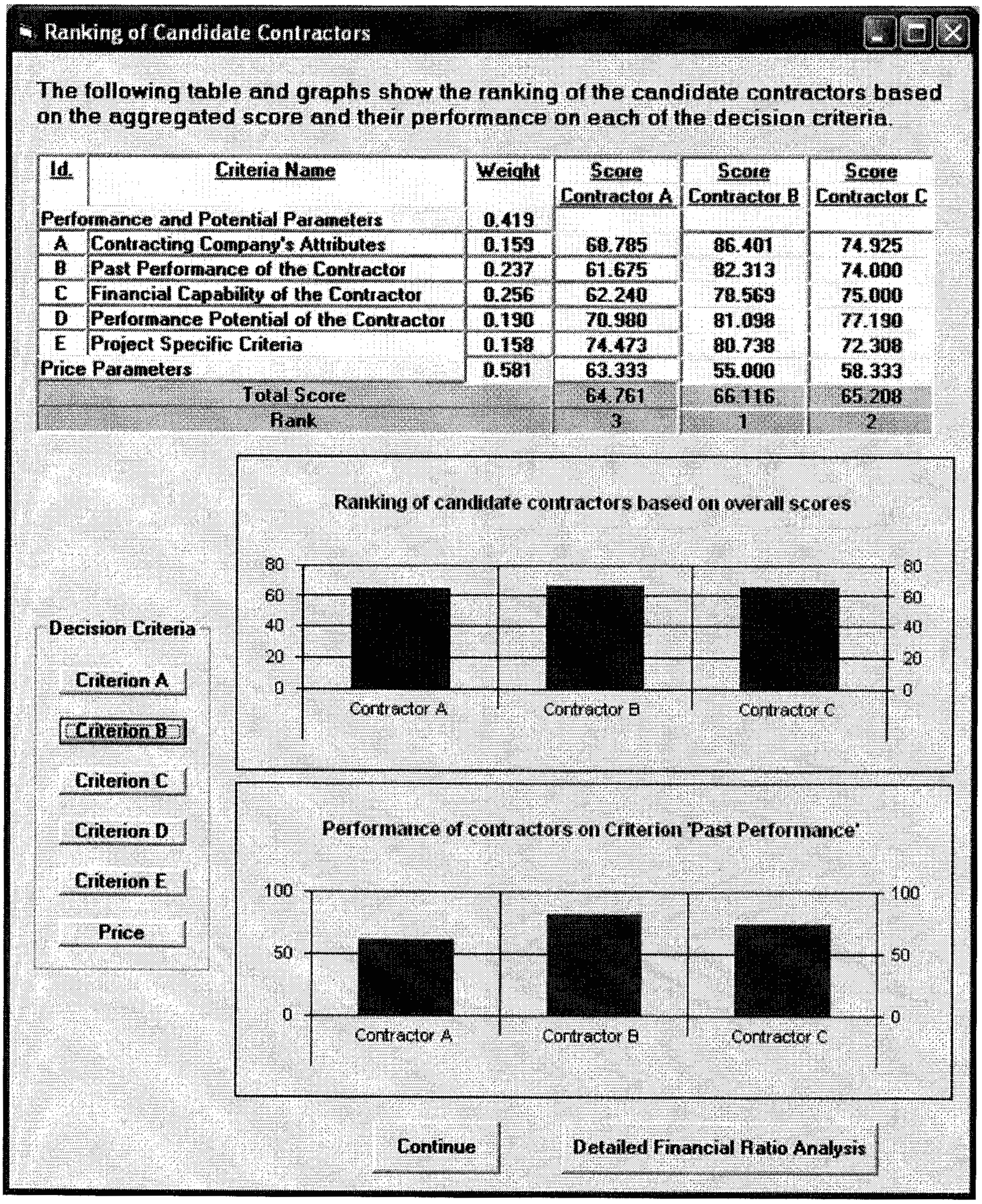


Figure 7.19 Template for Scoring Tender Proposals

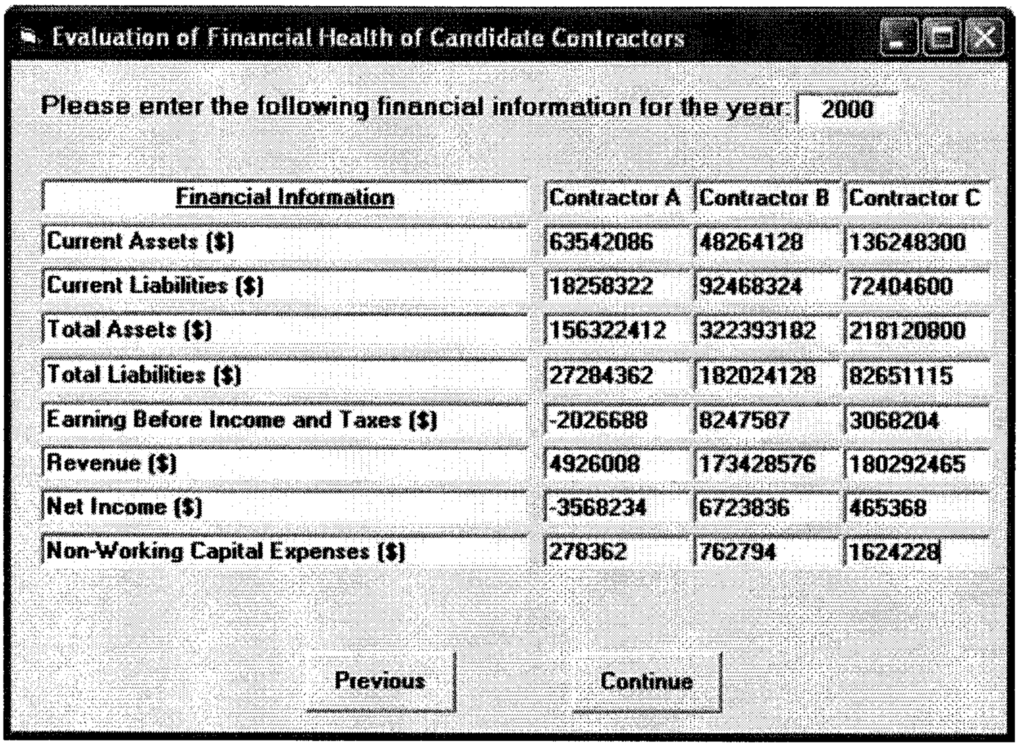


Id.	Criteria Name	Weight	Score Contractor A	Score Contractor B	Score Contractor C
Performance and Potential Parameters		0.419			
A	Contracting Company's Attributes	0.159	68.785	86.401	74.925
B	Past Performance of the Contractor	0.237	61.675	82.313	74.000
C	Financial Capability of the Contractor	0.256	62.240	78.569	75.000
D	Performance Potential of the Contractor	0.190	70.980	81.098	77.190
E	Project Specific Criteria	0.158	74.473	80.738	72.308
Price Parameters		0.581	63.333	55.000	58.333
Total Score			64.761	66.116	65.208
Rank			3	1	2

Figure 7.20 Ranking of Candidate Contractors Based on Overall Scores by DM 1

7.4.6 Investigating Financial Soundness

This step investigates the financial stability of candidate contractors. Figure 7.21 shows the template for entering financial information of candidate contractors for a particular financial year of the analysis period (for this case, year 2000-2002). When the "Continue" button is clicked weights for financial ratios are calculated using entropy method and the window pops up again to enter the information for the next year until the end of the analysis period. The system also allows users to modify the calculated weights of financial ratios by assigning weights representing their preferences as shown in Figure 7.22. Figure 7.23 shows the normalized weights of financial ratios. If the users are not satisfied with the weights, they can modify them by clicking the "Previous" button to go back to the previous window shown in Figure 7.22 to reassign weights.



Evaluation of Financial Health of Candidate Contractors

Please enter the following financial information for the year 2000

Financial Information	Contractor A	Contractor B	Contractor C
Current Assets ($)	63542086	48264128	136248300
Current Liabilities ($)	18258322	92468324	72404600
Total Assets ($)	156322412	322393182	218120800
Total Liabilities ($)	27284362	182024128	82651115
Earning Before Income and Taxes ($)	-2026688	8247587	3068204
Revenue ($)	4926008	173428576	180292465
Net Income ($)	-3568234	6723836	465368
Non-Working Capital Expenses ($)	278362	762794	1624228

Previous | Continue

Figure 7.21 Template for Entering Financial Information

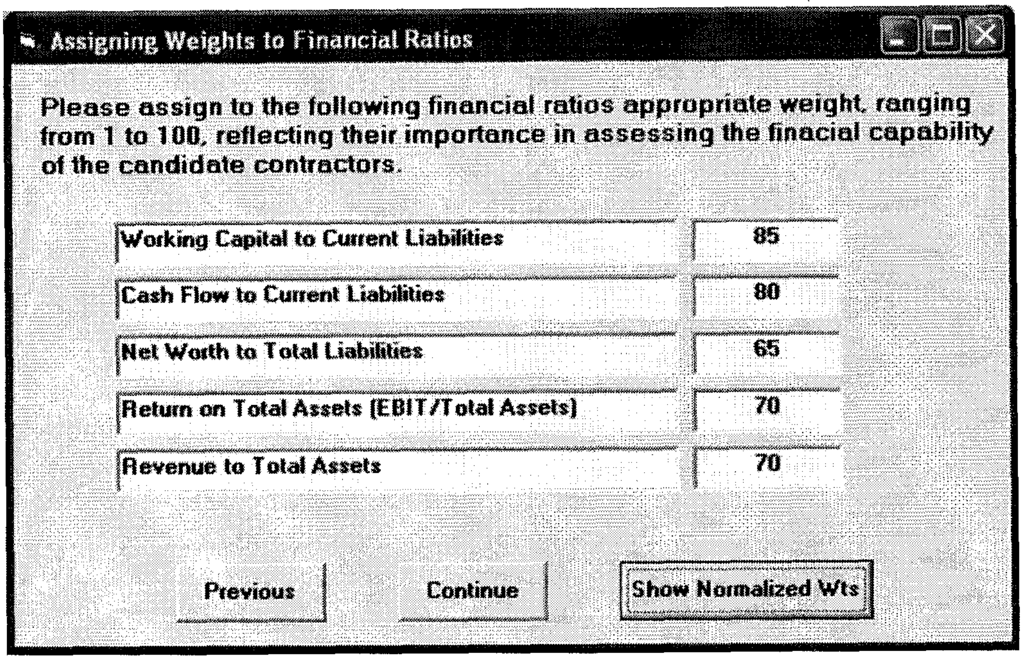


Figure 7.22 Template for Assigning Weights to Financial Ratios

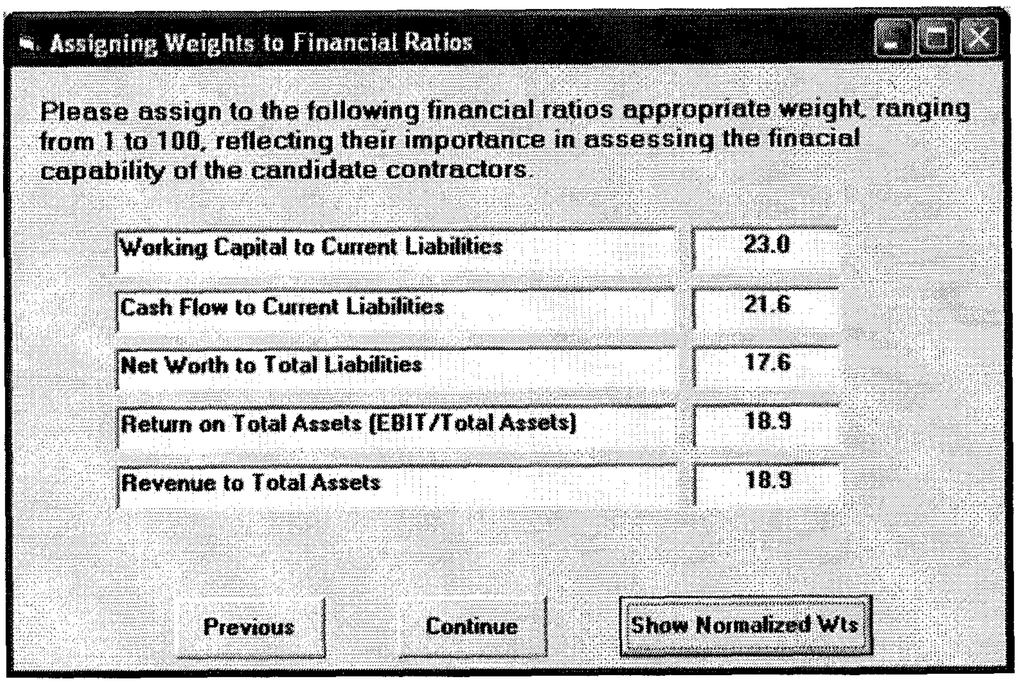


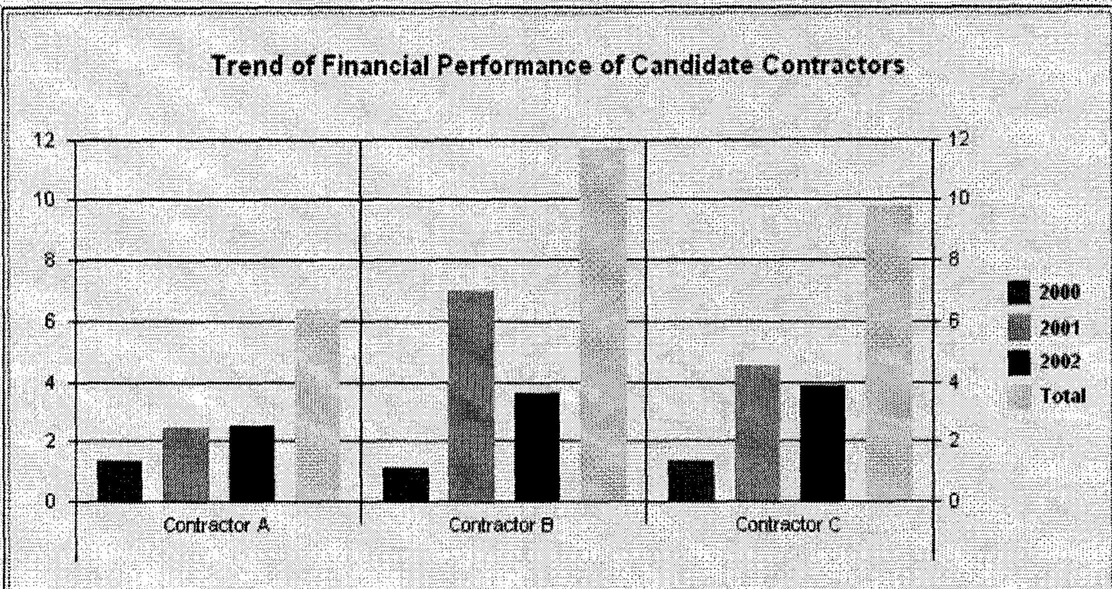
Figure 7.23 Normalized Weights (%) Assigned to Financial Ratios by a DM

Figure 7.24 shows the trend of financial performance of candidate contractors based on the results of the financial ratio analysis. The results show how each contractor is performing relative to his competitors in the industry. This model can also be used to compare financial performance of candidate contractors with respect to the industry's average.

Ranking of Candidate Contractors Based on Their Financial Soundness

The following table shows the ranking of candidate contractors based on their financial performance over analysis period. The graphical representation of the trend of their financial performance is also shown. It indicates how the management is trying to improve the financial stability of the company and how well a company is performing relative to its competitiors in the industry.

Contractor	Score (2000)	Score (2001)	Score (2002)	Score (Total)	Rank
A	1.369	2.461	2.511	6.341	3
B	1.111	6.940	3.612	11.663	1
C	1.351	4.537	3.876	9.764	2



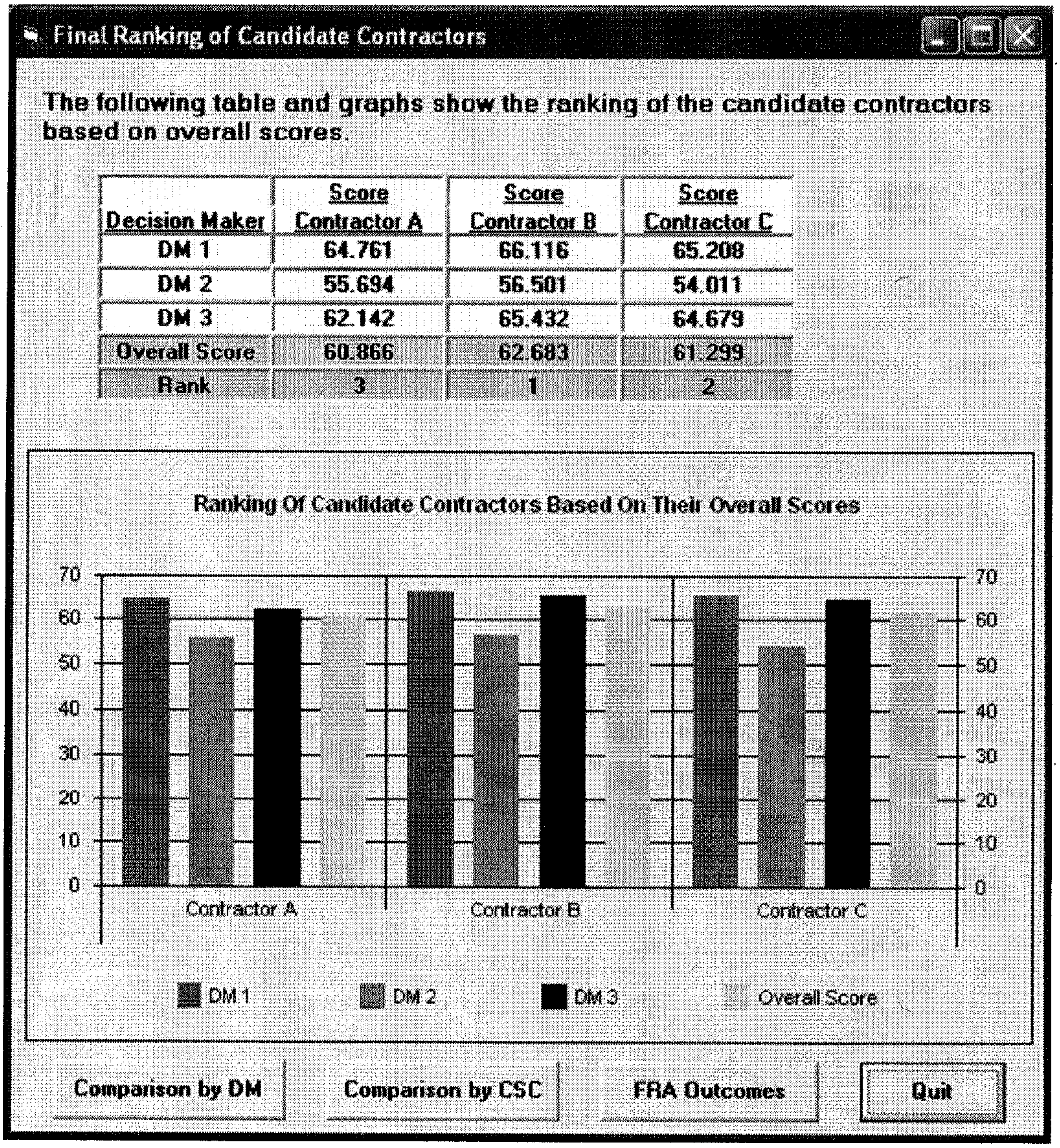
Final Ranking Table

Figure 7.24 Trend of Financial Performance of Candidate Contractors

7.4.7 Reporting Outcomes of Selection Process

After all DMs have participated in the evaluation exercise, the final outcomes of the selection process are presented. The results include

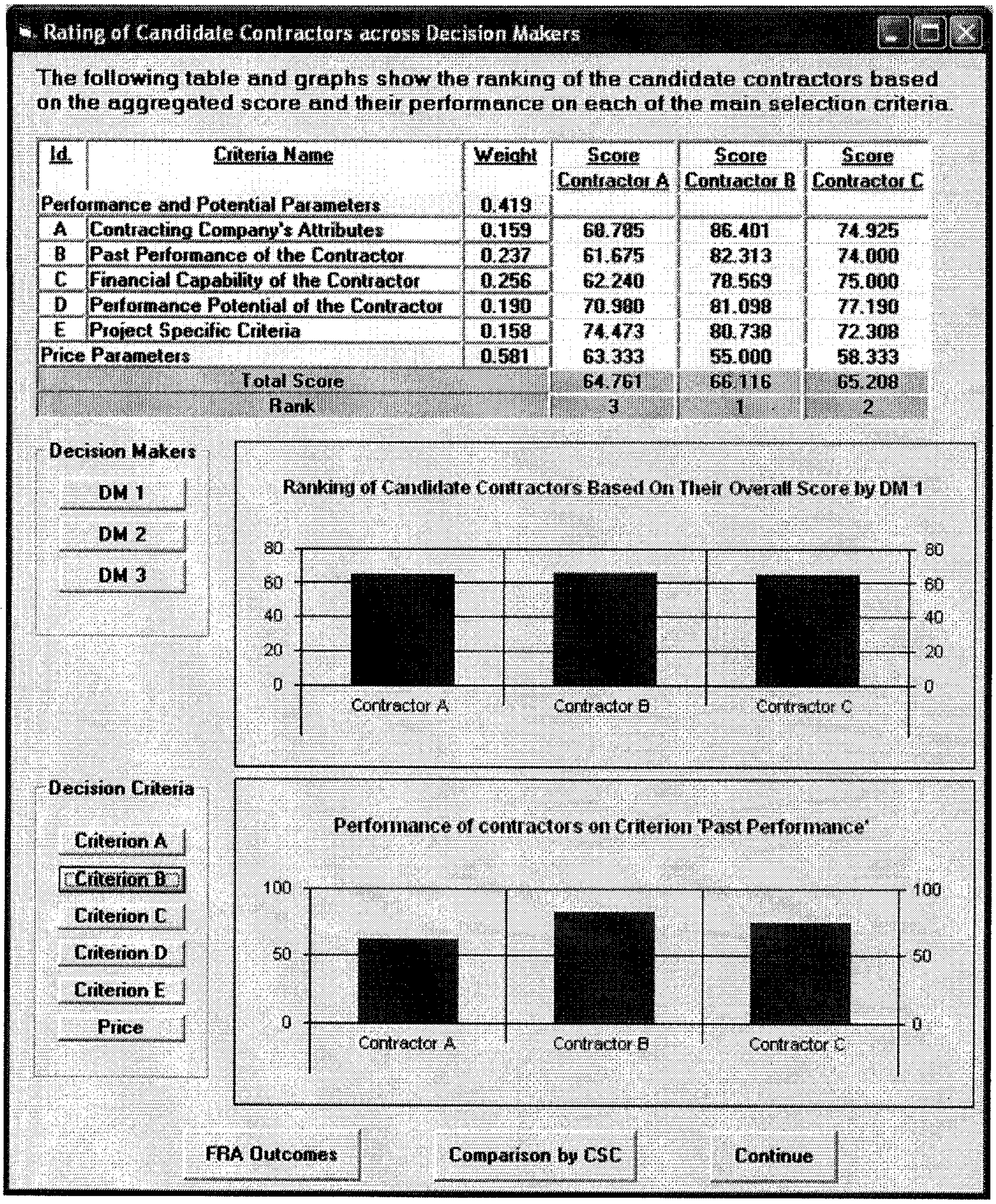
- Ranking of candidate contractors based on overall (aggregated) scores and comparison graph as shown in Figure 7.25.



Decision Maker	Score Contractor A	Score Contractor B	Score Contractor C
DM 1	64.761	66.116	65.208
DM 2	55.694	56.501	54.011
DM 3	62.142	65.432	64.679
Overall Score	60.866	62.683	61.299
Rank	3	1	2

Figure 7.25 Ranking of Candidate Contractors Based on Overall (Aggregated) Score

- Ranking of candidate contractors based on total scores by each DM and comparison graph depicting performance of contactors on each CSC as shown in Figure 7.26.

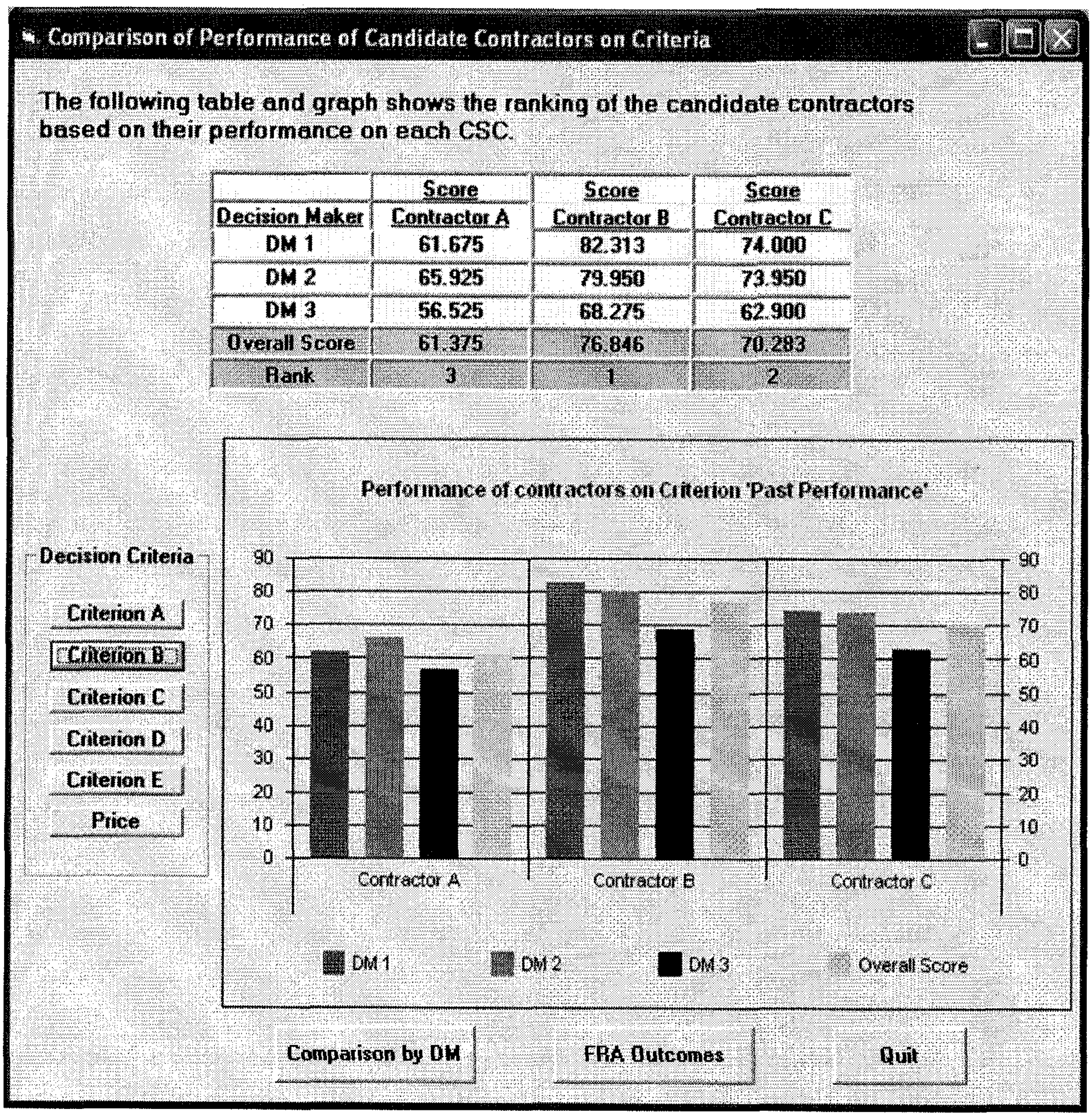


Id.	Criteria Name	Weight	Score Contractor A	Score Contractor B	Score Contractor C
Performance and Potential Parameters		0.419			
A	Contracting Company's Attributes	0.159	68.785	86.401	74.925
B	Past Performance of the Contractor	0.237	61.675	82.313	74.000
C	Financial Capability of the Contractor	0.256	62.240	78.569	75.000
D	Performance Potential of the Contractor	0.190	70.980	81.098	77.190
E	Project Specific Criteria	0.158	74.473	80.738	72.308
Price Parameters		0.581	63.333	55.000	58.333
Total Score			64.761	66.116	65.208
Rank			3	1	2

Figure 7.26 Ranking of Candidate Contractors by Each DM

- Ranking of candidate contractors based overall scores on each CSC and comparison graph as shown in Figure 7.27.

Windows in Figure 7.24-7.27 are interrelated to help DMs make multiple comparisons as to how each contractor is performing on each CSC. From Figure 7.27, the system considers Contractor B as the most appropriate contractor for the project under consideration.



Decision Maker	Score Contractor A	Score Contractor B	Score Contractor C
DM 1	61.675	82.313	74.000
DM 2	65.925	79.950	73.950
DM 3	56.525	68.275	62.900
Overall Score	61.375	76.846	70.283
Rank	3	1	2

Figure 7.27 Ranking of Candidate Contractors Based on Their Performance on Each CSC

7.5 Conclusion

Selection of the most appropriate contractor for any construction project is a crucial challenge faced by every construction client. Many researchers and construction practitioners have developed models or techniques to select the most appropriate contractor for construction project. All of them suffer from shortcomings such as those associated with methodologies selected for the models or lack of simultaneous consideration of multiple DMs and multiple criteria in the evaluation process. Based on the concept of fuzzy set theory and MCDM method, and the findings observed through the questionnaire survey of the industry, a computer-interactive decision system for contractor selection is developed. This chapter discusses main processes involved in the structure of the computer-based selection system and also demonstrates the mechanics of the system with the help of some screen shots from an actual contractor selection case used for validation of the system. The system can perform P&P qualification only or P&P qualification plus tender evaluation.

Based on the findings from the review of literature regarding contractor selection and the interviews with the construction practitioners, CSC are categorized into five main groups for inclusion in the system. Their relative weights are established on the basis of mean DIA of criteria observed through the questionnaire survey. However, the system allows the DMs to modify the weights of CSC as per requirements. Each CSC group consists of a number of sub-criteria or factors to gauge candidate contractors' attributes on CSC. The system also has a facility that allows the DMs to add or remove criteria from the suggested list and modify their weights.

In order to avoid the overestimation of the importance value of a particular CSC, the concept of Shapley value is employed to establish global or overall importance value of CSC, i.e. the marginal contribution of each CSC to overall goal, which is determined not solely by the importance value of that CSC but also by the value of all other CSC considered in the evaluation process. This process reflects the relationship among the CSC and DMs' preferences and concerns in decision-making process.

The system allows the DMs to express their opinions about the candidate contractors' attributes on CSC in more realistic manner as the use of fuzzy set theory facilitates assessment to be made in linguistic terms which better corresponds to real-world situations. Seven linguistic variables and their corresponding fuzzy numbers and the scale of preference structure are established and used in the system for describing level of performance of contractors' attributes on criteria. If the selection exercise is only for P&P qualification, the system presents the results of the evaluation process and ranking of candidate contractors based on overall P&P scores, with the option to go for the investigation of the financial soundness of candidate contractors.

Tender proposals are evaluated on the basis of attractiveness of tender price, value engineering consideration and life cycle cost consideration in the proposals. The DMs can add more criteria to the list for evaluating tender proposals. For selection exercise considering both P&P qualification and tender evaluation, ranking of candidate contractors is done on the basis of overall combined scores of P&P score and Price score. Since CSC do not compensate each other, i.e. a bad score on one criterion cannot be adjusted by a good score on any other complementary criteria, the final selection of the contractor should not be solely based on overall score. Performance of candidate contractors on each CSC should also be taken into consideration while making the final selection of the contractor. Therefore, results are presented in such a way that helps DMs to make multiple comparisons in order to better observe the performance of candidate contractors on each of CSC, and the scores by individual DMs.

The evaluation model for financial stability of candidate contractors, which is developed as a sub-model of the contractor selection system, employs entropy method to determine objective weights of financial ratios selected for the study. However, the model allows DMs to be able to reflect their preferences in relative weights of financial ratios by multiplying the calculated weights by the assigned weights reflecting the DMs' preferences. The results are presented both in tabular form and graph showing the trend of financial performance of contractors over analysis period. Though the model provides a quick and effective assessment of financial performance of candidate contractors it is, however, recommended that the evaluation outcomes be used only as a guideline for observing changes in the financial health of contractors on tender list or their performance with respect to the industry's average.

Final outcomes of the evaluation process are presented both in tabular format and graphs. Once a DM has finished the evaluation of all candidate contractors, the system does not allow going back to previous windows in order to prevent the users from manipulating ratings and relative weights in order to get the results of their choice. When all DMs have participated in the evaluation process the team leader may call for a meeting for post-mortem analysis of the outcomes of the selection process. If different DMs have used different set of criteria in evaluation process, it can be discussed during the meeting why a particular DM wants to use a particular criterion and a group consensus can be reached on a common set of evaluation criteria for the project. Then the evaluation process can again start with the common set of criteria. DMs can also establish cut-off points for overall score or for any of CSC and any candidate contractor who obtained overall score or score on any CSC less than the cut-off value can be eliminated from bidding. If there were a large number of contractors on prequalification list, this elimination method can be quite useful so as to limit the number of unsuccessful bidders.

However, the system needs to be tested for its efficiency and effectiveness in dealing with real-world problems. Therefore, the focus of the next chapter would be testing the system for its applicability to real contractor selection process with eight actual contractor selection cases.

Chapter 8
Testing of the Contractor Selection System

8.1 Chapter Overview

The previous chapters discuss acquisition of knowledge through literature review, collection of data through questionnaire survey, selection of an appropriate methodology and development of the theoretical concept for the selection system, and development and mechanics of the computer-interactive contractor selection system. This chapter concentrates on testing of the developed system to verify and validate its overall applicability to the actual contractor selection cases. The system is tested for its user-friendliness, functionality, usefulness and sensitivity to variation in input parameters. The results from the tests confirm that the developed system predicts a reasonable representation of the actual cases results and is capable of performing contractor selection involving multiple CSC and multiple DMs as it is intended to do.

8.2 Introduction

With the aim of optimizing all the risks associated with the nature of construction such as uniqueness of construction projects and high volatile construction environment, selection of an appropriate contractor to deliver the project as per requirements is the most crucial challenge faced by any construction client. Therefore, the principal objective of this research work is set out as to develop a computer-based fuzzy multiple criteria decision system for contractor selection, well-structured in approach and robust in analysis, to assist the construction clients in making complex decision, in a more realistic manner, regarding the selection of a contractor capable of delivering the project as per their requirements. In line with this objective a computer-interactive contractor selection system, based on fuzzy MCDM method, capable of handling uncertainty and associated risks is developed.

The confirmation of accomplishing this research objective is carried out by testing the selection system for (1) user-friendliness, (2) functionality, (3) usefulness, and (4) sensitivity, that is, how sensitive the system outcomes is to changes in relative weights of CSC. The tests show that the proposed contractor selection system is capable of handling multiple DMs and multiple selection criteria simultaneously and the use of fuzzy theory allows the DMs to make linguistic assessment of contractors making the system well-structured in approach and more realistic in manner than other contractor selection models. Results from the tests confirm that the computer-interactive contractor selection system can perform those tasks well.

8.3 Selection System Testing

The effectiveness of a computer application in a business environment is determined by how usable, helpful, and meaningful the application is in performing the function of the user. Testing is the process of establishing confidence that a program does as it is supposed to do. Hence, this process aims at testing the contractor selection system for user-friendliness, functionality, usefulness and sensitivity.

8.3.1 User-friendliness

Testing of user-friendliness includes testing how well the computer interaction satisfies the requirements of the construction practitioners or the users during the contractor selection process, that is, to check whether the computer application provides all the interfacing facilities required by the users in evaluating the appropriateness of candidate contractors for the job.

The computer application for the contractor selection system comprises two features- user interaction and data analysis. The programming language, Microsoft Visual Basic, is used to develop user-friendly interfaces between the users and the selection system and thus enhancing an easy access to data analysis. A good quality of interfacing dialogs or windows is very important since some users may not be very much familiar with using the Microsoft Excel which is used to execute all data analysis part of the selection system and Visual Basic forms, dialogs or windows can visually be helpful for users to express their opinions and preferences and to record their inputs to the system, hiding all the tedious calculations and operations from the users' eyes.

In order to test the user-friendliness of the system and to improve its suitability to users some construction practitioners were contacted to seek their assistance for this purpose. Two construction professionals each having a vast experience with contractor selection processes finally agreed to participate in testing of the system. A computer software developer was also shown the system to seek his professional judgment and views on the computer programming, appropriateness of the interfaces developed for inputs recording and results presentation. Based on their comments, suggestions and recommendation the selection system was modified until it satisfied the construction practitioners' requirements. During the testing process, it was observed that presentation of the final outcomes of the system in both tabular format and graphs is quite helpful in making comparison of how each candidate contractor is performing on each CSC.

8.3.2 Functionality

The purpose of testing the functionality of the system is to verify that the developed system can perform its function as accurately as it is intended to do, that is, the system developed is structurally sound and functions correctly as per the requirements and specifications. In other words, it is to test the efficiency of the system designed. Therefore, testing of functionality includes detecting bugs and errors and investigating the workability of the system by checking the consistency of logic used in the data analysis part of the computer application and efficiency of interaction between different components of the selection system- mainly the user interface component and the data analysis component.

Program testing is an important aspect of verification of the accuracy of the program in terms of logic consistency and workability. Many techniques are available for testing efficiency of a computer-based system (Perry, 2000 and Myers, 2004). However, selecting an appropriate method for testing is the subjective judgment of the tester based on importance and needs, and beneficial results required. For verification of the developed selection system, two testing techniques seem promising. They are:

- **Parallel testing technique**

  Parallel testing is used to determine that the results of the new model or system are consistent with those obtained from the previous version of or existing models or systems. This testing requires that the same input data be run through the two models performing similar applications. However, the existing contractor selection models are with disparate logic and structures and require different data formats making the verification of the system difficult. Hence, this technique is less attractive and not considered for this study.

- **Manual testing technique**

  In this method, a hypothetical or real case is used to compare the system results with those manually solved. As the computer application for the system is designed in modules, the proper interaction between these modules or the integrity of the system as a whole should be investigated for accuracy. Therefore, a step by step checking of bugs and interaction between different components of the system is necessary and manual testing technique is quite useful for this purpose.

A real case of contractor selection the results of which are presented in Chapter 7 is manually solved and the scores and ranking order are used for comparison purpose. During the testing, the computer program for the system is broken down into a number of modules in order to trace the logic and computation processes of each modules and data (value) exchange between those modules in order to confirm that multiple components of the system interact according to the system design. All the errors found in the design and analysis or in the coding of the program are properly corrected. Table 8.1 shows the comparison of the system results and those manually solved. The slight differences in overall scores can be attributed to a truncation effect during the calculation process. The fact that the system results are in match with the manually-calculated results verifies that the performance of the selection system is accurate and hence, its functionality is considered acceptable.

Table 8.1 Comparison of the Selection System Results and Manually-Calculated Results

Contractor	The System Results		Manually-Calculated Results	
	Overall Score	**Rank**	**Overall Score**	**Rank**
A	60.684	3	60.872	3
B	62.683	1	62.703	1
C	61.299	2	61.134	2

8.3.3 Usefulness and Validation of the System

The purpose of testing the usefulness of the system is to check how close the system results are to the actual case results and how flexible the system is in dealing with the uniqueness of construction projects. Hence, this process includes validation of the system using actual contractor selection cases for projects of different types. In order to investigate and validate the usefulness of the developed computer-interactive contractor selection system, eight actual contractor selection cases, all from the Singapore construction industry, are selected for the validation of the system. Tables 8.2 to 8.9 summarize the comparison of the actual results and the system results. Two professionals for case 1-5 and three professionals for case 6-8 participated in the selection exercise. All of them have more than 10 years of experience in contract management and extensively involved in contractor selection process. The cases selected for the study cover a wide range of construction projects- four building construction projects and the remaining four civil engineering projects. Due to confidentiality of information requested by the participants and the organizations which provided the data for the system validation purpose only, all project information is removed and referred to as Project tender case #.

Table 8.2 Comparison of Results: Project Tender Case 1

Contractor	Actual Ranking Order	The System Ranking Order
A	3	3
B	1	1
C	2	2

Table 8.3 Comparison of Results: Project Tender Case 2

Contractor	Actual Ranking Order	The System Ranking Order
A	3	3
B	1	1
C	2	2

Table 8.4 Comparison of Results: Project Tender Case 3

Contractor	Actual Ranking Order	The System Ranking Order
A	1	1
B	2	2
C	3	3

Table 8.5 Comparison of Results: Project Tender Case 4

Contractor	Actual Ranking Order	The System Ranking Order
A	1	1
B	2	2
C	3	3

Table 8.6 Comparison of Results: Project Tender Case 5

Contractor	Actual Ranking Order	The System Ranking Order
A	1	1
B	2	2

Table 8.7 Comparison of Results: Project Tender Case 6

Contractor	Actual Ranking Order	The System Ranking Order
A	1	1
B	2	2

Table 8.8 Comparison of Results: Project Tender Case 7

Contractor	Actual Ranking Order	The System Ranking Order
A	1	2
B	2	1
C	3	3
D	4	4

Table 8.9 Comparison of Results: Project Tender Case 8

Contractor	Actual Ranking Order	The System Ranking Order
A	3	3
B	2	1
C	1	2
D	4	4

From the results in the Tables, it can be observed that for cases 7 and 8 the system suggested a different contractor (the contractor ranked 2 in actual case) as the most appropriate contractor for the job. The participants are, however, of the view that even though multiple decision criteria are considered in the evaluation process, in certain situations where the difference in overall scores is marginal only, other factors such as government policy usually gets the upper hand in the final selection of the contractor for the job. This could be a possible reason why there is a slight difference between the system's final ranking order and the actual ranking.

Financial information of candidate contractors is available for only five out of eight cases selected for the study. The detailed analysis of financial soundness of candidate contractors is carried out using the financial ratio model developed in Chapter 6. Tables 8.10-8.14 summarize the comparison of the ranking orders based on the financial performance of candidate contractors. Results from the Tables confirm that the system predictions are very close to the results of the actual cases only except for case 2 and 4 (Table 8.11 and 8.13). One possible reason for slight lack of accuracy could be due to the DMs' perceptions regarding the importance and preferences of financial ratios used in the analysis.

Table 8.10 Comparison of Ranking of Candidate Contractors Based on Their Financial Performance: Case 1

Contractor	**Ranking by DMs**	**Ranking by the System**
A	3	3
B	1	1
C	2	2

Table 8.11 Comparison of Ranking of Candidate Contractors Based on Their Financial Performance: Case 2

Contractor	Ranking by DMs	Ranking by the System
A	1	2
B	2	1
C	3	3

Table 8.12 Comparison of Ranking of Candidate Contractors Based on Their Financial Performance: Case 3

Contractor	Ranking by DMs	Ranking by the System
A	1	1
B	2	2
C	3	3

Table 8.13 Comparison of Ranking of Candidate Contractors Based on Their Financial Performance: Case 4

Contractor	Ranking by DMs	Ranking by the System
A	1	1
B	2	3
C	3	2
D	4	4

Table 8.14 Comparison of Ranking of Candidate Contractors Based on Their Financial Performance: Case 5

Contractor	Ranking by DMs	Ranking by the System
A	3	3
B	2	2
C	1	1
D	4	4

8.3.4 Sensitivity Analysis

Computer-aided decision systems or models are widely used in many complex decision-making processes. As no decision system or model can emulate human cognition in complex decision-making involving the search for an optimal solution, the system results should be considered as only an approximation to reality. When a decision system is developed, certain assumptions and restraints that are associated with the methodology used for the system are also inherent in the developed system. Moreover, these systems typically require some parameters as input from the users. Therefore, it is always desirable to investigate the effect of variation in the input parameters on the final outcomes of a system by performing sensitivity analysis.

The purpose of sensitivity analysis is to estimate the variation in the final outcomes of a system with respect to changes in the system input parameters. Such knowledge is important for assessing the applicability of the system by understanding the behavior of the system to small variation in the input parameters. The simplest and most common procedure for assessing the effects of parameter variations on a system is to vary selected input parameters and record the corresponding changes in the final outcomes of the system. The parameters responsible for the largest relative changes in the final outcomes are then considered to be the most important to have the accurate input value.

The developed contractor selection system requires the weights of CSC and ratings of contractors' attributes on CSC as input parameters from the users. Different users with different experience levels will have different perceptions regarding the importance (weight) and preferences of CSC used for evaluation. Therefore, the applicability and flexibility, that is, the facility of the system permitting the users to change CSC and/or their weights as required, of the developed system need to be ascertained by observing the effect of the variation of the input parameters-weights and ratings on the final outcome of the system. As the uncertainty associated with the subjective judgment of ratings has been reasonably reflected through the use of membership function as the representation of fuzzy values the sensitivity analysis is performed to check only the effect of the variation of CSC weights resulting from uncertainty and inconsistency arising from individuals' perceptions and preferences.

As for most contractor selection processes containing both prequalification and tender evaluation, the weightage assigned to performance and potential qualification score and tender evaluation score are made known in tender documents, there is no uncertainty of sensitivity of judgment regarding the weights for them. Hence, only five main CSC, the weights of which the users can modify as per requirements, are considered in the sensitivity analysis. In order to assess the sensitivity range of the system, CSC weights are varied up to ± 25% for all of contractor selection cases considered in the previous section. Table 8.15 shows maximum and minimum percentage changes in overall (aggregated) scores of the contractors as a result of ± 25% changes in the value of the assigned CSC weights.

The results in the table show that no CSC dominantly influences the changes in overall scores, that is, the system is not sensitive to a single CSC. It is also observed that variation of CSC weights for up to ± 25% does not change the final outcome of the system, i.e. the ranking order of the candidate contractors in any case. This confirms the robustness of the selection system in absorbing the uncertainty and inconsistency resulting from varying individuals' perceptions and preferences.

Table 8.15 Percentage Change in Overall Scores due to ± 25% Variation in CSC Weights

Contractor Selection Criteria (CSC)	**% Change in Overall Scores as a Result of up to ± 25% Variation in Weights of CSC**	
	Maximum	**Minimum**
Contracting Company's Attributes	0.12	-0.13
Past Performance of the Contractor	0.21	-0.18
Financial Capability of the Contractor	0.20	-0.18
Performance Potential of the Contractor	0.13	-0.13
Project Specific Criteria	0.19	-0.20

8.4 Conclusion

This chapter discusses the testing of the developed computer-interactive contractor selection system in terms its user-friendliness, functionality, usefulness, and sensitivity analysis. The test for user-friendliness checks whether the computer application provides a sufficient interface between the users and the system. The system interfacing facility is modified till it satisfies the participating construction practitioners' requirements. The functionality of the system is tested to verify that the system developed is structurally sound and functions correctly as per the requirements and specifications. Testing of functionality includes detecting bugs and errors and investigating the workability of the system by checking the consistency of logic used in the data analysis part of the computer application and efficiency of interaction between different components of the selection system- mainly the user interface component and the data analysis component. An actual contractor selection case is manually solved and the results are compared with the system results. The test confirms the consistency of the logic and the integrity of different components of the system. The test for usefulness validates the flexibility and applicability of the system by observing how close the system results are to the actual cases results.

Eight actual contractor selection cases are analyzed using the developed selection system and the results are compared with the actual case results. Though the developed system predictions are not completely consistent with the actual cases results, a reasonable representation of the actual results is observed.

Sensitivity analysis is also performed to observe the effect of variation in input parameters on the final outcomes of the system in order to understand the behavior of the system to small variation in the input parameters. The analysis results show that the system predictions are not sensitive to a single criterion and that up to ± 25% variation of CSC weights does not change the final results of the system. This confirms the system ability to absorb uncertainty and inconsistency resulting from differing individuals' perceptions and preferences.

All these tests together confirm that the computer-aided selection system developed is capable of performing contractor selection involving multiple decision-makers and multiple decision criteria as it is intended to do. The implication of the results from these tests is that the selection system should find favor with construction practitioners and researchers in contractor selection when compared with other models developed for contractor selection. One main constraint to implementing the proposed computerized selection system would be the reluctance on the part of construction practitioners to use the system since they may not be familiar with the computer language for modifying the system code to adjust the system as per their requirements.

Chapter 9

Conclusion and Recommendations

9.1 Chapter Overview

This chapter briefly covers various research works carried out in this study and conclusions from the study. It also discusses contributions of research to the existing knowledge base and topics worthy of further research.

9.2 Conclusion

The success level of any construction project is largely dependent on the contractor's ability to troubleshoot unforeseen problems and to deliver the project within the stipulated time and budget, and as per the quality standards required by the client. Therefore, the main aim of any contractor selection process is to choose the right contractor for the right project so that achievement of best value for money is ensured. Selection of the most appropriate contractor for the project has always been a crucial challenge for construction clients. Even though many construction practitioners and researchers have suggested different sets of CSC and several methodologies or models for selection of the most appropriate contractor, who demonstrates a proper balance between performance and potential or non-economic and economic attributes, for the project, the construction industry still has a poor image for time and cost overruns, poor quality standards and litigation problems. Recent project delivery problems in the Singapore construction industry have also made construction practitioners recognize the need for a closer examination of the current contractor selection methodologies and called for the development of a contractor selection system that can assist construction clients in a more realistic and systematic way during the evaluation process.

Therefore, an attempt has been made to develop a comprehensive contractor selection system capable of dealing with uncertainty resulting from the nature of construction and subjectivity and vagueness surrounding the nature of decision-making in contractor selection process.

With an aim to gain some insights into the various contractor selection practices currently in use, CSC and evaluation techniques used by construction clients in various countries, review of a wide range of literature covering these issues is carried out. It highlights that there is no universal set of CSC that can be used in all cases of contractor selection owing to the one-off nature of construction and differing requirements of client organizations. However, the most common CSC, apart from tender price, generally considered by clients include those relating to company's track record, past performance, financial capability, performance potential and project specific criteria. The review also reveals that the preference of CSC and the DIA attached to them vary considerably among client types, nature of works, selection types and geographical location. It also shows that though construction clients in different organizations use different procedures or techniques for contractor selection they are becoming more aware of the fact that awarding of contract solely based on the price criterion is the root cause of almost all the problems related to project failure resulting from selecting a contractor not properly equipped, in terms of performance and capability, for the project, which is an indication of paradigm shift in contractor selection practice, i.e., from lowest-price win approach to best-value or multiple criteria selection approach. Therefore, the selection system must have a facility that allows the users to modify the criteria and their weights as per requirements and be capable of handling multiple criteria.

In order to elicit the information regarding the preferences of contractor selection process and CSC used by construction clients and to establish a list of important criteria and their weights for inclusion in the system, a questionnaire survey was conducted. After preliminary interviews with construction practitioners 48 criteria selected for the study are divided into five groups- contracting company's attributes, past performance, financial capability, performance potential and project specific criteria.

Out of 390 questionnaire forms sent to Singapore public and private sectors clients and contractors, 128 (32.82%) complete responses were received. The survey responses are statistically analyzed using SPSS. The results from the statistical analysis show that all 48 criteria are relevant and important from the viewpoints of all the respondents surveyed. It also highlights that the CSC pertinent to the contractor's ability to troubleshoot a wide range of construction problems, for example, depth of experience on similar type of project, qualification and experience level of project manager, qualification and experience of management staffs, type and scale of project completed in past 3 years, qualification and experience of technical staffs, and liquidity status of the company, working capital and debarment and/or demerit point in past projects, are considered (very) important for assessing the capabilities of contractors.

Both parametric and non-parametric tests are performed to investigate the significant differences between respondents' organization types- public clients, private clients and contractors. The results reflect that though the respondents share some degree of commonality with respect to the relevance of CSC, their decision-making preferences during the selection process are context specific, i.e. they assign varying level of importance to CSC depending upon the specific requirements of the project, their personal experiences and preferences during the decision-making process. This finding indicates that though there may be a possibility to identify a universal set of CSC to be used for assessing the capabilities of the candidate contractors during the selection process, the establishment of generalized weight for those CSC seems to be difficult as well as inappropriate. Though these samples of the respondents surveyed prefer the price criterion over other CSC a good representation of proper balance between price and non-price criteria can be considered as a reflection of Singapore construction practitioners' realization of the importance of multiple criteria selection approach.

Since the lowest DIA attached to CSC observed is 2.84, which is near medium importance, 47 criteria, except the criterion "*E10: Risk sharing level of project owner*" which is removed as suggested by some construction practitioners during post-questionnaire interview, are selected for inclusion in the system. Based on the DIA observed through the questionnaire survey, the normalized weights (%) established for five CSC groups-contracting company's attributes, past performance, financial capability, performance potential and project specific criteria, are 17.0, 22.3, 25.2, 19.7, and 15.8 respectively. The findings may help construction clients in reviewing decision factors they consider when assessing the attributes of candidate contractors, and also be useful for contractors in improving their attributes in line with important decision factors considered by construction clients.

The developed contractor selection system can be used to assist construction clients in performing P&P qualification or P&P qualification plus tender evaluation process. P&P qualification focuses on matching the candidate contractors' performance and potential attributes in light of the project under consideration, whereas tender evaluation process concentrates on tender price and merits of the tender proposal itself. A model for assessing financial performance of contractors during evaluation process is designed as a sub-model of the system. The model employs entropy method to establish the objective weights of the selected financial ratios and MCDM method to determine the overall financial performance scores of candidate contractors. It provides a quick and effective way of observing the changes in financial health of contractors on tender list.

Each construction project has its own distinct characteristics and requirements and this uniqueness of the construction projects poses the problem of establishing a universal set of CSC for all types of construction projects. In order to enhance the flexibility of the contractor selection system for adapting and reflecting the individuality of construction projects, the system is made computer-interactive with a mechanism that allows the users to add/remove decision criteria or change their weights as per requirements, hence widening its applicability to real contractor selection cases.

The computer application comprises two main components-user interaction and data analysis. Microsoft Visual Basic is used to develop a user-friendly interface in order to provide the users an easy access to data analysis component of the system hiding all complex calculations from the eyes of the users. Microsoft Excel which provides many facilities for mathematical and statistical computation is used for handling computational tasks of the computer application and as database for storing and retrieving data.

The computer-interactive contractor selection system carries out the evaluation process through seven main steps- recording basic information for selection process, selecting criteria and establishing their weights, establishing global or overall importance value of CSC, evaluating P&P attributes on CSC, scoring tender proposals, investigating financial soundness of candidate contractors, and reporting final outcomes of the evaluation process. In criteria and weights selection process, the system allows the DMs to modify the weights of the criteria established through the questionnaire, that is to add or remove criteria and their weights or accept the criteria and their weights as suggested. This feature enhances the flexibility of the system in adapting the individuality of construction projects making it independent of type of project and client's organization. The process of investigating financial soundness of candidate contractors is optional and can be bypassed if the situation does not warrant the detailed financial analysis of contractors. The results are provided in such a way that enables the DMs to observe how each contractor is performing on each CSC and how each DM has rated the contractors on each CSC.

The developed system is tested for its user-friendliness, functionality, usefulness and sensitivity to changes in input parameters. During user-friendliness test all the interfacing facilities of the system is modified as required by participating construction practitioners. Functionality of the system is tested by comparing the system results with manually solved results of an actual contractor selection case. All the performance glitches resulting from poor interaction between different components of the system are modified during the test. The final results confirm the efficiency and effectiveness of the interaction between different components of the system. Eight actual contractor selection cases are used to test the usefulness of the system. Financial evaluation model is tested with only five cases for which financial data are available. Though the system does not predict the same ranking as the actual selection for all the cases, a high level of accuracy and a reasonable representation of the actual results is reflected in the system predictions. In order to understand the effect of small variation in the input parameters on the behavior and the final outcomes of the system sensitivity analysis is also performed. The weights of CSC are varied from -25% to +25%. The analysis results show that the system predictions are not sensitive to a single criterion and that up to ± 25% variation of CSC weights does not change the final results of the system. This confirms the system robustness to absorb the variation in CSC weights due to uncertainty and inconsistency resulting from differing individuals' perceptions and preferences. All these tests together verify and validate the system's ability to predict as it is intended to do.

The system assumes that candidate contractors have satisfied all mandatory requirements such as completeness and thoroughness of submission and information supplied and conformance to specifications. It is also assumed that performances of attributes on decision criteria are fuzzy whereas the performances of the DMs are not. Hence, the allocation of weightings to individual criteria is done using numerical scale values and the assessment of contractors' performances of attributes on criteria is carried out in linguistic terms. The results from sensitivity analysis show that the risk associated with the variation in weights assigned to CSC resulting from individual perception and judgment is insignificant as considerable variation in CSC weights does not change the final ranking of candidate contractors. The risk associated with the uncertainty resulting from subjective judgment of performances of attributes on CSC is reflected in fuzzy membership function.

One major weakness of the system is that the exhaustive establishment of weights for different combinations of criteria for determination of overall importance value of CSC puts burden on DMs and is also time consuming if there are many criteria. However, the computer interaction reduces the burden of tedious and a large amount of calculation time on the part of DMs. Another limitation is that the linguistic variables, their fuzzy numbers and preference structure considered in the system cannot be adjusted by the DMs. However, with a little knowledge of programming the source code can be modified to change them as per requirements. In fact, linguistic variables included, after a careful review of literature and discussion with practitioners, in the system represent a sufficient number of response categories which are sensitive enough to discriminate between DMs with differing views. The major advantage of the system is that it makes the selection process more systematic and realistic as the use of fuzzy set theory allows the DMs to assess the contractors' performance on CSC in linguistic terms rather than as crisp values and in MPMC environment, DMs are mostly less reluctant to handle the uncertainty associated with decision-making directly in the scores of performance on particular criteria by using approximate values than by using crisp values. Another advantage of this selection system is that all the DMs need not be present at the same place and at the same time for participating in the evaluation process, if the password-protected access to the system is made available to the DMs through the Internet or intranet modality.

The implication for practice in the adoption of the proposed system is that the contractor selection system was developed primarily for traditional construction projects. To efficiently apply the proposed system to other non-traditional construction projects, the decision criteria that are critical to the project requirements should be identified and added into the system. The level of detail required for evaluating the capability of the contractor for a construction project is primarily a function of its size and complexity. Though the selection system includes a certain degree of detail in respect of selection criteria to provide the user of the system with a comprehensive and structured aid in selecting the right contractor, in many instances, certain criteria included in the system will only be investigated if doubt exits regarding the capability of candidate contractors on the criteria. It is therefore assumed that all the information required for the user of the system is available prior to the beginning of the selection process and is prerogative of the user of the system to modify the criteria and their weights as per the requirements.

The use of the developed contractor selection system, even though it is no panacea for all potential problems of decision-making regarding contractor selection process, will assist construction clients in performing more realistic, linguistic assessment of the contractors to select 'the right contractor for the right project' so that the risk to the client of project failure due to the selection of an inappropriate contractor is reduced and more efficient utilization of resources by all parties associated with the selection process is ensured. However, the developed system is not intended to supplant the work of decision-making teams in contractor selection process, but rather to help them make informed, quality evaluation of the available candidate contractors. It is highly recommended that the results from the system should not be used as a sole measure for the selection of the most appropriate contractor for the job, but rather be tempered with experiential judgment of the DMs to arrive at the final decision.

9.3 Research Contributions

The research contributions include:

- **Best value approach**

  The study has, through the questionnaire survey conducted in Singapore, confirmed the importance of use of best value approach or multiple criteria approach for selecting the most appropriate contractor for construction projects. Particularly for public clients who generally accept the lowest tender price on grounds of public accountability the system results provide a good basis for comparing performance and potential attributes of contractors and for rejecting with greater confidence tenders with very low prices, but high performance risk.

- **List of important CSC**

  A list of important and relevant selection criteria, though it is not a universal set of CSC, that should be considered during the selection process has been established. It is also useful for contractors to improve their attributes on those CSC that are considered important by construction clients. It can also be used as a starting point for construction practitioners and researchers in contractor selection for further research.

- **Fuzzy MPMC method**

  Contractor selection is a decision-making process, complex and subjective in nature, involving the development and consideration of a large number of sufficient and necessary decision criteria as well as participation of many DMs. Use of a combination of fuzzy set theory and MPMC method enhances the system's capability in handling uncertainty and vagueness resulting from differing individuals' perceptions and preferences and multiple DMs and multiple criteria simultaneously. In an actual contractor selection process, a large number of decision criteria and sub-criteria need to be considered simultaneously and in most cases the DMs are less reluctant to handle the uncertainty associated with decision-making directly in the scores of performance on particular criteria by using approximate values than by using crisp values. Use of fuzzy linguistic variables allows the DMs to express their opinions about contractors' performances on CSC in linguistic terms which better correspond to real-world situations.

- **Consideration of overall or global importance value**

  An important aspect of multi-person multi-criteria decision making involving the search for an optimal solution is trade-off between criteria which are non-compensatory in nature. Use of the concept of global importance value of CSC reflects the interaction and relationships among CSC and DMs' preferences and concerns in decision-making process.

- **Financial evaluation model**

  Development of financial ratio model for evaluation of financial health of contractors using objective weighting method eliminates the problem of establishing cut-off values for financial ratios and contradictory indications that can arise from the application of traditional ratio analysis. Unlike other ratio models developed for construction, the developed model provides the trend of financial performance of contractors over a period of time reflecting proactive stance necessary for making decision regarding the financial soundness of contractors.

- **Computer interaction**

  Making the system computer interactive reduces time and effort on the part of DMs and facilitates to adapt to the changes as per requirements. It also facilitates the system to present the results showing the ranking of contractors based on overall aggregated scores, how each contractor is performing on each of CSC and how each DM rates contractors on each of CSC. This provides a basis for comparison for strength and weakness of contractors which should be taken into consideration while making final decision. Computer interaction also helps create a database for contractors which can be used for classification of contractors based on their performance.

- **Application to other decision-making problems**
  With a little modification the developed system can also be used as a support tool for selection of architects, consultants, project managers or construction managers by construction clients or selection of subcontractors by main contractors, if the proper selection criteria can be identified for each selection case.

9.4 Limitations of the Research

Though the research has made significant contributions, there are several limitations as well. The main limitations are:

- The actual contractor selection cases selected for testing are relatively limited in number and to traditional procurement methods only. More cases-both traditional and non-traditional methods, would enable a comprehensive testing of the system. This limitation may be due to the requirement of the sensitive and confidential nature of data for testing the system.

- Though a reasonable representation of the actual results is observed during the testing of the developed system with actual contractor selection cases, it is open to the criticism that if the actual practice is wrong, the system's predictions would also be wrong. Hence, a better way to verify the performance of the system is to compare the system's predictions with the actual decisions in light of the degree of project success.

- The entropy method adopted for the financial ratio model does not take into account the effect of different accounting standards, as well as may attach undue larger weightings to some financial ratios due to the effect of one-off events such as asset write-down in construction (as discussed in Section 6.6). It is therefore recommended that all these points be taken into consideration in making final decision regarding the financial soundness of candidate contractors.

9.5 Recommendations for Future Works

- It would be of more benefit to construction practitioners if the proposed contractor selection system be launched through the Internet or intranet modality. The program can be reformatted using VB script or Java script to develop Active Server Pages (ASP) which can be integrated into Hyper Text Markup Language (HTML) enabling the system to be used via World Wide Web (WWW).

- Though the findings from the study suggest the slight possibility of developing a universal set of decision criteria for contractor selection, it would be more appropriate to develop a common set of important CSC that are more project-specific, i.e. for different types of construction projects. Establishing an industry-wide database would help benchmark common set of important CSC for different types of construction projects.

- An important area for further work would be to develop a feedback process for contractors' performance in terms of the degree of project success so that the selection system performance can be improved continuously. This may, in turn, help calibrate the default weightings of CSC for different types of construction projects more objectively, e.g., by regression analysis.

- A potential direction for further research could be to develop contractor classification model which can assist construction clients in tracing the trend of contractor performance. This could be accomplished by developing an industry-wide database, which is the Internet-based, for contractors' performance on time, cost, quality and health and safety for different kinds of construction projects.

- Due to the limited availability of data, the financial evaluation model developed was tested with only a small number of real cases. Therefore, it would be over optimistic to suggest that the model will provide accurate prediction in its present form. Further research will be needed to improve the robustness of the model. This could be achieved by testing the performance of the model with more and more actual contractor selection cases of different types and scales of construction projects and by incorporating other 'soft data' on contractors' financial performance in combination with financial data from audited accounts.

REFERENCES

References

AASHTO (1998). *Primer on Contracting 2000*, Second Ed., A Report of the Contract Administration Task Force of American Association of State Highways and Transportation Officials Subcommittee on Construction, USA.

Abidali, A. F. (1900). "A Methodology for Predicting Company Failure in the Construction Industry." PhD thesis, Loughborough University of Technology, UK.

ACTIVE (1996). *ACTIVE Engineering Construction Initiative: The Action Plan*, ACTIVE, London.

Alhazmi, T., and McCaffer, R. (2000). "Project Procurement System Selection Model", *Construction Engineering and Management, ASCE,* 126(3), 176-184.

Alsugair, A. M. (1999). "Framework for Evaluating Bids of Construction Contractors", *J. of Management in Engineering*, 15(2), 72-78.

Altman, E. I. (1968). "Financial Ratios, Discriminant Analysis and the Predication of Corporate Bankruptcy." *J. of Finance*, Sep, pp 589-609.

Altman, E. I. (1983). "Predicting Corporate Bankruptcy: The Z-score Model." In: *Corporate Financial Distress: A Complete Guide to Predicting, Avoiding and Dealing with Bankruptcy.* John Wiley & Sons Inc., NY, USA.

Ang, A. H-S., and Tang, W. H. (1984). *Probability Concepts in Engineering Planning and Design, Vol. II- Decision, Risk and Reliability*, John Wiley, NY, USA.

Barrie, D., and Paulson, B. (1992). *Professional Construction Management*, 3rd Ed., McGraw-Hill, NY, USA.

BCA (2002). "BCA Contractors Registry." Building and Construction Authority, Singapore, <http://www.dir.bca.gov.sg/bca/index.asp> (May 12, 2003).

BCA (2003). "BCA Contractors Registry." Building and Construction Authority, Singapore, <http://www.dir.bca.gov.sg/bca/index.asp> (March 15, 2004).

BCA (2004a). "BCA Contractors Registry: Registration Requirements." Building and Construction Authority, Singapore, <http://www.dir.bca.gov.sg/ContractorsRegistry/contractors_registration_requirements.html> (March 30, 2005).

BCA (2004b). "Bonus Scheme for Construction Quality (BSCQ)." Building and Construction Authority, Singapore, <http://www.bca.gov.sg/Professionals/IQUAS/bqphomepage.asp> (March 30, 2005).

BCA (2005). "Design & Build: Percentage of D&B Projects Awarded in Singapore." Building and Construction Authority, Singapore. < http://www.bca.gov.sg/DesignBuild/design_build_statistics_fig4.html> (July 15, 2005).

Bellenger, D. N., and Greenberg, B. A. (1976). *Marketing Research: A Management Information Approach*, Richard D. Irwin, Inc., Homewood, Illinois, USA.

Bellman, R. E., and Zadeh, L. A. (1970). "Decision Making in a Fuzzy Environment." *Management Science*, 17(4), 141-164.

Bennett, J., Pothecary, E., and Robinson, G. (1996). *Designing and Building a World-Class Industry*, Reading: Center for Strategic Studies in Construction.

Blum, M. (1974). "Failing Company Discriminant Analysis." *J. of Accounting Research*, 12 (1), 1-25.

Brans, J. P., and Vincke, Ph. (1985). "A Preference Ranking Organization Method, the PROMETHEE Method." *Management Science*, 31, 647-656.

Brown, J. (1994). "Partnering to Save Troubled Projects." J. of Management in Engineering, ASCE, May/June, 23-25.

Bryman, A. and Crammer, D. (1999). *Quantitative Data Analysis with SPSS for Windows*. Routledge, London.

______ (2001). *Quantitative data analysis with SPSS release 10 for Windows- A guide for social scientists*, Routledge, London.

Calpine, H. C., and Golding, A. (1976). "Some Properties of Pareto-Optimal Choices in Decision Problems." *OMEGA*, 4(2), 141-147.

Chau, K. W., Leung, H. F., and Ho, D. C. W. (1996). "The Economics of Procurement Methods with Special Reference to Public Housing Projects in Hong Kong." In R. G. Taylor (Ed.), *Proceedings of CIB W92- Procurement Systems: North meets South: Developing Ideas (pp40-52),* University of Natal, Durban, South Africa.

Cheng, C. H., and Mon, D. L. (1994). "Evaluating Weapon System by Analytic Hierarchy Process Based on Fuzzy Scales." *Fuzzy Sets and Systems*, 63, 1-10.

Cheong, S-W., and Tan, H. Y. (2003). "Out of Site, Out of Money." *The Strait Times*, June 14, Singapore.

CII (1989). *Partnering: Meeting the Challenges of the Future*, CII Special Publication, Construction Industry Institute, Austin, TX, USA.

______ (1991). *In Search of Partnering Excellence*, CII Special Publication, Construction Industry Institute, Austin, TX, USA.

Cohen, J. (1977). *Statistical Power Analysis for the Behavioral Sciences*, Revised Ed., Academic, NY, USA.

Construction Industry Development Agency (CIDA) (1993). *The Australian construction industry prequalification criteria for contractors and subcontractors*, CIDA, Australia.

Contractual Arrangements: Report A7 (1982). Business Roundtable, NY, USA.

Cook, T. D., and D. T. Campbell (1979). *Quasi-Experimentation: Design and Analysis Issues for Field Settings*, Rand McNally, Chicago, USA.

Corcoran, J., and Mc Lean, F. (1998). "The Selection of Management Consultants-How Are Governments Dealing with This Difficult Decision? An Exploratory Study." *Intl. J. of Public Sector Management*, Bradford, UK, 11(1), 37-54.

CRINE (1994). *CRINE Report*, Institute of Petroleum, London.

David, J. L., and Ronald, S. R. (1987). *Marketing Research*, Seventh Ed., Prentice-Hall Inc., NJ, USA.

Diekmann, J. E. (1981). "Cost-Plus Contractor Selection: A Case Study." *J. of the Technical Council of ASCE*, 107 (1), 13-25.

Dietel, H. M., Dietel, P. J., Niet, T., and Nieto, T. R. (1999). *Visual Basic 6 How to Program*, Prentice Hall, NJ, USA.

DLSI (2005). *World Construction Review/Outlook 2003/4*. David Langdon & Seah International, <http://www.davislangdon.com.au/publications/worldreview0304.pdf> (Aug 15, 2005).

Dubois, D., and Prade, H. (1985) "Recent Models of Uncertainty and Imprecision as a Basis for Decision Theory: Toward Less Normative Frameworks." In: *Intelligent Decision Support in Process Environments (pp3-24)*, E. Hollnage, G. Mancini, and D. Woods (Ed.), Springer-Verlag, NY, USA.

Edmister, R. A. (1972). "An Empirical Test of Financial Ratio Analysis for Small Business Failure Prediction." *J. of Financial and Quantitative Analysis*, 7 (1), 1477-93.

Edum-Fotwe, F., Price, A., and Thorpe, A. (1996). "A Review of Financial Ratio Tools for Predicting Contractor Insolvency." *Construction Management and Economics*, 14(3), 317-325.

Edwards, W. (1977). "Use of Multiattribute Utility Measurement for Social Decision Making." In: *Conflicting Objectives in Decisions*, Bell, D. E., Keeney, R. L., and Raffia, H. (ed.), Wiley, NY, USA.

Efstathiou, J. (1979). *A Practical Development of Multi-Attribute Decision Making Using Fuzzy Set Theory*, Ph.D. Dissertation, Dept. of Comput., University of Durham, England.

Fong, P. Ski-Wah and Choi, S. Kit-Yung (2000). "Final Contractor Selection Using Analytical Hierarchy Process." *Construction Management and Economics*, 18, 547-57.

Goodman, L. A. (1961). "Snowball Sampling." *Annals of Mathematical Statistics*, 32, 148-170.

Gordon, C. M. (1994). "Choosing Appropriate Construction Contracting Method." *Construction Engineering and Management, ASCE,* 120 (1), 196-210.

Government of Singapore (2002). "Singapore Government Directory interactive (SGDi)." Government of Singapore, <http://www.sgdi.gov.sg> (May 10, 2003).

Green, P. E., Tull, D., and Albaum, G. (1988). *Research for Marketing Decision*, Fifth Ed., Prentice Hall, NJ, USA.

Grogan, T. (1992). "Low Bids Raise Hidden Costs." *ENR*, 228, 30-31.

Guevara, V., and Tan, H. Y. (2003). "Contractors Sink into Red after Undercutting Each Other." *The Strait Times*, June 11, Singapore.

Hair, J. F., Bush, R. P., and Ortinau, D. J. (2003). *Marketing Research: Within a Changing Information Environment*, McGraw-Hill/Irwin, NY, USA.

Harrison, J. (1989). *Bayesian Forecasting and Dynamic Models*, Springer, NY, USA.

Hardy, S., Norman, A., and Perry, J. (1981). "Evaluation of Bids for Contracts Using Discounted Cash Flow Techniques." *Proceedings. Institute of Civil Engineers*, Part1, February.

Hatush, Z. (1996). "Contractor Selection Using Multi-Attribute Utility Theory." PhD Thesis, University of Salford, UK.

Hatush, Z., and Skitmore, M. (1997a). "Criteria for Contractor Selection." *Construction Management and Economics*, 15, 19-38.

______ (1997b). "Evaluating Contractor Prequalification Data: Selection Criteria and Project Success Factors." *Construction Management and Economics*, 15, 129-147.

______ (1998). "Contractor Selection Using Multi-Criteria Utility Theory: An Additive Model." *Building and Environment*, 33 (2), 148-164.

Helmer, T. F., and Taylor, R. L. (1977). "The Evaluation of Contractor Management during Source Selection." In: *Proceedings AIIE Spring Annual Conference*, Dept. Economics, Geography and Management, USAF Academy, Colorado.

Herbsman, Z. J. (1995). "A+B Bidding Method–Hidden Success Storey for Highway Construction." *Construction Engineering and Management,* ASCE, 121(4), 430-437.

Herbsman, Z. J., and Ellis, R. (1992). "Multi-Parameter Bidding System-Innovation in Contract Administration." *Construction Engineering and Management,* ASCE, 118(1), 142-150.

Hipel, K. W., Radford, K. J., and Fang, L. (1993). "Multiple Participant-Multiple Criteria Decision Making." *IEEE Transaction on System, Man and Cybermatics*, 23, 1184-1189.

Holt, G. D. (1995). "A Methodology for Predicting the Performance of Construction Contractors." PhD Thesis, University of Wolverhampton, UK.

Holt, G. D., Olommolaiye, P. O., and Harris, F. C. (1993). "A Conceptual Alternative to Current Tendering Practice." *Building Research and Information*, 21(3), 167-72.

Holt, G. D., Olommolaiye, P. O., and Harris, F. C. (1994a). "Evaluating Performance Potential in the Selection of Construction Contractors." *Engineering, Construction and Architectural Management*, 1(1), 29-50.

Holt, G. D., Olomolaiye, P.O., and Harris, F. C. (1994b). "Evaluating Prequalification Criteria in Contractor Selection." *Building and Environment*, 29(4), 437-448.

Holt, G. D., Olomolaiye, P.O., and Harris, F. C. (1995a). "A Review of Contractor Selection Practices in the UK Construction Industry." *Building and Environment*, 30, 533-561.

Holt, G. D., Olommolaiye, P. O. and Harris, F. C. (1995b). "Applying Multi-Attribute Analysis to Contractor Selection Decisions." *European J. of Purchasing Supply Management*, 1(3), 139-148.

Hong Kong Housing Authority (1994). "PASS: Performance Assessment Scoring System." Housing Dept., Hong Kong Housing Authority.

Hwang, C-L., and Yoon, K. S. (1981). *Multiple Attribute Decision Making: Methods and Applications,* Springer-Verlag, NY, USA.

Hunt, H. W., Logan, D. H., Cobertta, R. H., Crimmins, A. H., Bayard, R. P., Lore, H. E., and Bogen, S.A. (1966). "Contract Award Practices." *J. of Construction Division, Proceedings of the ASCE,* 92, 1-16.

Ioannou, P. G., and Leu, S-S. (1993). "Average-Bid Method-Competitive Bidding Strategy." *Construction Engineering and Management, ASCE,* 119(1), 131-147.

Ishii, K., and Sugeno, M. (1985). "A Model of Human Evaluation Process Using Fuzzy Measures." *International J. of Man-Machine Studies,* 22, 19-38.

Jaafari, A., and Schub, A. (1990). "Surviving Failure: From Field Study." *Construction Engineering and Management, ASCE,* 116(1), 68-86.

Jaselskis, E. J. (1988). "Achieving Construction Projects through Predictive Discrete Choice Model." PhD Thesis, Univ. of Texas at Austin, USA.

Jaselskis, E. J., and Suazo, G. A. (1994). "A Survey of Construction Site Safety in Honduras." *Construction Management and Economics,* 12, 245- 255.

Kangari, R. (1988). "Business Failure in Construction Industry." *Construction Engineering and Management, ASCE*, 114 (2), 172-190.

Kapur, S. K. (1991). *Elements of Practical Statistics*, Second Ed., Oxford and IBH Pte. Ltd., New Delhi, India.

Karels, G. V., and Prakash, A. J. (1987). "Multivariate Normality and Forecasting of Business Bankruptcy." *J. of Business Finance*, 14(4), 573-593.

Kaufmann, A., and Gupta, M. M. (1988). *Fuzzy Mathematical Models in Engineering and Management Science*, North-Holland, Amsterdam.

______ (1991). *Introduction to Fuzzy Arithmetic Theory and Application*, Van Nostrand Reinhold, NY, USA.

Kaur, S. (2003). "HDB Tendering Process Being Reviewed." *The Strait Times*, June 23, Singapore.

Keasey, K. and Watson, R. (1986). "The Prediction of Small Company Failure: Some Behavioral Evidence for the UK." *Accounting and Business Research*, Winter, 49-57.

Kerre, E. E. (1982). "The Use of Fuzzy Set Theory in Electro Cardiological Diagnostics." In: Gupta, M. M. and Sanchez, E. (Ed.,), *Approximate Reasoning and Decision Analysis*, North-Holland, Amsterdam.

Khosrowshahi, F. (1999). "Neural Network Model for Contractor's Prequalification for Local Authority Projects." *Engineering, Construction and Architectural Management*, 6 (3), 315-328.

Kiong, T. S., and Yun, Z. (1998). "Procurement Methods Used in the Construction Industry." Paper presented at The Eighth KKNN Seminar on Civil Engineering, Singapore, Nov 30-Dec 1.

Kirk, R. E. (1995). *Experimental Design: Procedures for the Behavioral Sciences*, Third Ed., ITP, USA.

Klein, R. (1994). "Tendering Anarchy in the U.K." *Building*, 15 July, 30.

Klir, G. J., and Folger, T. A. (1988). *Fuzzy Sets, Uncertainty and Information*, Prentice-Hall Inc., Englewood Cliffs, NJ, USA.

Konchar, M., and Sanvido, V. (1998). "Comparison of US Project Delivery Systems." *Construction Engineering and Management,* ASCE, 124(6), 435-444.

Kumaraswamy, M. M. (1996). "Contractor Evaluation and Selection: A Hong Kong Perceptive." *Building and Environment*, 31 (3), 273-82.

Kwakye, A. A. (1994). *Understanding Tendering and Estimating*, Gower, Aldershot.

Lam, K. C., Hu, T., Ng, S. T., Skitmore, M., and Cheung, S. O. (2001). "A Fuzzy Neural Network Approach for Contractor Prequalification." *Construction Management and Economics*, 19, 175-88.

Langford, D., Iyagba, T., and Komba, D. M. (1993). "Prediction of Solvency in Construction Companies." *Construction Management and Economics*, 11(5), 317-25.

Larson, E. (1997). "Partnering on Construction Projects: A Study of the Relationship between Partnering Activities and Project Success." IEEE Transactions on Engineering Management, 44(2), 188-195.

Latham, M. (1994). *Constructing the Team*, HMSO, London.

Lev, B. (1974). *Financial Statement Analysis*, Prentice Hall, Englewood Cliffs, NJ, USA.

Levy, S. M. (1996). *Build Operate Transfer: Paving the Way for Tomorrow's Infrastructure*, John Wiley & Sons, NY, USA.

Lewis, C. M. (1981). "Contract Award Practices." *Proceeding of the CIB W-65. Third Symposium on Organization and Management of Construction*, 6-8 July, Dublin, 354-361.

Ling, Y. Y., Khee, H. Y., and Lim, K. S. G. (2000). "The Reasons Why Clients Prefer to Procure More Projects Based on Design-Bid-Build than Design-and-Build." *J. of Construction Procurement*, 6(2), 135-146.

Liston, J. (1994). "Contractor Prequalification." M. S. Thesis, Queensland University of Technology, Brisbane, Australia.

Liston, J. (1999). *Contracts Administration.* The Lecture Notes Hand-out, School of Civil Engg., Queensland University of Technology, Brisbane, Australia.

Liu, A. M. M. and Walker, A. (1998). "Evaluation of Project Outcomes." *Construction Management and Economics*, 16, 209-219.

Luce, R. D. (1956). "Semiorders and a Theory of Utility Discrimination." *Econometrica*, 24(2), 178-191.

MacCrimmon, K. R. (1968). "Decision Making among Multiple Attribute Alternatives: A Survey and Consolidated Approach." *RAND Memorandum*, RM-4823-ARPA.

Mahdi, I. M., Riley, M. J., Fereig, S. M., and Alex, A. P. (2002). "A Multi-Criteria Approach to Contractor Selection." *Engineering, Construction and Architectural Management,* 9(1), 29-37.

Mason, R. J., and Harris, F. C. (1979). "Predicting Company Failure in the Construction Industry." *Proceedings, Institution of Civil Engineers*, 66, 301-7.

Mawhinney, M. (2001) *International Construction*, Blackwell Science, Oxford, U.K.

Maxwell, N. (1994). "Private Participation in Infrastructure Projects – the Importance of Understanding the Perceptive of Private Participants." *IntraData Infrastructure Handbook*, World Infrastructure Forum, October 17-21, Jakarta, Indonesia.

McNamee, P. B. (1985). *Tools and Techniques for Strategic Management*, Pergamon Press, Oxford, U.K.

Mehrens, W. A., and Lehmann, I. J. (1984). *Measurement and Evaluation in Education and Psychology*, Third Ed., Holt, Rinehart and Winston, NY, USA.

Merna, A., and Smith, N. J. (1990). "Bid Evaluation for the U.K Public Sector Construction Contracts." *Proc., Inst. of Civ. Engrs.* Part I: Des. and Constr., Institution of Civ. Engrs., London, 88, 91-105.

Ministry of Manpower (2002). "Information on Occupational Safety and Health." Ministry of Manpower, Singapore, <http://www.mom.gov.sg/MOM/CDA/0,1858,963------------,00.html> (May 12, 2005).

Ministry of Public Building and Works (MPBW 1964). *The Placing and Management of Contractor for Building and Civil Engineering Works,* (Banwell Report). Her Majesty's Stationery Office, London.

Montgomery, D. C., and Runger, G. C. (2003). *Applied Statistics and Probability for Engineers*, Third Ed., John Wiley, USA.

Moore, M. J. (1985a). "Selecting a Contractor for Fast Track Projects. Part 1: Principles of Contractor Evaluation." *Plant Engineering*, 39, 74-75.

______ (1985b). "Selecting a Contractor for Fast Track Projects. Part 2: Quantitative Evaluation Method." *Plant Engineering*, 39, 54-56.

Moser, C. A., and Kalton, G., (1971). *Survey Methods in Social Investigation,* Second Ed., Dartmouth, USA.

Murdoch, J., and Hughes, W. (1996). *Construction Contracts, Law and Management*, E & FN SPON, London, U.K.

Mustafa, M. A., and Ryan, T. C. (1990). "Decision Support for Bid Evaluation." *Project Management*, 8(4), 230-235.

Myers, G. J. (2004). *The Art of Software Testing*, Second Ed., John Wiley & Sons, NJ, USA.

Nahapiet, H., and Nahapiet, J. (1985). "A Comparison of Contractual Arrangement for Building Projects." *Construction Management and Economics*, 3, 217-231.

Nahapiet, H., and Nahapiet, J. (1985). "A Comparison of Contractual Arrangement for Building Projects", *Construction Management and Economics*, 3, 217-231.

Neo, R. (1997). "Design & Build, the Ultimate Procurement Concept." In: *Proceedings of the First International Conference on Construction Industry Development: Building the Future Together (pp 400-409),* NUS, Singapore.

Neter, J., Wasserman, W. and Whitmore, G. A. (1993). *Applied Statistics,* Fourth Ed., Prentice Hall, N. J., USA.

Ng, S. T., Smith, N. J., and Skitmore, R. M. (1995). "Case-based Reasoning for Contractor Prequalification- A Feasibility Study." In. *Developments in Artificial Intelligence for Civil and Structural Engineering* (Ed. B. H. V. Topping) 61-66. Civil-Comp Press, England.

Ng, S. T., Skitmore, R. M., and Smith, N. J. (1999). "Decision-makers' Perceptions in the Formulation of Prequalification Criteria." *Engineering, Construction and Architectural Management*, 6 (2), 155-165.

Ng, S. T., and Skitmore, R. M. (2001). "Contractor Selection Criteria: A Cost-Benefit Analysis." IEEE Transactions on Engineering Management, 48(1), 96-106.

Nguyen, V. U (1985). "Tender Evaluation by Fuzzy Sets." *Construction Engineering and Management, ASCE,* 111 (3), 231- 43.

Norusis, M. J. (1993). *SPSS for Windows: Base System Users Guide Release 6.0*, SPSS Inc., Chicago, USA.

Nunnally, J. and Bernstein, I. H. (1994). *Psychometric Theory*, Third Ed., McGraw-Hill, NY, USA.

Ofori, G. (1988). "Construction Industry and Economic Growth in Singapore." *Construction Management and Economics*, 6(1), pp57-70.

Ohlson, J. A. (1980). "Financial Ratios and Probability of Bankruptcy." *J. of Accounting Res.*, 18 (1), 109-131.

Onisawa, T., Sugeno, M., Nishiwaki, Y., Kawai, H., and Harima, Y. (1986). "Fuzzy Measures Analysis of Public Attitude towards the Use of Nuclear Energy." *Fuzzy Sets and System*, 20, 259-289.

Oppenheim, M. A. (1992) *Questionnaire Design, Interviewing and Attitude Measurement*, Second Ed., Pinter, London.

Osama, A. (1994). "Partnering: A Team Building Approach to Quality Construction Management." *J. of Management in Engineering, ASCE,* 10 (5), 26-29.

Pain, J. (1993). "Design and Build Compared with Traditional Contracts." *Architect's Journal,* Nov, 34-35.

Palaneeswaran, E., and Kumaraswamy, M. M. (2000). "Benchmarking Contractor Selection Practices in Public-Sector Construction-A Proposed Model." *Engineering, Construction and Architectural Management*, 7(3), 285-299.

______ (2001). "Recent Advances and Proposed Improvements in Contractor Prequalification Methodologies." *Building and Environment*, 36(1), 73-87.

Pearson, G. (1985). "Tender Assessment." *Charted Quantity Surveyor, RICS*, 8, 194-195.

Perry, W. E. (2000). *Effective Methods for Software Testing*, Second Ed., John Wiley & Sons, NJ, USA.

Pomerol, J-C., and Barba-Romero, S., (2000). *Multicriterion Decision in Management: Principles and Practice*, Kluwer Academic Publishers, London, UK.

Pongpeng, J., and Liston, J. (2003a). "TenSeM: A Multicriteria and Multidecision-Makers' Model in Tender Evaluation." *Construction Management and Economics*, 21(1), 21-30.

______ (2003b). "Contractor Ability Criteria: A View from the Thai Construction Industry." *Construction Management and Economics*, 21, 267-282.

Ramsey-Dawber, P. J. (1989). "Of Strategies, Deliberate and Emergent." In: *Reading in Strategic Management*, Asch, D. and Bowman, C. (Eds), Macmillan, London, pp. 5-19.

Rescher, N. (1969). *Many-Valued Logic*, McGraw-Hill, NY, USA.

REDAS (2002). "eDirectory." Real Estate Developer Association of Singapore, <http://www.redas.com> (May 12, 2003).

Rizzo, J. (1998). "Design/Build Alternative: A Contracting Method." *J. of Management in Engineering, ASCE,* 14(6), 44-47.

Roger, A., Roger, C. H., and Allan, A. (1993). *The Construction Industry of Great Britain*, Butterworth-Heinemann Ltd., London, U.K.

Rosenthal, R., and Rosnow, R. (1991) *Essentials of Behavioral Research: Method and Data Analysis*, Second Ed., McGraw-Hill, USA.

Rowlinson, S. (1987). *Design Build-Its development and Present Status*, Ascot: CIOB.

Roy, B. (1973). "How Outranking Relation Helps Multiple Criteria Decision Making." In: *Multiple Criteria Decision Making*, Cochrane, J. L., and Zeleny, M. (Ed.), University of South Carolina Press, South Carolina, USA.

Russell, J. S. (1900a). "Model for Owner Prequalification of Contractors." *J. of Management in Engineering, ASCE,* 6 (1), 59-75.

Russell, J. S. (1900b). "Surety Industry: Overview." *J. of Management in Engineering, ASCE,* 6 (3), 323-341.

______ (1991). "Model for Owner Pre-qualification of Contractors." *J. of Management in Engineering, ASCE,* 6(1), 59-75.

Russell, J. S., Hancher, D. E., and Skibniewski, M. J. (1992). "Contractor Prequalification Data for Construction Owners." *Construction Management and Economics*, 10, 117-29.

Russell, J. S., Hanna, A. S., Anderson, S. D., Wiseley, P. W., and Smith, R. J. (1999). "The Warranty Alternative." *Civil Engineering*, 69, 60-63.

Russell, J. S., and Jaselskis, E. J. (1991). "An Efficient Structure Approach for Selection of Most Promising Construction Contractors." *J. of Project Management*, 12 (4), 31-39.

______ (1992a). "Quantitative Study of Contractor Evaluation Programs and Their Impact." *Construction Engineering and Management, ASCE,* 118(3), 612-624.

______ (1992b). "Predicting Construction Contractor Failure Prior to Contract Award." *Construction Engineering and Management, ASCE,* 118 (4), 791-811.

Russell, J. S., and Skibniewski, M. J. (1988). "Decision Criteria in Contractor Pre-qualification." *J. of Management in Engrg., ASCE,* 4 (2), 148-164.

Russell, J. S., and Skibniewski, M. J. (1990). "Qualifier-1: Contractor Prequalification Model." *J. of Computing in Civil Engineering, ASCE,* 4(1), 77-90.

Russell, J. S., Skibniewski, M. J., and Cozier, D. R. (1990). "Qualifier-2: Knowledge-Based System Constructor Prequalification." *Construction Engineering and Management, ASCE,* 116(1), 157-71.

Saaty, T. L. (1977). "A Scaling Method for Priorities in Hierarchical Structures." *J. of Math. Psychology*, 15(1), 234-281.

______ (1980). *The Analytic Hierarchy Process*, McGraw-Hill, NY, USA.

______ (1994). *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process,* Vol. IV, RWS Publication, Pittsburg, USA.

Samelson, N. M., Levitt, R. E., and Parker, H. W. (1981). "The Role of Owners in Reducing Construction Accident Costs." *The 13th Project Management Institute Proceedings*, Drexell Hill, PA, 194-200.

Samelson, N. M., and Levitt, R. E. (1982). "Owner's Guidelines for Selecting Safe Contracts." *J. of the Construction Division*, ASCE, 4(2), 148-164.

Schmucker, K. J. (1984). *Fuzzy Sets, Natural Language Computation, and Risk Analysis*, Computer Science Press, NY, USA.

Sekaran, U. (2003). *Research Methods for Business: A Skill Building Approach*, Fourth Ed., John Wiley & Sons, Inc., USA.

Shannon, C. E., and Weaver, W., (1949). *The Mathematical Theory of Communication*, University of Illinois Press, Chicago.

Shao, A. T. (2002). *Marketing Research: An Aid to Decision Making*, Second Ed., Thomson Learning, USA.

Shapley, L. S. (1953). "A Value for n-Person Games." In: H. W. Kuhn and A. W. Tucker (Ed.) *Contribution to the Theory of Games*, Vol. II, (Annals of Mathematics Studies, 28), Princeton University Press, NJ, 307-317.

SIA (2002). "SIA Member Listing." Singapore Institute of Architects, Singapore, <http://www.sia.org.sg/efirms/member_firms.php> (May 12, 2003).

Siegel, S., and Castellan, N. J. (1988). *Nonparametric Statistics for Behavioral Sciences*, Second Ed., McGraw-Hill, NY, USA.

Singh, D., Hong, G. N., and Tiong, R. L. K. (2003). "Local Practice on Procurement and Tender Evaluation System." Paper resented at SMa Federation & IES Building & Construction Conference, Oct 10, Expo, Singapore.

______ (2005). "Procurement and Contract Award Practices – a Review of the Singapore Construction Industry." In: *Proceedings of the 9th PAQS Congress*, June 27-28, Dalian, China.

SISV (2002). "SISV Member Listing." Singapore Institute of Surveyors and Valuers, Singapore, <http://www.sisv.org.sg/index.html> (May 12, 2003).

Smith, R. C. (1991). *Estimating and Tendering for Building Works*, Longman Scientific & Technical, UK.

Songer, A. D., and Molenaar, K. R. (1996). "Selecting Design-Build: Public and Private Sector Owner Attitudes." *J. of Management in Engineering*, 12 (6), 47-53.

Sonmez, M., Yang, J. B., and Holt, G. D. (2001). "Addressing the Contractor Selection Problem Using an Evidential Reasoning Approach." *Engineering, Construction and Architectural Management*, 8(3), 198-210.

Statistics Singapore (2003). "GDP by Industry [Table A1.1]", Singapore Department of Statistics, Singapore. <http://www.singstat.gov.sg/keystats/mqstats/ ess/essa11.pdf> (May 15, 2003).

Statistics Singapore (2005). "GDP by Industry [Table A1.1]", Singapore Department of Statistics, Singapore. <http://www.singstat.gov.sg/keystats/mqstats/ess/essa11.pdf> (Aug 15, 2005).

Taffler, R. J. (1993). "The Z-Score Approach to Measuring Company Solvency." *The Accountant's Magazine*, March, pp 91-96.

Tan, A. A. (1996). *Project Management in Malaysia: A Comprehensive Approach for Success of Property Development Projects form Inception until Completion*, Synergy Books International, Kuala Lumpur.

Tan, H. Y. (2004a). "Going Bust: Two More Contractors." *The Strait Times*, June 12, Singapore.

______ (2004b). "Joint Panel to Review Safety at Worksites." *The Strait Times*, May 20, Singapore.

______ (2005). "Building Contractors May Be Given Credit Ratings." *The Strait Times*, Sep 21, Singapore.

Terry, H. (1963). "Comparative Evaluation of Performance Using Multiple Criteria." *Management Science*, 9(3), 431-442.

The Business Roundtable (1982). "Improving Construction Safety Performance." *Report A-3, Construction Industry Cost Effectiveness Report*, pp 3-4, The Business Roundtable, NY, USA.

Vichas, R. P. (1982). *Complete Handbook of Profitable Marketing Research Techniques*, Prentice-Hall, NJ, USA, p521.

Vorster, M. (1997). "When the Lowest Tender Isn't the Lowest." *Construction in Southern Africa*, February, 37-43.

Walpole, R. E, Myers, R. H., Myers, S. L., and Ye, K. (2002). *Probabilities & Statistics for Engineers & Scientists*, Seventh Ed.., Prentice Hall, NJ, USA.

Weston, D. C., and Gibson, G. E. (1993). "Partnering-Project Performance in U. S. Army Corps of Engineers." *J. of Management in Engineering, ASCE,* 9(4), 410-425.

Winner, B. J., Brown, D., R. and Michels, K. M. (1991). *Statistical Principles in Experimental Design*, Third Ed., McGraw Hill, USA.

Wong, C. H., Holt, G. D., and Harris, P. (2001). "Multi-criteria Selection or Lowest Price? Investigation of UK Construction Clients' Tender Evaluation Preferences." *Engineering, Construction and Architectural Management,* 8(4), 257-241.

Zadeh, L. A. (1965). "Fuzzy Sets." *Information and Control*, 8, 338-353.

______ (1973). "The Concept of a Linguistic Variable and Its Application to Approximate Reasoning." ERL-M 411, Berkeley.

Zeleny, M. (1982). *Multiple Criteria Decision Making*, McGraw-Hill, NY.

Zimmerman, H. -J. (1985). *Fuzzy Set Theory – and Its Application,* Kluwer-Nijhoff Publishing, Hingham, MA.

APPENDIX A

Survey Form for Preliminary Interview

lege of Engineering
ol of Civil and Environmental Engineering

Nanyang
Technological University

survey form contains a list contractor selection criteria generally considered by construction :s or their representatives for assessing the contractors' capabilities to execute the project under deration. Please express your opinion as to whether the selected criteria are relevant in the context :al construction industry. If a particular criterion is relevant or important please tick it with (√) or wise mark with (X).

. Age of the company (contractor)	☐
. Type of ownership	☐
. Organization of the company	☐
. Origin of the company	☐
. Approximate annual contract value	☐
. Minimum contract value	☐
. Maximum contract value	☐
. Whether the contractor is unionized or nonunionized	☐
. Familiarity with regulating authorities	☐
0. Familiarity with local working culture	☐
1. Familiarity with geographical conditions	☐
2. Familiarity with weather conditions	☐
3. Familiarity with local labor	☐
4. Health and safety record of the company	☐
5. Achievement of quality level (e.g. ISO: 9000;14000)	☐
6. Quality system implementation	☐
7. Post-business attitude (e.g. claims and counter-claims)	☐
8. Past failure	☐
9. Type and scale of projects completed in past 3 (5) years	☐
0. Quality of works in past projects (e.g. CONQUAS rating)	☐
1. Percent of previous works completed on schedule	☐
2. Percent of previous works completed within budget	☐
3. Percent of previous works completed with own forces	☐
4. Standard of sub-contractors' works in past projects	☐
5. Attitude towards correcting faulty works	☐

5. Experience modification rating ☐
7. Familiarity with sub-contractors ☐
3. Relationship with sub-contractors ☐
9. Familiarity with suppliers ☐
0. Relationship with suppliers ☐
1. Line of credit from suppliers ☐
2. Credit rating by suppliers ☐
3. Relationship with regulating authorities ☐
4. Debarment and/or demerit points in past projects ☐
5. Current commitments ☐
6. Approximate percentage of works subcontracted in past 3 (5) projects ☐
7. Availability of resources for the project ☐
8. Authorized and paid-up capitals ☐
9. Working capital ☐
0. Current and fixed assets ☐
1. Current liabilities ☐
2. Total assets ☐
3. Net worth ☐
4. Turnover ☐
5. Earning before interest and taxes ☐
6. Profit generating ability of the company ☐
7. Quick ratio ☐
8. Capital structure of the company (amount of debt and equity) ☐
9. Finance arrangement ☐
0. Current banking organization ☐
1. Length of time in business with the current bank ☐
2. Line of credit from the bank ☐
3. Credit rating of the contractor ☐
4. Depth of experience on similar type of project ☐
5. Qualification and experience of management staffs ☐
6. Qualification and experience of technical staffs ☐
7. Man power resources ☐

8. Staff training program ☐
9. Availability of owned construction equipment ☐
0. Types of available equipment ☐
1. Models of available equipment ☐
2. Suitability of available equipment for this project ☐
3. Maintenance program of available equipment ☐
4. Equipment plan ☐
5. Materials procurement plan ☐
6. Materials management plan ☐
7. Housekeeping plan ☐
8. Project planning and control techniques ☐
9. Present workload and capability to support the current project ☐
0. Quality control and assurance program ☐
1. Specialized knowledge of particular construction method ☐
2. Construction method statement ☐
3. Proposed project time schedule ☐
4. Schedule control plan ☐
5. Budget control plan ☐
6. Contingency plan ☐
7. IT knowledge (e.g. risk management software) ☐
8. Location of home office relative job site ☐
9. Communication and transport methods from main office to job site ☐
0. Qualification and experience level of the project manager ☐
1. Qualification & experience of professional and technical staffs for this project ☐
2. No of years with the company ☐
3. Skill level of craftsmen ☐
4. Experience level of the project team on similar type of project ☐
5. Ability to deal with unanticipated surprises (e.g. risk management) ☐
6. Site organization ☐
7. Frequency of site meeting ☐
8. Communication procedure at site ☐
9. Interface of contractor with other parties to the contract ☐

). Number of direct workers available for the project ☐
. Availability of testing equipment as quality assurance ☐
2. Health and safety setup for the project ☐
3. Environmental impact awareness ☐
4. The contractor's cost and time saving considerations ☐
5. Method of reviewing drawings and change orders ☐
5. Method to manage conflict ☐
7. Risk sharing level of the project owner ☐
3. Prior relationship with the project owner ☐
). Reputation of sub-contractors to be used for the project ☐
)0. Type of performance bond (through bank or surety company) ☐
)1. Cash-out/payment schedule ☐
)2. References ☐

APPENDIX B

Questionnaire Survey Form

College of Engineering
School of Civil and Environmental Engineering

Nanyang
Technological University

24th June 2003

Dear Sir or Madam:

I am a Ph.D candidate at School of Civil and Environmental Engineering, Nanyang Technological University under the supervision of Associate Professor Robert Tiong. The objective of my research is to explore the existing contractor selection practices for design-bid-build projects in Singapore construction industry and to develop a decision support system for contractor selection process. To develop such a system I need to, with your kind co-operation and assistance, elicit the information regarding the current practices of tendering methods, the decision criteria used for tender evaluation and the criteria evaluation methods used by the construction project owners or their representatives for assessing the capabilities of the contractors to deliver the project successfully in terms of time, cost and quality standards so that the best value for money is achieved.

The attached questionnaire is designed in such a way that it takes less time for the respondent to answer the questions. The information provided by you will be treated with strict confidentiality.

In anticipation, I gratefully acknowledge your time and effort devoted for responding to the questionnaire.

Thanking you,

Yours sincerely,

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Block N1, # B4b-05, 50 Nanyang Avenue, Singapore 639798
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School of CEE, NTU

Part I. This part lists the various evaluation criteria, sub-criteria and their measures that are generally considered by the project owners or their representatives for assessing the contractors' capabilities to execute the project at hand. Please rate, by ticking appropriate one, based on your experience with contractor selection process, their relevance or degree of importance in assessing the contractors' capabilities to deliver the project at hand.

Scale	Meaning
IR	Particular criterion (measure) is **irrelevant** in assessing the contractors' capabilities
VL	It has **very low** importance in assessing the contractors' capabilities
L	It has **low** importance in assessing the contractors' capabilities
M	It has **medium** importance in assessing the contractors' capabilities
I	It is **important** in assessing the contractors' capabilities
VI	It is **very important** in assessing the contractors' capabilities

A	Contracting Company's Attributes	IR	VL	L	M	I	VI
1.	Age (experience) of the company (contractor)						
2.	Familiarity with regulating authorities						
3.	Familiarity with local working culture						
4.	Health and safety record of the company						
5.	Achievement of quality level (e.g. ISO: 9000;14000)						
6.	Post-business attitude (e.g., claims and counter-claims)						
7.	Past failure						
8.	Any other (Pls. Specify)						
9.							
10.							

B.	Past Performance of the Contractor	IR	VL	L	M	I	VI
1.	Type and scale of projects completed in past 3 (5) years						
2.	Quality of works in past projects (e.g. CONQUAS rating)						
3.	Percent of previous works completed on schedule						
4.	Standard of sub-contractors' works in past projects						
5.	Attitude towards correcting faulty works						
6.	Good relationship with past project owners						
7.	Relationship with sub-contractors						
8.	Relationship with suppliers						
9.	Relationship with regulating authorities						
10.	Debarment and/or demerit points in past projects						
11.	Any other (Pls. Specify)						
12.							
13.							

C.	Financial Capability of the Contractor	IR	VL	L	M	I	VI
1.	Current commitments						
2.	Authorized and paid-up capitals						
3.	Working capital						
4	Current and fixed assets						
5.	Net worth						
6	Turnover						
7.	Profit generating ability of the company						
8.	Liquidity status of the company						
9.	Capital structure of the company (amount of debt and equity)						
10.	Finance arrangement						
11.	Any other (Pls. Specify)						
12.							
13.							

D.	Performance Potential of the Contractor	IR	VL	L	M	I	VI
1.	Depth of experience on similar type of project						
2.	Qualification and experience of management staffs						
3.	Qualification and experience of technical staffs						
4.	Man power resources						
5.	Availability of owned construction equipment						
6.	Present workload and capability to support the current project						
7.	Quality control and assurance program						
8.	Specialized knowledge of particular construction method						
9.	Any other (Pls. Specify)						
10.							
11.							

E.	Project Specific Criteria	IR	VL	L	M	I	VI
1.	Construction method statement						
2.	Proposed project time schedule						
3.	Qualification and experience level of the project manager						
4.	Qualification & experience of professional and technical staffs						
5.	Experience level of the project team on similar type of project						
6.	Number of direct workers available for the project						
7.	Availability of testing equipment as quality assurance						
8.	Health and safety setup for the project						
9.	The Contractor's cost and time saving considerations						
10.	Risk sharing level of the project owner						
11.	Reputation of sub-contractors to be used for the project						
12.	Type of performance bond (through bank or surety company)						
13.	Cash-out/payment schedule						
14.	Any other (Pls. Specify)						
15.							
16.							

Part II. Which tendering method(s) does your organization generally use for the selection of the contractor for the construction projects? Please tick for your answer(s).

1. Open competitive tendering ☐
2. Invited/Selected tendering ☐
3. Negotiated tendering ☐
4. Partnering (client and contractor) ☐
5. Other (Pls. specify) ______________________________

Part III. Which of the following evaluation method(s) does your organization generally use in assessing the contractors' attributes during evaluation of tender? Please tick for your answer(s).

1. Binary (Dichotomous) method (e.g., Accepted / Rejected) ☐
2. Weighted evaluation (Point system) ☐
3. Qualitative evaluation (e.g., Good / Average / Poor) ☐
4. Multiple regression method ☐
5. Utility value method ☐
6. Any other method ______________________________

Part IV. Please assign the weight (0 - 100) to different criteria according to their importance as criteria for evaluation of the contractors' capabilities during contractor selection and bid evaluation process.

	Evaluation Criteria	**Importance Weight**
1.	Contracting company's attributes	
2.	Past performance of the contractor	
3.	Financial capability of the contractor to execute the project	
4.	Performance potential of the contractor	
5.	Project specific criteria	
6.	Tender price	
7.	Any other(Pls. Specify)	
8.	Any other(Pls. Specify)	
9.	Any other(Pls. Specify)	

College of Engineering

School of Civil and Environmental Engineering

Nanyang Technological University

Respondent's Name:

Designation and Years of Experience:

Name of the Company:

Address:

Tel: E-mail:

Recommendation (if any):

1. Kindly return the duly-filled survey form in the pre-addressed, -postage-paid envelop enclosed or fax back to 6791 6697[Attn: Robert Tiong], not later than **24 July 2003**.

2. Would you like to receive the copy of the analysis report?

•Yes •No.

Thank you very much for your time, effort and recommendation, if any.

APPENDIX C

Results from Statistical Analysis Tests

Table C1 Results of ANOVA Test

Criteria		Sum of Squares	df	Mean Square	F	Sig.
A1	Between Groups	2.850	2	1.425	1.616	.200
	Within Groups	402.933	457	.882		
	Total	405.783	459			
A2	Between Groups	61.262	2	30.631	27.225	.000
	Within Groups	514.170	457	1.125		
	Total	575.433	459			
A3	Between Groups	50.429	2	25.215	20.704	.000
	Within Groups	556.571	457	1.218		
	Total	607.000	459			
A4	Between Groups	1.314	2	.657	.783	.458
	Within Groups	383.510	457	.839		
	Total	384.824	459			
A5	Between Groups	.731	2	.366	.339	.713
	Within Groups	492.799	457	1.078		
	Total	493.530	459			
A6	Between Groups	33.850	2	16.925	20.571	.000
	Within Groups	376.011	457	.823		
	Total	409.861	459			
A7	Between Groups	14.957	2	7.479	8.069	.000
	Within Groups	423.554	457	.927		
	Total	438.511	459			
B1	Between Groups	2.659	2	1.329	2.394	.092
	Within Groups	253.732	457	.555		
	Total	256.391	459			
B2	Between Groups	2.557	2	1.278	1.524	.219
	Within Groups	383.409	457	.839		
	Total	385.965	459			
B3	Between Groups	1.551	2	.776	1.363	.257
	Within Groups	260.023	457	.569		
	Total	261.574	459			
B4	Between Groups	35.068	2	17.534	18.308	.000
	Within Groups	437.669	457	.958		
	Total	472.737	459			
B5	Between Groups	37.555	2	18.778	26.668	.000
	Within Groups	321.791	457	.704		
	Total	359.346	459			
B6	Between Groups	69.795	2	34.897	38.378	.000
	Within Groups	415.551	457	.909		
	Total	485.346	459			
B7	Between Groups	45.616	2	22.808	24.278	.000
	Within Groups	429.330	457	.939		
	Total	474.946	459			

All tests are significant at the 0.05 level.

Table C1 (Continued)

Criteria		Sum of Squares	df	Mean Square	F	Sig.
B8	Between Groups	38.879	2	19.440	18.141	.000
	Within Groups	489.719	457	1.072		
	Total	528.598	459			
B9	Between Groups	50.016	2	25.008	19.881	.000
	Within Groups	574.845	457	1.258		
	Total	624.861	459			
B10	Between Groups	10.273	2	5.137	6.864	.001
	Within Groups	341.988	457	.748		
	Total	352.261	459			
C1	Between Groups	7.123	2	3.562	6.066	.003
	Within Groups	268.309	457	.587		
	Total	275.433	459			
C2	Between Groups	1.598	2	.799	1.329	.266
	Within Groups	274.826	457	.601		
	Total	276.424	459			
C3	Between Groups	1.072	2	.536	.994	.371
	Within Groups	246.361	457	.539		
	Total	247.433	459			
C4	Between Groups	3.307	2	1.654	1.998	.137
	Within Groups	378.125	457	.827		
	Total	381.433	459			
C5	Between Groups	2.775	2	1.387	1.718	.181
	Within Groups	369.005	457	.807		
	Total	371.780	459			
C6	Between Groups	.237	2	.118	.161	.852
	Within Groups	336.754	457	.737		
	Total	336.991	459			
C7	Between Groups	.852	2	.426	.555	.575
	Within Groups	351.096	457	.768		
	Total	351.948	459			
C8	Between Groups	4.490	2	2.245	3.701	.025
	Within Groups	277.171	457	.607		
	Total	281.661	459			
C9	Between Groups	4.684	2	2.342	3.423	.033
	Within Groups	312.662	457	.684		
	Total	317.346	459			
C10	Between Groups	2.996	2	1.498	2.173	.115
	Within Groups	315.091	457	.689		
	Total	318.087	459			
D1	Between Groups	2.918	2	1.459	3.008	.050
	Within Groups	221.680	457	.485		
	Total	224.598	459			

All tests are significant at the 0.05 level.

Table C1 (Continued)

Criteria		Sum of Squares	df	Mean Square	F	Sig.
D2	Between Groups	.433	2	.216	.458	.633
	Within Groups	215.765	457	.472		
	Total	216.198	459			
D3	Between Groups	1.910	2	.955	1.913	.149
	Within Groups	228.200	457	.499		
	Total	230.111	459			
D4	Between Groups	4.634	2	2.317	4.406	.013
	Within Groups	240.363	457	.526		
	Total	244.998	459			
D5	Between Groups	1.654	2	.827	.846	.430
	Within Groups	447.093	457	.978		
	Total	448.748	459			
D6	Between Groups	11.694	2	5.847	9.143	.000
	Within Groups	292.254	457	.640		
	Total	303.948	459			
D7	Between Groups	24.410	2	12.205	19.606	.000
	Within Groups	284.483	457	.623		
	Total	308.893	459			
D8	Between Groups	4.733	2	2.367	4.222	.015
	Within Groups	256.160	457	.561		
	Total	260.893	459			
E1	Between Groups	.239	2	.120	.153	.858
	Within Groups	357.141	457	.781		
	Total	357.380	459			
E2	Between Groups	.021	2	.010	.019	.981
	Within Groups	252.023	457	.551		
	Total	252.043	459			
E3	Between Groups	10.636	2	5.318	9.995	.000
	Within Groups	243.145	457	.532		
	Total	253.780	459			
E4	Between Groups	12.863	2	6.432	12.901	.000
	Within Groups	227.824	457	.499		
	Total	240.687	459			
E5	Between Groups	22.028	2	11.014	20.708	.000
	Within Groups	243.067	457	.532		
	Total	265.096	459			
E6	Between Groups	4.104	2	2.052	2.342	.097
	Within Groups	400.442	457	.876		
	Total	404.546	459			
E7	Between Groups	5.369	2	2.685	3.315	.037
	Within Groups	370.074	457	.810		
	Total	375.443	459			

All tests are significant at the 0.05 level.

Table C1 (Continued)

Criteria		Sum of Squares	df	Mean Square	F	Sig.
E8	Between Groups	5.440	2	2.720	3.049	.048
	Within Groups	407.725	457	.892		
	Total	413.165	459			
E9	Between Groups	14.831	2	7.416	9.945	.000
	Within Groups	340.769	457	.746		
	Total	355.600	459			
E10	Between Groups	23.889	2	11.944	11.566	.000
	Within Groups	469.904	455	1.033		
	Total	493.793	457			
E11	Between Groups	15.026	2	7.513	8.549	.000
	Within Groups	401.607	457	.879		
	Total	416.633	459			
E12	Between Groups	19.915	2	9.957	8.325	.000
	Within Groups	546.596	457	1.196		
	Total	566.511	459			
E13	Between Groups	66.871	2	33.436	32.923	.000
	Within Groups	464.109	457	1.016		
	Total	530.980	459			

All tests are significant at the 0.05 level.

Table C2 Results of *Kruskal-Wallis* Test

	A1	A2	A3	A4	A5	A6	A7
Chi-Square	5.997	53.785	42.344	3.172	.695	36.224	9.376
df	2	2	2	2	2	2	2
Asymp. Sig.	.050	.000	.000	.205	.706	.000	.009

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Chi-Square	5.239	2.364	4.171	31.219	36.093	61.364	37.837	28.292	32.037	10.860
df	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.073	.307	.124	.000	.000	.000	.000	.000	.000	.004

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Chi-Square	11.037	2.016	2.806	2.670	.779	.656	1.746	9.642	5.814	2.225
df	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.004	.365	.246	.263	.677	.720	.418	.008	.055	.329

	D1	D2	D3	D4	D5	D6	D7	D8
Chi-Square	9.276	.789	3.769	8.958	1.653	16.704	40.338	9.429
df	2	2	2	2	2	2	2	2
Asymp. Sig.	.010	.674	.152	.011	.438	.000	.000	.009

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13
Chi-Square	1.998	.951	16.597	26.190	39.166	7.134	9.488	5.096	21.958	11.929	24.332	8.686	48.205
df	2	2	2	2	2	2	2	2	2	2	2	2	2
Asymp. Sig.	.368	.621	.000	.000	.000	.028	.009	.078	.000	.003	.000	.013	.000

Grouping Variable: Respondents
All tests are significant at the 0.05 level.

Table C3 Results of *Dunnett T3* Test

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
A1	Pub. Sec. Clients	Priv. Sec. Clients	-.10	.122	.802	-.44	.24
		Contractors	.09	.129	.867	-.27	.45
	Priv. Sec. Clients	Pub. Sec. Clients	.10	.122	.802	-.24	.44
		Contractors	.19	.095	.137	-.08	.45
	Contractors	Pub. Sec. Clients	-.09	.129	.867	-.45	.27
		Priv. Sec. Clients	-.19	.095	.137	-.45	.08
A2	Pub. Sec. Clients	Priv. Sec. Clients	-.90(*)	.136	.000	-1.28	-.52
		Contractors	-.47(*)	.154	.008	-.90	-.04
	Priv. Sec. Clients	Pub. Sec. Clients	.90(*)	.136	.000	.52	1.28
		Contractors	.43(*)	.116	.001	.11	.75
	Contractors	Pub. Sec. Clients	.47(*)	.154	.008	.04	.90
		Priv. Sec. Clients	-.43(*)	.116	.001	-.75	-.11
A3	Pub. Sec. Clients	Priv. Sec. Clients	-.83(*)	.127	.000	-1.18	-.47
		Contractors	-.68(*)	.155	.000	-1.12	-.25
	Priv. Sec. Clients	Pub. Sec. Clients	.83(*)	.127	.000	.47	1.18
		Contractors	.14	.131	.622	-.22	.51
	Contractors	Pub. Sec. Clients	.68(*)	.155	.000	.25	1.12
		Priv. Sec. Clients	-.14	.131	.622	-.51	.22
A4	Pub. Sec. Clients	Priv. Sec. Clients	-.08	.103	.813	-.37	.21
		Contractors	-.16	.126	.514	-.51	.19
	Priv. Sec. Clients	Pub. Sec. Clients	.08	.103	.813	-.21	.37
		Contractors	-.08	.110	.869	-.38	.23
	Contractors	Pub. Sec. Clients	.16	.126	.514	-.19	.51
		Priv. Sec. Clients	.08	.110	.869	-.23	.38
A5	Pub. Sec. Clients	Priv. Sec. Clients	.05	.121	.966	-.29	.39
		Contractors	.12	.136	.778	-.26	.50
	Priv. Sec. Clients	Pub. Sec. Clients	-.05	.121	.966	-.39	.29
		Contractors	.07	.116	.921	-.26	.39
	Contractors	Pub. Sec. Clients	-.12	.136	.778	-.50	.26
		Priv. Sec. Clients	-.07	.116	.921	-.39	.26
A6	Pub. Sec. Clients	Priv. Sec. Clients	-.66(*)	.112	.000	-.98	-.35
		Contractors	-.31	.141	.081	-.70	.08
	Priv. Sec. Clients	Pub. Sec. Clients	.66(*)	.112	.000	.35	.98
		Contractors	.35(*)	.111	.005	.04	.66
	Contractors	Pub. Sec. Clients	.31	.141	.081	-.08	.70
		Priv. Sec. Clients	-.35(*)	.111	.005	-.66	-.04
A7	Pub. Sec. Clients	Priv. Sec. Clients	-.18	.103	.231	-.47	.11
		Contractors	.26	.148	.220	-.15	.68
	Priv. Sec. Clients	Pub. Sec. Clients	.18	.103	.231	-.11	.47
		Contractors	.44(*)	.130	.003	.07	.81
	Contractors	Pub. Sec. Clients	-.26	.148	.220	-.68	.15
		Priv. Sec. Clients	-.44(*)	.130	.003	-.81	-.07

* The mean difference is significant at the 0.017 level.

Table C3 (Continued)

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
B1	Pub. Sec. Clients	Priv. Sec. Clients	-.18	.088	.129	-.42	.07
		Contractors	-.06	.105	.929	-.35	.24
	Priv. Sec. Clients	Pub. Sec. Clients	.18	.088	.129	-.07	.42
		Contractors	.12	.087	.423	-.12	.36
	Contractors	Pub. Sec. Clients	.06	.105	.929	-.24	.35
		Priv. Sec. Clients	-.12	.087	.423	-.36	.12
B2	Pub. Sec. Clients	Priv. Sec. Clients	-.19	.119	.312	-.52	.15
		Contractors	-.14	.131	.614	-.51	.22
	Priv. Sec. Clients	Pub. Sec. Clients	.19	.119	.312	-.15	.52
		Contractors	.04	.097	.960	-.23	.31
	Contractors	Pub. Sec. Clients	.14	.131	.614	-.22	.51
		Priv. Sec. Clients	-.04	.097	.960	-.31	.23
B3	Pub. Sec. Clients	Priv. Sec. Clients	-.14	.084	.271	-.37	.10
		Contractors	-.14	.111	.499	-.45	.17
	Priv. Sec. Clients	Pub. Sec. Clients	.14	.084	.271	-.10	.37
		Contractors	.00	.096	1.000	-.27	.27
	Contractors	Pub. Sec. Clients	.14	.111	.499	-.17	.45
		Priv. Sec. Clients	.00	.096	1.000	-.27	.27
B4	Pub. Sec. Clients	Priv. Sec. Clients	-.67(*)	.134	.000	-1.05	-.30
		Contractors	-.64(*)	.152	.000	-1.06	-.21
	Priv. Sec. Clients	Pub. Sec. Clients	.67(*)	.134	.000	.30	1.05
		Contractors	.04	.106	.978	-.26	.33
	Contractors	Pub. Sec. Clients	.64(*)	.152	.000	.21	1.06
		Priv. Sec. Clients	-.04	.106	.978	-.33	.26
B5	Pub. Sec. Clients	Priv. Sec. Clients	-.72(*)	.117	.000	-1.04	-.39
		Contractors	-.56(*)	.139	.000	-.95	-.17
	Priv. Sec. Clients	Pub. Sec. Clients	.72(*)	.117	.000	.39	1.04
		Contractors	.16	.096	.290	-.11	.43
	Contractors	Pub. Sec. Clients	.56(*)	.139	.000	.17	.95
		Priv. Sec. Clients	-.16	.096	.290	-.43	.11
B6	Pub. Sec. Clients	Priv. Sec. Clients	-.93(*)	.125	.000	-1.28	-.58
		Contractors	-.95(*)	.139	.000	-1.34	-.56
	Priv. Sec. Clients	Pub. Sec. Clients	.93(*)	.125	.000	.58	1.28
		Contractors	-.02	.101	.997	-.30	.27
	Contractors	Pub. Sec. Clients	.95(*)	.139	.000	.56	1.34
		Priv. Sec. Clients	.02	.101	.997	-.27	.30
B7	Pub. Sec. Clients	Priv. Sec. Clients	-.79(*)	.129	.000	-1.15	-.43
		Contractors	-.49(*)	.153	.005	-.91	-.06
	Priv. Sec. Clients	Pub. Sec. Clients	.79(*)	.129	.000	.43	1.15
		Contractors	.30	.111	.022	-.01	.61
	Contractors	Pub. Sec. Clients	.49(*)	.153	.005	.06	.91
		Priv. Sec. Clients	-.30	.111	.022	-.61	.01

* The mean difference is significant at the 0.017 level.

Table C3 (Continued)

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
B8	Pub. Sec. Clients	Priv. Sec. Clients	-.72(*)	.138	.000	-1.10	-.33
		Contractors	-.64(*)	.158	.000	-1.08	-.20
	Priv. Sec. Clients	Pub. Sec. Clients	.72(*)	.138	.000	.33	1.10
		Contractors	.08	.114	.875	-.24	.40
	Contractors	Pub. Sec. Clients	.64(*)	.158	.000	.20	1.08
		Priv. Sec. Clients	-.08	.114	.875	-.40	.24
B9	Pub. Sec. Clients	Priv. Sec. Clients	-.75(*)	.143	.000	-1.15	-.35
		Contractors	-.86(*)	.157	.000	-1.30	-.42
	Priv. Sec. Clients	Pub. Sec. Clients	.75(*)	.143	.000	.35	1.15
		Contractors	-.10	.120	.768	-.44	.23
	Contractors	Pub. Sec. Clients	.86(*)	.157	.000	.42	1.30
		Priv. Sec. Clients	.10	.120	.768	-.23	.44
B10	Pub. Sec. Clients	Priv. Sec. Clients	.20	.091	.096	-.06	.45
		Contractors	.44(*)	.133	.004	.07	.81
	Priv. Sec. Clients	Pub. Sec. Clients	-.20	.091	.096	-.45	.06
		Contractors	.24	.118	.121	-.09	.57
	Contractors	Pub. Sec. Clients	-.44(*)	.133	.004	-.81	-.07
		Priv. Sec. Clients	-.24	.118	.121	-.57	.09
C1	Pub. Sec. Clients	Priv. Sec. Clients	.30(*)	.086	.002	.06	.55
		Contractors	.14	.096	.357	-.13	.41
	Priv. Sec. Clients	Pub. Sec. Clients	-.30(*)	.086	.002	-.55	-.06
		Contractors	-.16	.085	.172	-.40	.08
	Contractors	Pub. Sec. Clients	-.14	.096	.357	-.41	.13
		Priv. Sec. Clients	.16	.085	.172	-.08	.40
C2	Pub. Sec. Clients	Priv. Sec. Clients	.11	.078	.395	-.11	.33
		Contractors	.17	.101	.257	-.11	.45
	Priv. Sec. Clients	Pub. Sec. Clients	-.11	.078	.395	-.33	.11
		Contractors	.06	.097	.904	-.21	.33
	Contractors	Pub. Sec. Clients	-.17	.101	.257	-.45	.11
		Priv. Sec. Clients	-.06	.097	.904	-.33	.21
C3	Pub. Sec. Clients	Priv. Sec. Clients	-.11	.083	.446	-.34	.12
		Contractors	-.12	.107	.576	-.42	.18
	Priv. Sec. Clients	Pub. Sec. Clients	.11	.083	.446	-.12	.34
		Contractors	-.01	.092	.999	-.27	.24
	Contractors	Pub. Sec. Clients	.12	.107	.576	-.18	.42
		Priv. Sec. Clients	.01	.092	.999	-.24	.27
C4	Pub. Sec. Clients	Priv. Sec. Clients	-.17	.097	.210	-.44	.10
		Contractors	-.01	.127	1.000	-.36	.35
	Priv. Sec. Clients	Pub. Sec. Clients	.17	.097	.210	-.10	.44
		Contractors	.17	.114	.374	-.15	.49
	Contractors	Pub. Sec. Clients	.01	.127	1.000	-.35	.36
		Priv. Sec. Clients	-.17	.114	.374	-.49	.15

* The mean difference is significant at the 0.017 level.

Table C3 (Continued)

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
C5	Pub. Sec. Clients	Priv. Sec. Clients	-.04	.084	.954	-.27	.20
		Contractors	.15	.127	.554	-.20	.50
	Priv. Sec. Clients	Pub. Sec. Clients	.04	.084	.954	-.20	.27
		Contractors	.19	.122	.323	-.15	.53
	Contractors	Pub. Sec. Clients	-.15	.127	.554	-.50	.20
		Priv. Sec. Clients	-.19	.122	.323	-.53	.15
C6	Pub. Sec. Clients	Priv. Sec. Clients	.04	.081	.937	-.18	.27
		Contractors	.07	.113	.915	-.25	.38
	Priv. Sec. Clients	Pub. Sec. Clients	-.04	.081	.937	-.27	.18
		Contractors	.02	.111	.995	-.29	.34
	Contractors	Pub. Sec. Clients	-.07	.113	.915	-.38	.25
		Priv. Sec. Clients	-.02	.111	.995	-.34	.29
C7	Pub. Sec. Clients	Priv. Sec. Clients	.03	.103	.991	-.26	.32
		Contractors	.12	.125	.726	-.23	.47
	Priv. Sec. Clients	Pub. Sec. Clients	-.03	.103	.991	-.32	.26
		Contractors	.09	.104	.773	-.20	.38
	Contractors	Pub. Sec. Clients	-.12	.125	.726	-.47	.23
		Priv. Sec. Clients	-.09	.104	.773	-.38	.20
C8	Pub. Sec. Clients	Priv. Sec. Clients	-.05	.082	.900	-.28	.18
		Contractors	.19	.098	.151	-.08	.46
	Priv. Sec. Clients	Pub. Sec. Clients	.05	.082	.900	-.18	.28
		Contractors	.24	.091	.026	-.01	.50
	Contractors	Pub. Sec. Clients	-.19	.098	.151	-.46	.08
		Priv. Sec. Clients	-.24	.091	.026	-.50	.01
C9	Pub. Sec. Clients	Priv. Sec. Clients	-.03	.096	.980	-.30	.23
		Contractors	.21	.114	.186	-.11	.53
	Priv. Sec. Clients	Pub. Sec. Clients	.03	.096	.980	-.23	.30
		Contractors	.24	.097	.037	-.03	.51
	Contractors	Pub. Sec. Clients	-.21	.114	.186	-.53	.11
		Priv. Sec. Clients	-.24	.097	.037	-.51	.03
C10	Pub. Sec. Clients	Priv. Sec. Clients	-.19	.115	.272	-.51	.13
		Contractors	-.07	.124	.934	-.41	.28
	Priv. Sec. Clients	Pub. Sec. Clients	.19	.115	.272	-.13	.51
		Contractors	.12	.084	.371	-.11	.36
	Contractors	Pub. Sec. Clients	.07	.124	.934	-.28	.41
		Priv. Sec. Clients	-.12	.084	.371	-.36	.11
D1	Pub. Sec. Clients	Priv. Sec. Clients	.01	.079	.998	-.21	.24
		Contractors	.20	.090	.089	-.06	.45
	Priv. Sec. Clients	Pub. Sec. Clients	-.01	.079	.998	-.24	.21
		Contractors	.18	.078	.059	-.04	.40
	Contractors	Pub. Sec. Clients	-.20	.090	.089	-.45	.06
		Priv. Sec. Clients	-.18	.078	.059	-.40	.04

* The mean difference is significant at the 0.017 level.

Table C3 (Continued)

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
D2	Pub. Sec. Clients	Priv. Sec. Clients	-.03	.079	.965	-.25	.19
		Contractors	.04	.095	.963	-.22	.31
	Priv. Sec. Clients	Pub. Sec. Clients	.03	.079	.965	-.19	.25
		Contractors	.07	.081	.732	-.15	.30
	Contractors	Pub. Sec. Clients	-.04	.095	.963	-.31	.22
		Priv. Sec. Clients	-.07	.081	.732	-.30	.15
D3	Pub. Sec. Clients	Priv. Sec. Clients	-.16	.082	.171	-.39	.08
		Contractors	-.07	.102	.884	-.35	.22
	Priv. Sec. Clients	Pub. Sec. Clients	.16	.082	.171	-.08	.39
		Contractors	.09	.085	.658	-.15	.33
	Contractors	Pub. Sec. Clients	.07	.102	.884	-.22	.35
		Priv. Sec. Clients	-.09	.085	.658	-.33	.15
D4	Pub. Sec. Clients	Priv. Sec. Clients	.18	.084	.090	-.05	.41
		Contractors	.29(*)	.092	.006	.03	.55
	Priv. Sec. Clients	Pub. Sec. Clients	-.18	.084	.090	-.41	.05
		Contractors	.11	.080	.425	-.11	.33
	Contractors	Pub. Sec. Clients	-.29(*)	.092	.006	-.55	-.03
		Priv. Sec. Clients	-.11	.080	.425	-.33	.11
D5	Pub. Sec. Clients	Priv. Sec. Clients	.06	.102	.909	-.22	.35
		Contractors	.17	.129	.458	-.19	.53
	Priv. Sec. Clients	Pub. Sec. Clients	-.06	.102	.909	-.35	.22
		Contractors	.11	.121	.741	-.23	.45
	Contractors	Pub. Sec. Clients	-.17	.129	.458	-.53	.19
		Priv. Sec. Clients	-.11	.121	.741	-.45	.23
D6	Pub. Sec. Clients	Priv. Sec. Clients	-.10	.090	.615	-.35	.15
		Contractors	.29	.113	.032	-.02	.61
	Priv. Sec. Clients	Pub. Sec. Clients	.10	.090	.615	-.15	.35
		Contractors	.39(*)	.097	.000	.12	.66
	Contractors	Pub. Sec. Clients	-.29	.113	.032	-.61	.02
		Priv. Sec. Clients	-.39(*)	.097	.000	-.66	-.12
D7	Pub. Sec. Clients	Priv. Sec. Clients	-.51(*)	.077	.000	-.72	-.29
		Contractors	-.10	.113	.749	-.42	.21
	Priv. Sec. Clients	Pub. Sec. Clients	.51(*)	.077	.000	.29	.72
		Contractors	.41(*)	.106	.001	.11	.71
	Contractors	Pub. Sec. Clients	.10	.113	.749	-.21	.42
		Priv. Sec. Clients	-.41(*)	.106	.001	-.71	-.11
D8	Pub. Sec. Clients	Priv. Sec. Clients	-.20	.086	.068	-.44	.04
		Contractors	.01	.103	.999	-.28	.30
	Priv. Sec. Clients	Pub. Sec. Clients	.20	.086	.068	-.04	.44
		Contractors	.21	.087	.053	-.04	.45
	Contractors	Pub. Sec. Clients	-.01	.103	.999	-.30	.28
		Priv. Sec. Clients	-.21	.087	.053	-.45	.04

* The mean difference is significant at the 0.017 level.

Table C3 (Continued)

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
E1	Pub. Sec. Clients	Priv. Sec. Clients	-.06	.092	.905	-.31	.20
		Contractors	-.03	.120	.995	-.36	.31
	Priv. Sec. Clients	Pub. Sec. Clients	.06	.092	.905	-.20	.31
		Contractors	.03	.111	.991	-.28	.34
	Contractors	Pub. Sec. Clients	.03	.120	.995	-.31	.36
		Priv. Sec. Clients	-.03	.111	.991	-.34	.28
E2	Pub. Sec. Clients	Priv. Sec. Clients	.02	.079	.995	-.21	.24
		Contractors	.01	.111	.999	-.30	.33
	Priv. Sec. Clients	Pub. Sec. Clients	-.02	.079	.995	-.24	.21
		Contractors	.00	.098	1.000	-.28	.27
	Contractors	Pub. Sec. Clients	-.01	.111	.999	-.33	.30
		Priv. Sec. Clients	.00	.098	1.000	-.27	.28
E3	Pub. Sec. Clients	Priv. Sec. Clients	-.27(*)	.086	.006	-.51	-.03
		Contractors	.06	.112	.939	-.25	.37
	Priv. Sec. Clients	Pub. Sec. Clients	.27(*)	.086	.006	.03	.51
		Contractors	.33(*)	.091	.001	.07	.59
	Contractors	Pub. Sec. Clients	-.06	.112	.939	-.37	.25
		Priv. Sec. Clients	-.33(*)	.091	.001	-.59	-.07
E4	Pub. Sec. Clients	Priv. Sec. Clients	-.37(*)	.080	.000	-.59	-.15
		Contractors	-.07	.098	.859	-.34	.20
	Priv. Sec. Clients	Pub. Sec. Clients	.37(*)	.080	.000	.15	.59
		Contractors	.30(*)	.085	.002	.06	.54
	Contractors	Pub. Sec. Clients	.07	.098	.859	-.20	.34
		Priv. Sec. Clients	-.30(*)	.085	.002	-.54	-.06
E5	Pub. Sec. Clients	Priv. Sec. Clients	-.35(*)	.087	.000	-.59	-.10
		Contractors	.15	.103	.364	-.14	.44
	Priv. Sec. Clients	Pub. Sec. Clients	.35(*)	.087	.000	.10	.59
		Contractors	.50(*)	.084	.000	.27	.73
	Contractors	Pub. Sec. Clients	-.15	.103	.364	-.44	.14
		Priv. Sec. Clients	-.50(*)	.084	.000	-.73	-.27
E6	Pub. Sec. Clients	Priv. Sec. Clients	.12	.108	.601	-.18	.42
		Contractors	.28	.121	.070	-.06	.61
	Priv. Sec. Clients	Pub. Sec. Clients	-.12	.108	.601	-.42	.18
		Contractors	.15	.103	.357	-.13	.44
	Contractors	Pub. Sec. Clients	-.28	.121	.070	-.61	.06
		Priv. Sec. Clients	-.15	.103	.357	-.44	.13
E7	Pub. Sec. Clients	Priv. Sec. Clients	-.24	.103	.059	-.53	.05
		Contractors	-.05	.121	.962	-.39	.29
	Priv. Sec. Clients	Pub. Sec. Clients	.24	.103	.059	-.05	.53
		Contractors	.19	.104	.201	-.10	.48
	Contractors	Pub. Sec. Clients	.05	.121	.962	-.29	.39
		Priv. Sec. Clients	-.19	.104	.201	-.48	.10

* The mean difference is significant at the 0.017 level.

Table C3 (Continued)

Dunnett T3: Multiple Comparisons (Equal variance not assumed)

Dependent Variable	(I) RESPONDENT	(J) RESPONDENT	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
E8	Pub. Sec. Clients	Priv. Sec. Clients	.26	.103	.034	-.03	.55
		Contractors	.11	.125	.769	-.24	.46
	Priv. Sec. Clients	Pub. Sec. Clients	-.26	.103	.034	-.55	.03
		Contractors	-.15	.113	.442	-.47	.16
	Contractors	Pub. Sec. Clients	-.11	.125	.769	-.46	.24
		Priv. Sec. Clients	.15	.113	.442	-.16	.47
E9	Pub. Sec. Clients	Priv. Sec. Clients	-.45(*)	.098	.000	-.73	-.18
		Contractors	-.34(*)	.113	.008	-.66	-.03
	Priv. Sec. Clients	Pub. Sec. Clients	.45(*)	.098	.000	.18	.73
		Contractors	.11	.098	.621	-.17	.38
	Contractors	Pub. Sec. Clients	.34(*)	.113	.008	.03	.66
		Priv. Sec. Clients	-.11	.098	.621	-.38	.17
E10	Pub. Sec. Clients	Priv. Sec. Clients	-.50(*)	.147	.003	-.91	-.09
		Contractors	-.58(*)	.156	.001	-1.02	-.15
	Priv. Sec. Clients	Pub. Sec. Clients	.50(*)	.147	.003	.09	.91
		Contractors	-.09	.102	.788	-.37	.20
	Contractors	Pub. Sec. Clients	.58(*)	.156	.001	.15	1.02
		Priv. Sec. Clients	.09	.102	.788	-.20	.37
E11	Pub. Sec. Clients	Priv. Sec. Clients	-.45(*)	.104	.000	-.74	-.17
		Contractors	-.32	.128	.044	-.67	.04
	Priv. Sec. Clients	Pub. Sec. Clients	.45(*)	.104	.000	.17	.74
		Contractors	.14	.113	.521	-.18	.46
	Contractors	Pub. Sec. Clients	.32	.128	.044	-.04	.67
		Priv. Sec. Clients	-.14	.113	.521	-.46	.18
E12	Pub. Sec. Clients	Priv. Sec. Clients	-.51(*)	.156	.004	-.95	-.07
		Contractors	-.24	.173	.430	-.72	.25
	Priv. Sec. Clients	Pub. Sec. Clients	.51(*)	.156	.004	.07	.95
		Contractors	.27	.113	.052	-.05	.59
	Contractors	Pub. Sec. Clients	.24	.173	.430	-.25	.72
		Priv. Sec. Clients	-.27	.113	.052	-.59	.05
E13	Pub. Sec. Clients	Priv. Sec. Clients	-.85(*)	.140	.000	-1.25	-.46
		Contractors	-1.01(*)	.158	.000	-1.45	-.57
	Priv. Sec. Clients	Pub. Sec. Clients	.85(*)	.140	.000	.46	1.25
		Contractors	-.15	.108	.402	-.45	.15
	Contractors	Pub. Sec. Clients	1.01(*)	.158	.000	.57	1.45
		Priv. Sec. Clients	.15	.108	.402	-.15	.45

* The mean difference is significant at the 0.017 level.

Table C4 Results of *Bonferroni* Tests

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
A1	Pub. Sec. Clients	Priv. Sec. Clients	-.10	.110	1.000	-.41	.21
		Contractors	.09	.128	1.000	-.27	.45
	Priv. Sec. Clients	Pub. Sec. Clients	.10	.110	1.000	-.21	.41
		Contractors	.19	.107	.239	-.11	.49
	Contractors	Pub. Sec. Clients	-.09	.128	1.000	-.45	.27
		Priv. Sec. Clients	-.19	.107	.239	-.49	.11
A2	Pub. Sec. Clients	Priv. Sec. Clients	-.90(*)	.124	.000	-1.25	-.56
		Contractors	-.47(*)	.145	.004	-.87	-.07
	Priv. Sec. Clients	Pub. Sec. Clients	.90(*)	.124	.000	.56	1.25
		Contractors	.43(*)	.121	.001	.09	.77
	Contractors	Pub. Sec. Clients	.47(*)	.145	.004	.07	.87
		Priv. Sec. Clients	-.43(*)	.121	.001	-.77	-.09
A3	Pub. Sec. Clients	Priv. Sec. Clients	-.83(*)	.130	.000	-1.19	-.47
		Contractors	-.68(*)	.151	.000	-1.10	-.26
	Priv. Sec. Clients	Pub. Sec. Clients	.83(*)	.130	.000	.47	1.19
		Contractors	.14	.126	.774	-.21	.49
	Contractors	Pub. Sec. Clients	.68(*)	.151	.000	.26	1.10
		Priv. Sec. Clients	-.14	.126	.774	-.49	.21
A4	Pub. Sec. Clients	Priv. Sec. Clients	-.08	.108	1.000	-.38	.22
		Contractors	-.16	.125	.634	-.51	.19
	Priv. Sec. Clients	Pub. Sec. Clients	.08	.108	1.000	-.22	.38
		Contractors	-.08	.105	1.000	-.37	.22
	Contractors	Pub. Sec. Clients	.16	.125	.634	-.19	.51
		Priv. Sec. Clients	.08	.105	1.000	-.22	.37
A5	Pub. Sec. Clients	Priv. Sec. Clients	.05	.122	1.000	-.29	.39
		Contractors	.12	.142	1.000	-.28	.51
	Priv. Sec. Clients	Pub. Sec. Clients	-.05	.122	1.000	-.39	.29
		Contractors	.07	.119	1.000	-.26	.40
	Contractors	Pub. Sec. Clients	-.12	.142	1.000	-.51	.28
		Priv. Sec. Clients	-.07	.119	1.000	-.40	.26
A6	Pub. Sec. Clients	Priv. Sec. Clients	-.66(*)	.106	.000	-.96	-.37
		Contractors	-.31	.124	.037	-.66	.03
	Priv. Sec. Clients	Pub. Sec. Clients	.66(*)	.106	.000	.37	.96
		Contractors	.35(*)	.104	.002	.06	.64
	Contractors	Pub. Sec. Clients	.31	.124	.037	-.03	.66
		Priv. Sec. Clients	-.35(*)	.104	.002	-.64	-.06
A7	Pub. Sec. Clients	Priv. Sec. Clients	-.18	.113	.342	-.49	.14
		Contractors	.26	.132	.144	-.10	.63
	Priv. Sec. Clients	Pub. Sec. Clients	.18	.113	.342	-.14	.49
		Contractors	.44(*)	.110	.000	.13	.75
	Contractors	Pub. Sec. Clients	-.26	.132	.144	-.63	.10
		Priv. Sec. Clients	-.44(*)	.110	.000	-.75	-.13

* The mean difference is significant at the 0.017 level.

Table C4 (Continued)

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
B1	Pub. Sec. Clients	Priv. Sec. Clients	-.18	.087	.131	-.42	.07
		Contractors	-.06	.102	1.000	-.34	.23
	Priv. Sec. Clients	Pub. Sec. Clients	.18	.087	.131	-.07	.42
		Contractors	.12	.085	.478	-.12	.36
	Contractors	Pub. Sec. Clients	.06	.102	1.000	-.23	.34
		Priv. Sec. Clients	-.12	.085	.478	-.36	.12
B2	Pub. Sec. Clients	Priv. Sec. Clients	-.19	.107	.247	-.49	.11
		Contractors	-.14	.125	.751	-.49	.20
	Priv. Sec. Clients	Pub. Sec. Clients	.19	.107	.247	-.11	.49
		Contractors	.04	.105	1.000	-.25	.33
	Contractors	Pub. Sec. Clients	.14	.125	.751	-.20	.49
		Priv. Sec. Clients	-.04	.105	1.000	-.33	.25
B3	Pub. Sec. Clients	Priv. Sec. Clients	-.14	.089	.354	-.38	.11
		Contractors	-.14	.103	.520	-.43	.15
	Priv. Sec. Clients	Pub. Sec. Clients	.14	.089	.354	-.11	.38
		Contractors	.00	.086	1.000	-.24	.24
	Contractors	Pub. Sec. Clients	.14	.103	.520	-.15	.43
		Priv. Sec. Clients	.00	.086	1.000	-.24	.24
B4	Pub. Sec. Clients	Priv. Sec. Clients	-.67(*)	.115	.000	-.99	-.35
		Contractors	-.64(*)	.134	.000	-1.01	-.26
	Priv. Sec. Clients	Pub. Sec. Clients	.67(*)	.115	.000	.35	.99
		Contractors	.04	.112	1.000	-.27	.35
	Contractors	Pub. Sec. Clients	.64(*)	.134	.000	.26	1.01
		Priv. Sec. Clients	-.04	.112	1.000	-.35	.27
B5	Pub. Sec. Clients	Priv. Sec. Clients	-.72(*)	.098	.000	-.99	-.44
		Contractors	-.56(*)	.115	.000	-.88	-.24
	Priv. Sec. Clients	Pub. Sec. Clients	.72(*)	.098	.000	.44	.99
		Contractors	.16	.096	.315	-.11	.42
	Contractors	Pub. Sec. Clients	.56(*)	.115	.000	.24	.88
		Priv. Sec. Clients	-.16	.096	.315	-.42	.11
B6	Pub. Sec. Clients	Priv. Sec. Clients	-.93(*)	.112	.000	-1.24	-.62
		Contractors	-.95(*)	.130	.000	-1.31	-.58
	Priv. Sec. Clients	Pub. Sec. Clients	.93(*)	.112	.000	.62	1.24
		Contractors	-.02	.109	1.000	-.32	.28
	Contractors	Pub. Sec. Clients	.95(*)	.130	.000	.58	1.31
		Priv. Sec. Clients	.02	.109	1.000	-.28	.32
B7	Pub. Sec. Clients	Priv. Sec. Clients	-.79(*)	.114	.000	-1.11	-.47
		Contractors	-.49(*)	.133	.001	-.86	-.12
	Priv. Sec. Clients	Pub. Sec. Clients	.79(*)	.114	.000	.47	1.11
		Contractors	.30	.111	.021	-.01	.61
	Contractors	Pub. Sec. Clients	.49(*)	.133	.001	.12	.86
		Priv. Sec. Clients	-.30	.111	.021	-.61	.01

* The mean difference is significant at the 0.017 level.

Table C4 (Continued)

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
B8	Pub. Sec. Clients	Priv. Sec. Clients	-.72(*)	.121	.000	-1.05	-.38
		Contractors	-.64(*)	.142	.000	-1.03	-.25
	Priv. Sec. Clients	Pub. Sec. Clients	.72(*)	.121	.000	.38	1.05
		Contractors	.08	.118	1.000	-.25	.41
	Contractors	Pub. Sec. Clients	.64(*)	.142	.000	.25	1.03
		Priv. Sec. Clients	-.08	.118	1.000	-.41	.25
B9	Pub. Sec. Clients	Priv. Sec. Clients	-.75(*)	.132	.000	-1.12	-.39
		Contractors	-.86(*)	.153	.000	-1.28	-.43
	Priv. Sec. Clients	Pub. Sec. Clients	.75(*)	.132	.000	.39	1.12
		Contractors	-.10	.128	1.000	-.46	.25
	Contractors	Pub. Sec. Clients	.86(*)	.153	.000	.43	1.28
		Priv. Sec. Clients	.10	.128	1.000	-.25	.46
B10	Pub. Sec. Clients	Priv. Sec. Clients	.20	.102	.164	-.09	.48
		Contractors	.44(*)	.118	.001	.11	.77
	Priv. Sec. Clients	Pub. Sec. Clients	-.20	.102	.164	-.48	.09
		Contractors	.24	.099	.046	-.03	.52
	Contractors	Pub. Sec. Clients	-.44(*)	.118	.001	-.77	-.11
		Priv. Sec. Clients	-.24	.099	.046	-.52	.03
C1	Pub. Sec. Clients	Priv. Sec. Clients	.30(*)	.090	.002	.05	.55
		Contractors	.14	.105	.513	-.15	.44
	Priv. Sec. Clients	Pub. Sec. Clients	-.30(*)	.090	.002	-.55	-.05
		Contractors	-.16	.088	.204	-.40	.08
	Contractors	Pub. Sec. Clients	-.14	.105	.513	-.44	.15
		Priv. Sec. Clients	.16	.088	.204	-.08	.40
C2	Pub. Sec. Clients	Priv. Sec. Clients	.11	.091	.674	-.14	.36
		Contractors	.17	.106	.331	-.13	.46
	Priv. Sec. Clients	Pub. Sec. Clients	-.11	.091	.674	-.36	.14
		Contractors	.06	.089	1.000	-.19	.31
	Contractors	Pub. Sec. Clients	-.17	.106	.331	-.46	.13
		Priv. Sec. Clients	-.06	.089	1.000	-.31	.19
C3	Pub. Sec. Clients	Priv. Sec. Clients	-.11	.086	.588	-.35	.13
		Contractors	-.12	.100	.661	-.40	.16
	Priv. Sec. Clients	Pub. Sec. Clients	.11	.086	.588	-.13	.35
		Contractors	-.01	.084	1.000	-.25	.22
	Contractors	Pub. Sec. Clients	.12	.100	.661	-.16	.40
		Priv. Sec. Clients	.01	.084	1.000	-.22	.25
C4	Pub. Sec. Clients	Priv. Sec. Clients	-.17	.107	.315	-.47	.12
		Contractors	-.01	.124	1.000	-.35	.34
	Priv. Sec. Clients	Pub. Sec. Clients	.17	.107	.315	-.12	.47
		Contractors	.17	.104	.329	-.12	.46
	Contractors	Pub. Sec. Clients	.01	.124	1.000	-.34	.35
		Priv. Sec. Clients	-.17	.104	.329	-.46	.12

* The mean difference is significant at the 0.017 level.

Table C4 (Continued)

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
C5	Pub. Sec. Clients	Priv. Sec. Clients	-.04	.105	1.000	-.33	.25
		Contractors	.15	.123	.667	-.19	.49
	Priv. Sec. Clients	Pub. Sec. Clients	.04	.105	1.000	-.25	.33
		Contractors	.19	.103	.198	-.10	.48
	Contractors	Pub. Sec. Clients	-.15	.123	.667	-.49	.19
		Priv. Sec. Clients	-.19	.103	.198	-.48	.10
C6	Pub. Sec. Clients	Priv. Sec. Clients	.04	.101	1.000	-.24	.32
		Contractors	.07	.117	1.000	-.26	.39
	Priv. Sec. Clients	Pub. Sec. Clients	-.04	.101	1.000	-.32	.24
		Contractors	.02	.098	1.000	-.25	.30
	Contractors	Pub. Sec. Clients	-.07	.117	1.000	-.39	.26
		Priv. Sec. Clients	-.02	.098	1.000	-.30	.25
C7	Pub. Sec. Clients	Priv. Sec. Clients	.03	.103	1.000	-.26	.31
		Contractors	.12	.120	.992	-.22	.45
	Priv. Sec. Clients	Pub. Sec. Clients	-.03	.103	1.000	-.31	.26
		Contractors	.09	.100	1.000	-.19	.37
	Contractors	Pub. Sec. Clients	-.12	.120	.992	-.45	.22
		Priv. Sec. Clients	-.09	.100	1.000	-.37	.19
C8	Pub. Sec. Clients	Priv. Sec. Clients	-.05	.091	1.000	-.31	.20
		Contractors	.19	.107	.226	-.11	.49
	Priv. Sec. Clients	Pub. Sec. Clients	.05	.091	1.000	-.20	.31
		Contractors	.24	.089	.021	-.01	.49
	Contractors	Pub. Sec. Clients	-.19	.107	.226	-.49	.11
		Priv. Sec. Clients	-.24	.089	.021	-.49	.01
C9	Pub. Sec. Clients	Priv. Sec. Clients	-.03	.097	1.000	-.30	.24
		Contractors	.21	.113	.190	-.10	.53
	Priv. Sec. Clients	Pub. Sec. Clients	.03	.097	1.000	-.24	.30
		Contractors	.24	.095	.031	-.02	.51
	Contractors	Pub. Sec. Clients	-.21	.113	.190	-.53	.10
		Priv. Sec. Clients	-.24	.095	.031	-.51	.02
C10	Pub. Sec. Clients	Priv. Sec. Clients	-.19	.097	.157	-.46	.08
		Contractors	-.07	.114	1.000	-.38	.25
	Priv. Sec. Clients	Pub. Sec. Clients	.19	.097	.157	-.08	.46
		Contractors	.12	.095	.581	-.14	.39
	Contractors	Pub. Sec. Clients	.07	.114	1.000	-.25	.38
		Priv. Sec. Clients	-.12	.095	.581	-.39	.14
D1	Pub. Sec. Clients	Priv. Sec. Clients	.01	.082	1.000	-.21	.24
		Contractors	.20	.095	.124	-.07	.46
	Priv. Sec. Clients	Pub. Sec. Clients	-.01	.082	1.000	-.24	.21
		Contractors	.18	.080	.069	-.04	.40
	Contractors	Pub. Sec. Clients	-.20	.095	.124	-.46	.07
		Priv. Sec. Clients	-.18	.080	.069	-.40	.04

* The mean difference is significant at the 0.017 level.

Table C4 (Continued)

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
D2	Pub. Sec. Clients	Priv. Sec. Clients	-.03	.081	1.000	-.26	.19
		Contractors	.04	.094	1.000	-.22	.30
	Priv. Sec. Clients	Pub. Sec. Clients	.03	.081	1.000	-.19	.26
		Contractors	.07	.079	1.000	-.14	.29
	Contractors	Pub. Sec. Clients	-.04	.094	1.000	-.30	.22
		Priv. Sec. Clients	-.07	.079	1.000	-.29	.14
D3	Pub. Sec. Clients	Priv. Sec. Clients	-.16	.083	.184	-.39	.07
		Contractors	-.07	.097	1.000	-.34	.20
	Priv. Sec. Clients	Pub. Sec. Clients	.16	.083	.184	-.07	.39
		Contractors	.09	.081	.823	-.14	.31
	Contractors	Pub. Sec. Clients	.07	.097	1.000	-.20	.34
		Priv. Sec. Clients	-.09	.081	.823	-.31	.14
D4	Pub. Sec. Clients	Priv. Sec. Clients	.18	.085	.101	-.06	.42
		Contractors	.29(*)	.099	.011	.02	.57
	Priv. Sec. Clients	Pub. Sec. Clients	-.18	.085	.101	-.42	.06
		Contractors	.11	.083	.558	-.12	.34
	Contractors	Pub. Sec. Clients	-.29(*)	.099	.011	-.57	-.02
		Priv. Sec. Clients	-.11	.083	.558	-.34	.12
D5	Pub. Sec. Clients	Priv. Sec. Clients	.06	.116	1.000	-.26	.38
		Contractors	.17	.135	.619	-.20	.55
	Priv. Sec. Clients	Pub. Sec. Clients	-.06	.116	1.000	-.38	.26
		Contractors	.11	.113	.993	-.20	.42
	Contractors	Pub. Sec. Clients	-.17	.135	.619	-.55	.20
		Priv. Sec. Clients	-.11	.113	.993	-.42	.20
D6	Pub. Sec. Clients	Priv. Sec. Clients	-.10	.094	.874	-.36	.16
		Contractors	.29	.109	.024	-.01	.60
	Priv. Sec. Clients	Pub. Sec. Clients	.10	.094	.874	-.16	.36
		Contractors	.39(*)	.091	.000	.14	.64
	Contractors	Pub. Sec. Clients	-.29	.109	.024	-.60	.01
		Priv. Sec. Clients	-.39(*)	.091	.000	-.64	-.14
D7	Pub. Sec. Clients	Priv. Sec. Clients	-.51(*)	.093	.000	-.77	-.25
		Contractors	-.10	.108	1.000	-.40	.20
	Priv. Sec. Clients	Pub. Sec. Clients	.51(*)	.093	.000	.25	.77
		Contractors	.41(*)	.090	.000	.16	.66
	Contractors	Pub. Sec. Clients	.10	.108	1.000	-.20	.40
		Priv. Sec. Clients	-.41(*)	.090	.000	-.66	-.16
D8	Pub. Sec. Clients	Priv. Sec. Clients	-.20	.088	.076	-.44	.05
		Contractors	.01	.102	1.000	-.27	.30
	Priv. Sec. Clients	Pub. Sec. Clients	.20	.088	.076	-.05	.44
		Contractors	.21	.086	.045	-.03	.45
	Contractors	Pub. Sec. Clients	-.01	.102	1.000	-.30	.27
		Priv. Sec. Clients	-.21	.086	.045	-.45	.03

* The mean difference is significant at the 0.017 level.

Table C4 (Continued)

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
E1	Pub. Sec. Clients	Priv. Sec. Clients	-.06	.104	1.000	-.34	.23
		Contractors	-.03	.121	1.000	-.36	.31
	Priv. Sec. Clients	Pub. Sec. Clients	.06	.104	1.000	-.23	.34
		Contractors	.03	.101	1.000	-.25	.31
	Contractors	Pub. Sec. Clients	.03	.121	1.000	-.31	.36
		Priv. Sec. Clients	-.03	.101	1.000	-.31	.25
E2	Pub. Sec. Clients	Priv. Sec. Clients	.02	.087	1.000	-.23	.26
		Contractors	.01	.102	1.000	-.27	.30
	Priv. Sec. Clients	Pub. Sec. Clients	-.02	.087	1.000	-.26	.23
		Contractors	.00	.085	1.000	-.24	.23
	Contractors	Pub. Sec. Clients	-.01	.102	1.000	-.30	.27
		Priv. Sec. Clients	.00	.085	1.000	-.23	.24
E3	Pub. Sec. Clients	Priv. Sec. Clients	-.27(*)	.086	.005	-.51	-.03
		Contractors	.06	.100	1.000	-.22	.34
	Priv. Sec. Clients	Pub. Sec. Clients	.27(*)	.086	.005	.03	.51
		Contractors	.33(*)	.083	.000	.10	.56
	Contractors	Pub. Sec. Clients	-.06	.100	1.000	-.34	.22
		Priv. Sec. Clients	-.33(*)	.083	.000	-.56	-.10
E4	Pub. Sec. Clients	Priv. Sec. Clients	-.37(*)	.083	.000	-.60	-.14
		Contractors	-.07	.097	1.000	-.34	.20
	Priv. Sec. Clients	Pub. Sec. Clients	.37(*)	.083	.000	.14	.60
		Contractors	.30(*)	.081	.001	.07	.52
	Contractors	Pub. Sec. Clients	.07	.097	1.000	-.20	.34
		Priv. Sec. Clients	-.30(*)	.081	.001	-.52	-.07
E5	Pub. Sec. Clients	Priv. Sec. Clients	-.35(*)	.086	.000	-.59	-.11
		Contractors	.15	.100	.382	-.12	.43
	Priv. Sec. Clients	Pub. Sec. Clients	.35(*)	.086	.000	.11	.59
		Contractors	.50(*)	.083	.000	.27	.73
	Contractors	Pub. Sec. Clients	-.15	.100	.382	-.43	.12
		Priv. Sec. Clients	-.50(*)	.083	.000	-.73	-.27
E6	Pub. Sec. Clients	Priv. Sec. Clients	.12	.110	.812	-.18	.43
		Contractors	.28	.128	.096	-.08	.63
	Priv. Sec. Clients	Pub. Sec. Clients	-.12	.110	.812	-.43	.18
		Contractors	.15	.107	.452	-.14	.45
	Contractors	Pub. Sec. Clients	-.28	.128	.096	-.63	.08
		Priv. Sec. Clients	-.15	.107	.452	-.45	.14
E7	Pub. Sec. Clients	Priv. Sec. Clients	-.24	.106	.069	-.53	.05
		Contractors	-.05	.123	1.000	-.39	.29
	Priv. Sec. Clients	Pub. Sec. Clients	.24	.106	.069	-.05	.53
		Contractors	.19	.103	.204	-.10	.47
	Contractors	Pub. Sec. Clients	.05	.123	1.000	-.29	.39
		Priv. Sec. Clients	-.19	.103	.204	-.47	.10

* The mean difference is significant at the 0.017 level.

Table C4 (Continued)

Bonferroni: Multiple Comparisons (Equal variance assumed)

Dependent Variable	(I) Respondents	(J) Respondents	Mean Difference (I-J)	Std. Error	Sig.	98.3% Confidence Interval	
						Lower Bound	Upper Bound
E8	Pub. Sec. Clients	Priv. Sec. Clients	.26	.111	.056	-.05	.57
		Contractors	.11	.129	1.000	-.25	.47
	Priv. Sec. Clients	Pub. Sec. Clients	-.26	.111	.056	-.57	.05
		Contractors	-.15	.108	.474	-.45	.15
	Contractors	Pub. Sec. Clients	-.11	.129	1.000	-.47	.25
		Priv. Sec. Clients	.15	.108	.474	-.15	.45
E9	Pub. Sec. Clients	Priv. Sec. Clients	-.45(*)	.101	.000	-.73	-.17
		Contractors	-.34(*)	.118	.011	-.67	-.02
	Priv. Sec. Clients	Pub. Sec. Clients	.45(*)	.101	.000	.17	.73
		Contractors	.11	.099	.837	-.17	.38
	Contractors	Pub. Sec. Clients	.34(*)	.118	.011	.02	.67
		Priv. Sec. Clients	-.11	.099	.837	-.38	.17
E10	Pub. Sec. Clients	Priv. Sec. Clients	-.50(*)	.122	.000	-.84	-.16
		Contractors	-.58(*)	.142	.000	-.98	-.19
	Priv. Sec. Clients	Pub. Sec. Clients	.50(*)	.122	.000	.16	.84
		Contractors	-.09	.119	1.000	-.42	.25
	Contractors	Pub. Sec. Clients	.58(*)	.142	.000	.19	.98
		Priv. Sec. Clients	.09	.119	1.000	-.25	.42
E11	Pub. Sec. Clients	Priv. Sec. Clients	-.45(*)	.110	.000	-.76	-.15
		Contractors	-.32	.128	.043	-.67	.04
	Priv. Sec. Clients	Pub. Sec. Clients	.45(*)	.110	.000	.15	.76
		Contractors	.14	.107	.579	-.16	.44
	Contractors	Pub. Sec. Clients	.32	.128	.043	-.04	.67
		Priv. Sec. Clients	-.14	.107	.579	-.44	.16
E12	Pub. Sec. Clients	Priv. Sec. Clients	-.51(*)	.128	.000	-.86	-.15
		Contractors	-.24	.150	.339	-.65	.18
	Priv. Sec. Clients	Pub. Sec. Clients	.51(*)	.128	.000	.15	.86
		Contractors	.27	.125	.094	-.08	.62
	Contractors	Pub. Sec. Clients	.24	.150	.339	-.18	.65
		Priv. Sec. Clients	-.27	.125	.094	-.62	.08
E13	Pub. Sec. Clients	Priv. Sec. Clients	-.85(*)	.118	.000	-1.18	-.53
		Contractors	-1.01(*)	.138	.000	-1.39	-.62
	Priv. Sec. Clients	Pub. Sec. Clients	.85(*)	.118	.000	.53	1.18
		Contractors	-.15	.115	.555	-.47	.17
	Contractors	Pub. Sec. Clients	1.01(*)	.138	.000	.62	1.39
		Priv. Sec. Clients	.15	.115	.555	-.17	.47

* The mean difference is significant at the 0.017 level.

Table C5 Normalized Value of Weights Established for CSC

Contractor Selection Criteria	Weight (%)
A. Contracting Company's Attributes	**17.0**
A1. Age of the company	14.0
A2. Familiarity with regulating authorities	14.2
A3. Familiarity with local working culture	13.1
A4. Health and safety record of the company	14.7
A5. Achievement of quality level (e.g., ISO: 14000)	13.8
A6. Post-business attitude	15.1
A7. Past failure	15.2
B. Past Performance of the Contractor	**22.3**
B1. Type & scale of the project completed in past 3(5) years	11.1
B2. Quality of works in past projects (CONQUAS rating)	10.5
B3. Percent of previous works completed on schedule	10.6
B4. Standard of sub-contractors' works in past projects	9.9
B5. Attitude towards correcting faulty works	10.7
B6. Good relationship with past project owners	9.3
B7. Relationship with sub-contractors	9.0
B8. Relationship with suppliers	8.8
B9. Relationship with regulating authorities	9.0
B10. Debarment and/or demerit point in past projects	11.1
C. Financial Capability of the Contractor	**25.2**
C1. Current commitments	11.0
C2. Authorized and paid-up capital	10.1
C3. Working Capital	10.8
C4. Current and fixed assets	9.5
C5. Net worth	9.6
C6. Turnover	9.1
C7. Profit generating ability of the company	9.0
C8. Liquidity status of the company	10.8
C9. Capital structure of the company	10.1
C10. Finance Arrangement	9.9

Table C5 (Continued)

Contractor Selection Criteria	Weight (%)
D. Performance Potential of the Contractor	**19.7**
D1. Depth of experience on similar type of projects	13.9
D2. Qualification and experience of management staffs	13.3
D3. Qualification and experience of technical staffs	13.1
D4. Manpower resources	12.5
D5. Availability of owned construction plant & equipment	9.6
D6. Present workload & capability to support the current project	12.9
D7. Quality control and assurance program	12.3
D8. Specialized knowledge of particular construction method	12.5
E. Project Specific Criteria	**15.8**
E1. Construction method statement	8.6
E2. Proposed project time schedule	9.2
E3. Qualification and experience level of project manager	9.6
E4. Qualification and exp. Of professional technical staffs	9.2
E5. Experience level of project team on similar type of project	9.2
E6. Number of direct workers available for the project	7.1
E7. Availability of testing equipment as quality assurance	6.7
E8. Health and safety setup for the project	8.2
E9. The contractor's time and cost saving considerations	8.5
E10. Reputation of the subcontractors to be used for the project	8.0
E11. Type of performance bond	7.8
E12. Cash-out/payment schedule	8.0

Table C6 Financial Information of Contractors for FY- 2000

Financial Information	Contractor A	Contractor B	Contractor C
Current Assets (S$)	63542086	48264128	136248300
Current Liabilities (S$)	18258322	92468324	72404600
Total Assets (S$)	156322412	322393182	218120800
Total Liabilities (S$)	27284362	182024128	82651115
Earning before Interest & Taxes (S$)	-2026688	8247587	3068204
Revenue (S$)	4926008	173428576	180292465
Net Income (S$)	-3568234	6723836	465368
Non-Working Capital Expenses (S$)	278362	762794	1624228

Table C7 Financial Information of Contractors for FY- 2001

Financial Information	Contractor A	Contractor B	Contractor C
Current Assets (S$)	98482684	52216209	152291680
Current Liabilities (S$)	17742363	126287326	96180620
Total Assets (S$)	153724362	290006336	202161822
Total Liabilities (S$)	19632456	162127254	99682265
Earning before Interest & Taxes (S$)	-46228663	15268362	-16852064
Revenue (S$)	762463	128358256	176182383
Net Income (S$)	-47362348	3673608	-188662412
Non-Working Capital Expenses (S$)	76364	562786	1362418

Table C8 Financial Information of Contractors for FY- 2002

Financial Information	Contractor A	Contractor B	Contractor C
Current Assets (S$)	76784333	40645528	160643382
Current Liabilities (S$)	16062362	72408216	86332432
Total Assets (S$)	143243342	226228247	228316473
Total Liabilities (S$)	16945263	110266278	112068328
Earning before Interest & Taxes (S$)	-7273684	26636742	26001212
Revenue (S$)	982684	138876093	190529267
Net Income (S$)	-10638824	17842963	6725826
Non-Working Capital Expenses (S$)	726824	824362	1865235

APPENDIX D

Instruction Manual for the Contractor Selection System Program

Installation and Running Manual for the Selection System

D.1 Hardware and Software Requirements

The following hardware or computer system and software are required for the smooth operation of the developed contractor selection system:

- IBM computer or any compatible computer system
- Minimum 64 MB of available RAM (Random Access Memory)
  (128 MB recommended for better operation and performance of the system.)
- 100 MB of hard disk drive
- CD ROM drive or USB port for installation purpose
- SVGA color monitor of 15" or bigger
- Microsoft Windows 98 or higher
- Microsoft Excel version 10
  (The system installed with the lower version of Microsoft Excel may not be able to run the program properly as most of the library functions used in the program are not available in the lower version of Excel.)
- Microsoft Visual Basic 5.0 or higher is preferable.

D.2 Installing and Running the Selection System Program

Before installing the Contractor Selection System program, make sure that operating system and all software necessary to run the program have already been installed on the computer system. For installation of the program from a CD or a removable storage device, please follow the instruction as below:

- Click "Start" Menu from the Taskbar
- Select "My Computer"
- Select the 'Drive' (for e.g., CD Drive (F:)) holding the device containing the program

- Copy the folder with the name "Fuzzy MCDM_ Cont. Sel. Sys" on to the hard drive (e.g., Local Drive (C:)) of the computer system
- Open the folder by double clicking the folder icon
- Open the Visual Basic file "SelectionModel"
- To run the program press 'F5' or select 'Run' option from the menu bar or press 'Start' button (▶) in the tool bar

- Once the program is in run mode, it will guide the user through the evaluation process.

- For financial evaluation process, the starting year of the analysis period cannot be earlier than 1900 and the end year cannot be later than 2099.

- If the user wants to modify the fuzzy values of the linguistic variables, it can be done by opening the file 'LinVar' contained in the folder "Fuzzy MCDM_ Cont. Sel. Sys" and modify the values as per requirements.