MULTICRITERIA AND MULTIDECISION-MAKERS IN TENDER EVALUATION

By

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Abstract

In the construction industry, problems such as budget overruns, extended schedules, low quality work and poor safety standards still exist due to not selecting the *best* contractor to complete a project. To select the *best* contractor, an owner needs a rational approach to evaluate candidate contractors. This evaluation involves mainly developing criteria and developing a model to interrelate these criteria. However, at present there is no consensus for the selection of a common hierarchy/set of criteria, showing a knowledge gap that needs to be bridged. Moreover, all existing models have a lack of integration in the joint area of simultaneously putting together *subjective inputs* of multiple decision-makers, covering elements of risk and uncertainty, and offering computer interaction. This presents another knowledge gap that needs to be filled. Therefore, the main research aims were to originally contribute to (1) developing a common set of criteria based on existing organisational units of contractors and (2) developing a more realistic working model including the necessary capabilities mentioned.

The methodology used in this research was an integrated approach to the suggestion and development through literature review, questionnaire survey, and model tests. The Thai construction industry was used to investigate tender evaluation procedures, criteria and models. The writer's ideas, together with concepts and techniques mainly from construction engineering, operations research, systems engineering, social sciences and computer sciences were blended into the suggestion and development.

A hierarchy/set of contractor ability criteria was developed on the basis of a combination of organisational units of contractors and the results of questionnaire

analyses, which is the initial initiative of this research. This hierarchy/set incorporates physical characteristics of contractors, which appear to offer a common set of contractor ability criteria. This common set could then result in the reduction of worldwide repetitive effort in developing contractor ability criteria thereby possibly decreasing world-owners' expenses.

Using the hierarchy/set of contractor ability criteria as a basis for its development, the multicriteria and multidecision-makers' model proposed in the research can overcome the mentioned lack of the existing models by simultaneously including the necessary capabilities mentioned. The vital theory behind the model was the method, using a combination of a utility function and a social welfare function, identified as state-of-the-art. This method provides the consideration of both risk arising from uncertainty and multiple decision-makers' involvement. To assemble the model, Microsoft Excel performed calculations whilst Visual Basic for Application (VBA) undertook interaction. The interactive capability of the model offers the flexibility to absorb changes, both in contractor ability criteria and in multidecision-makers' *subjective inputs*. With this flexibility, the model could be used in any country. For these reasons, the model has advantages over all existing models in tender evaluation.

The model tests for user friendliness, verification, sensitivity analysis and validation showed that the integration of multidecision-makers' *subjective inputs*, elements of risk and uncertainty and computer interaction was a rational and realistic approach in solving tender evaluation problems.

The research provides two main beneficial results filling the two knowledge gaps. One is a common hierarchy/set of contractor ability criteria including physical properties of contractors (ie, hierarchical organisational units of contractors), which potentially leads to the decrease of the waste of world-repetitive resources spent. The other is a more realistic working model (the multicriteira and multidecision-makers' model) including multidecision-makers' *subjective inputs*, risk arising from uncertainty and computer interaction; which results in a saving in time and higher efficiency of tender-data analysis. This then helps to reduce the construction problems mentioned. Consequently, the owner will enjoy the future growth.

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Notation and Abbreviations

DM	Decision-maker
CAC	Contractor Ability Criteria
CA	Contractor Ability
Bp	Bid price
ENC	ENgineering/Construction
PRC	PRocurement/Contract
PM	Project Managers
HR	Human Resources
QMS	Quality Management Systems
HS	Health and Safety
PLE	PLant/Equipment
FS	Financial Strength
PR	Public Relations
U_{RN}	Risk-neutrality utility
U_{RP}	Risk-propensity utility
U_{RA}	Risk-aversion utility

Statement of Original Authorship

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher educational institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signed: Jakrapong Pongpeng

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Dedication

To my parents

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Terminology

The terminology* of decision-making may be accepted differently. The following meanings are used in this research.

Criteria

Criteria is a broad term encompassing attributes, variables, objectives and goals.

Attributes/variables

Attributes/variables are measurable features of an objective(s). Strictly, an objective cannot be measured but its attributes/variables can (Nunnally, 1967) and can be used to objectively and subjectively describe the objective. In general, attributes/variables carry different weights of relative importance which functionally provide:

- a clear understanding of the objective(s) successfully achieved
- scales for measuring the objective in some particular dimensions.

Objectives

Objectives are defined as decision-makers' needs and desires. Objectives also represent directions (maximisation or minimisation) of improvement or preference along attributes/variables. In general, objectives are selected by an individual, individuals, groups, or organisations. Different decision-makers may select different objectives. These objectives may be conflicting: for example within an individual;

* There is no standard terminology for human decision-making. Nevertheless, groups of interchangeable terms are used:

- for describing and classifying objectives such as characteristics, aspects, properties, qualities, distinctions, attributes, traits, and cues
- for pursuing and striving towards such as goals, targets, aims, aspirations, objects, objectives, ends, intents, purposes, missions, aspirations, and ambitions
- for measuring effectiveness such as criteria, standards, gauges, principles, norms, and rules
- for considering or accomplishing pursuits such as objects of choice, options, actions, solutions, alternatives, items, strategies, and means (Zeleny, 1982).

between individuals; between groups; or between an individual, individuals, groups, and organisations. Often, each objective cannot be commensurate with another.

Goals

Goals are rather similar to objectives in that they are constituted by one or more attributes. However, a goal has a specified amount as a point of reference, or a level of aspiration to be satisfied as closely as possible, instead of having only a direction of improvement.

Solutions/alternatives

A solution/alternative represents one set of means of achieving an objective(s) or a goal(s). Two main components of a solution are a set of variables/attributes and a set of objectives or goals, which make a solution comparable with other solutions. There is strong interdependence and interaction between objectives and solutions (Zeleny, 1982). That is, for human decision-making, generating solutions without understanding of objectives or goals is rather impossible. Similarly, determining objectives and goals without apprehension of solutions is somewhat unachievable.

Non-dominated solutions

A non-dominated solution is a feasible solution where its set of values, with respect to all criteria, has the same or better performance than that of other solutions. An increase in value of any one objective within a non-dominated solution can be achieved by the sacrifice in value of at least one other objective, leading to the concept of value *trade-off*, which reflects subjective judgment and personal difference.

The *best* solution

The *best* solution is that which is judged as such by the decision-maker. In other words, it is the solution which is accepted and implemented with confidence.

Score

A score is the quantity of a criterion/variable/attribute of a solution. Also, a score is a *constructed* scale which has no elements of risk and uncertainty.

Utility

Utility is the preference of the decision-maker for a criterion/variable/attribute of a solution. Also, a utility is a *constructed* scale which includes the preference of a decision-maker towards risk and uncertainty.

Utility function

A utility function is a preference structure of a decision-maker. In simple terms, a utility function is a mapping of multicriteria values into a *constructed* function, or a mathematical form of preference structure.

Social welfare function

A social welfare function is a summation of utility functions of multiple decision-makers.

Satisfying

Satisfying is explained as efforts to succeed to a level of aspiration or a point of reference, which reflects personal difference and dynamic movement over time. The point of reference then provides a motivating force for a decision-maker to reach it as closely as possible, and also guides the selection of the final solution.

Tender evaluation

Tender evaluation is the process of selecting the best contractor to complete a project. This process may be performed with or without prequalification.

Multicriteria optimisation

Multicriteria optimisation (where an ultimisation is required for more than one criterion) is a process of searching for a single measure of merit of a solution that is greater than that of the other solutions. This process requires subjective inputs from the decision-makers.

Subjective inputs

Subjective inputs are any statements of preference from decision-makers, which are added to criteria in order to evaluate solutions. These subjective inputs differ from one decision-maker to another due to their different backgrounds, experiences, positions, and attitudes towards risk and uncertainty. Broadly, types of inputs are: (1) weights of relative importance of criteria/attributes/variables, (2) a set goal or a set of references, (3) a utility or a utility function.

Chapter 1

Introduction

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1.1 Background

In the construction industry, the future growth of any owner/client organisation depends largely on its investment decision. When the owner has decided on which project to invest in, they may engage outside contractors to complete this project. If the owner selects the *best* contractor, their organisation will enjoy future growth because this selection deeply influences the day-to-day operations and long-term performance of their organisation. If, however, the owner selects a low-qualified contractor, it is most likely that problems of planned-schedule delays, used-budget excesses, *low* quality of work, a large number of claims and litigation, suffering of both workers and the public, and the requirement of more supervision from the owner will occur. This then requires a rational approach to evaluate candidate contractors in order to select the *best* contractor. This evaluation involves mainly (1) the development of criteria and (2) the development of a model to interrelate these criteria. Such **tender evaluation** is the subject matter of this research.

In the past, particularly during times of hardship, a single criterion (eg, cost or time) was considered in tender evaluation. Over the past few decades, during peace time, multiple criteria have been suggested for tender evaluation (see, eg, CIDA, 1993; Diekmann, 1981; Hatush and Skitmore, 1997; Herbsman and Ellis, 1992; Liston, 1994ab; Nguyen, 1985; Russell, 1990, 1992; Russell and Skibniewski, 1988, 1990; Russell *et al.*, 1990, 1992). However, at present there is no consensus for the selection of a common set of tender evaluation criteria. Different researchers have suggested different sets of criteria. Also, most organisations have developed their own tender evaluation criteria. This shows waste of resources in repetitive effort to develop tender evaluation criteria.

Moreover, together with this suggestion, a number of models have been introduced to tender evaluation. Each model has different methods for dealing with multicriteria and interrelating them.

For example, a *weighting method* has been used in various studies. Russell and Skibniewski (1990) have introduced an interactive model, named *Qualifier-1*, to qualify contractors. This model combines all criteria into a new single criterion where weights are assigned to individual criteria according to their relative importance. On the other hand, Herbsman and Ellis (1992) cope with multiple criteria by converting them into expected monetary value by trading off between these criteria, and then interrelating them by using weights of relative importance.

Nguyen (1985) applied fuzzy set theory to tender evaluation. Here, a fuzzy set transforms multicriteria into a non-dimensional unit and then combines all criteria by weighting.

In the application of a multiattribute utility function, Diekmann (1981) suggested a *weighted additive* model (to represent the decision-maker's utility function) to evaluate contractors in a cost plus contract. This model manages non-commensurate issues similar to *Qualifier-1* by Russell and Skibniewski (1990) except that here Diekmann uses utility for the value of each criterion. Also, Hatush (1996) and Hatush and Skitmore (1998) introduced a weighted additive model to tender evaluation. This model operates similarly to that of Diekmann.

Based on computer technology, Russell et al (1990) developed an expert system, named *Qualifier-2*, for contractor prequalification, which integrated the expertise of four construction professions. In this system, criteria are ranked in a hierarchy. The rules for prequalification are applied at the lowest level of this hierarchy by asking "if-then" questions.

All of these models assume that only one decision-maker is involved in tender evaluation. However, in reality, multiple decision-makers are always involved. These decision-makers may come from different departments within the owner's organisation. They have different interests and judgment regarding the relative weighting and value of each criterion due to their different experience, position, background and attitude towards risk arising from uncertainty. This results in problems when each decision-maker gives different weights of relative importance to the same criteria and different values of these criteria for each contractor. Sometimes, the problem of selecting a contractor becomes an argument between these multiple decision-makers about what weights and values should be given to the selection criteria.

1.2 Problem statement

As discussed earlier, firstly there appears to be a lack of shared communal tender evaluation criteria, which presents an unnecessary use of repetitive effort in developing such criteria showing a gap of knowledge. To reduce the use of repetitive effort, this gap needs to be bridged.

Secondly, all the above models assume that one person makes a decision in tender evaluation but in most organisations multiple decision-makers are involved. Where multiple decision-makers are involved, the problems of different weights of relative importance for the same criteria and of different values for these criteria for each contractor occur. Furthermore, these weights can change over time in relation to a particular situation. Also, the values of these criteria are subject to risk and uncertainty regarding the consequences of engaging the contractor. Although the Association of Consulting Engineers Australia, ACEA (1998), has suggested an approach which considers the involvement of multiple decision-makers, there appears to be no consideration of the risk and uncertainty of solutions and no interactive nature. This represents the inadequacy of integrating all necessary features for tender evaluation, showing another gap of knowledge that needs to be filled.

Therefore, if the owner wants a tender evaluation decision for their whole organisation and includes elements of risk and uncertainty, they require a rational and realistic model which is capable of:

- compiling preferences of multiple decision-makers
- including elements of risk and uncertainty
- providing a flexibility to absorb the changes of preference in relation to a particular situation via computer interaction.

1.3 Aims of the research

As a result of the above problem statement, the major research aims were to contribute to (1) suggesting a common hierarchy/set of criteria based on existing organisational units of contractors and (2) developing a more realistic working model for use in evaluating tenders via imagination across various disciplines (ie, construction engineering, operations research, systems engineering, social sciences, and computer sciences). To achieve this, the aims were broken down into the following sub-aims.

- To investigate tender evaluation procedures, criteria and models used in the Thai construction industry in order to address the aspects of tender evaluation.

- To develop a common hierarchy/set of criteria for evaluating contractor ability, which satisfies a project's requirements. This hierarchy will include physical characteristics of all contractors in the world. Thus, this hierarchy may be applied universally leading to a worldwide decrease in repetitive efforts in developing contractor ability criteria.

- To identify a state-of-the-art model from interdisciplinary subjects, which is likely to support best practice. The research shows that a combination of a utility function and a social welfare function can be described as state-of-the-art.

- To develop utility measurement which includes risk stemming from uncertainty and which is suitable for tender evaluation practitioners.

- To provide an approach of suggesting utility for bid price whereby the onus of utility expression on the part of decision-makers can be reduced.

- To develop a realistic working method using the state-of-the-art model (a combination of a utility function and a social welfare function) identified for use in tender evaluation, which is able to integrate preferences of multiple decision-makers and to recognise risk arising from uncertainty.

- In line with all of the previous sub-aims, to develop an interactive and user-friendly program for the realistic working method which is able to provide an opportunity for changes in subjective inputs (a statement of preference) in relation to a particular situation and to reduce the difficulty in finding fixed and well-defined subjective inputs up front.

1.4 Significance of the research

It is shown in the literature review that a shortcoming in developing common criteria in tender evaluation exists and although multicriteria models have been suggested for tender evaluation, there is a lack of integration in the joint area of simultaneously (1) putting together preferences of multiple decision-makers, (2) covering elements of risk and uncertainty, and (3) offering computer interaction that makes a model flexible to any changes in situation. This presents two knowledge gaps that need to be filled.

To fill these two gaps, this research develops a common set of criteria and a more realistic working model including the necessary capabilities mentioned to help practitioners select the *best* contractor; which ensures the success of a project at a certain level. This development reduces the problems of planned-schedule delays, used-budget excesses, *low* quality of work, a large number of claims and litigation, suffering of both workers and the public, and the requirement of more supervision from the owner. This reduction then leads to future growth of the owner's organisation.

1.5 Methodology

The methodology used in this research is an integrated approach to the development of a common hierarchy/set of criteria and the realistic working model. The steps of the methodology were as follows.

- Review the literature on tender evaluation procedures to find the processes of tender evaluation used by the construction industry.

- Review the literature on tender evaluation criteria to identify related disciplines and areas which can underpin best practice.

- Review the literature on multicriteria models from various fields to find limitations based on their assumptions and solution-evaluation performance so as to determine the state-of-the-art model put forward.

- Review the literature on tender evaluation in the Thai construction industry, based on the above findings, to establish a conceptual framework in terms of (1) tender evaluation procedures, (2) tender evaluation criteria, and (3) tender evaluation models for a survey of tender evaluation, conducted in Bangkok, Thailand.

- Conduct a questionnaire survey to support the above findings from the literature and to test the conceptual framework in order to develop a hierarchy of common criteria based on existing organisational units of contractors and to provide a basis for subsequent modelling.

- Develop, based on the above findings of the questionnaire survey and the literature review, a realistic working model for tender evaluation.

- Develop an interactive and user-friendly computer program to guarantee the practicability of the proposed model.

- Conduct model tests in terms of user friendliness, verification, sensitivity analysis, and validation to show the superiority in reality of this model to the existing models in tender evaluation.

1.6 Outline

Chapter one is the introduction providing background, problem statement, aims, significance, methodology, outline of research and a publication list during the development of this research.

Chapter two is a literature review which is divided into three sections: tender evaluation procedures, criteria, and models for solving multicriteria problems. Measurement of criteria and the *theory of hierarchy, multilevel, systems* are also discussed for application in developing a common hierarchy of criteria. Moreover, multicriteria models in various areas are studied to identify the state-of-the-art model. A combination of a utility function and a social welfare function appears to be state-of-the-art. In addition, it is found that computer interaction is combined with multicriteria models in order to absorb changes of preference in relation to a particular situation and to reduce the difficulty in finding fixed and well-defined subjective inputs up front.

Chapter three is a literature review on tender evaluation in the Thai construction industry using the same structure as for Chapter two. However, the focus is on the practice in Thai construction organisations (in both government and private sectors). Three broad tender evaluation procedures are analysed: (1) the selective tendering process with prequalification, (2) the selective tendering process without prequalification and (3) the open tendering process. All of these procedures involve multiple criteria and multiple decision-makers.

Chapter four is the questionnaire design based on the findings in Chapters two and three. The data gathered focuses on (1) tender evaluation criteria, (3) tender evaluation procedures and (3) tender evaluation models. The data is then prepared for analyses using SPSS, a statistical package.

Chapter five presents the results of the data analyses of the questionnaire survey. The results on tender evaluation procedures support the findings in Chapters two and three that multicriteria and multidecision-makers are involved in tender evaluation. It is also shown that selective tendering with and without prequalification uses a two-step evaluation: step 1 evaluating contractor ability and step 2 evaluating tenders. On the other hand, the open tendering process uses a one-step evaluation. In addition, a hierarchy of criteria based on typical organisational units of contractors is presented. The hierarchy is the result of the initial initiative in the research in suggesting a common set of criteria. On the models used, a weighting method is the most popular in the Thai construction industry.

Chapter six further explains the ideas of a utility function and a social welfare function (identified as state-of-the-art) in order to apply them as the basis for developing the multicriteria and multidecision-makers' model. Simplification for utility measurement of contractor ability criteria is suggested by this research for tender evaluation practitioners. In addition, a suggested utility for bid price (based on percentile of bid price distribution) is introduced in this research so as to decrease the burden of utility expression. An example of how to combine the utility and social welfare functions is also presented.

Chapter seven describes the model process, development and program. The model process is divided into two main steps: step 1 evaluating contractor ability and step 2 evaluating tenders, which consist of three main processes: (1) contractor ability criteria selection process, (2) contractor ability balancing/measuring process and (3) bid price and contractor ability balancing/measuring process. An outline process and a flow diagram are developed to verify the logical order of the model. Microsoft Excel with Visual Basic for Application (VBA) is used to construct the multicriteria and multidecision-makers' model.

Chapter eight proves the realistic workability of the model by tests for user-friendliness, verification, sensitivity analysis, and validation. The tests have shown that the integration of multidecision-makers' preferences, elements of risk and uncertainty and computer interaction is a rational and realistic approach in solving tender evaluation problems.

Chapter nine concludes the research work. Also, recommendations for further research and for the construction industry are made. All the Chapters and their interaction as a whole are shown in Figure 1.

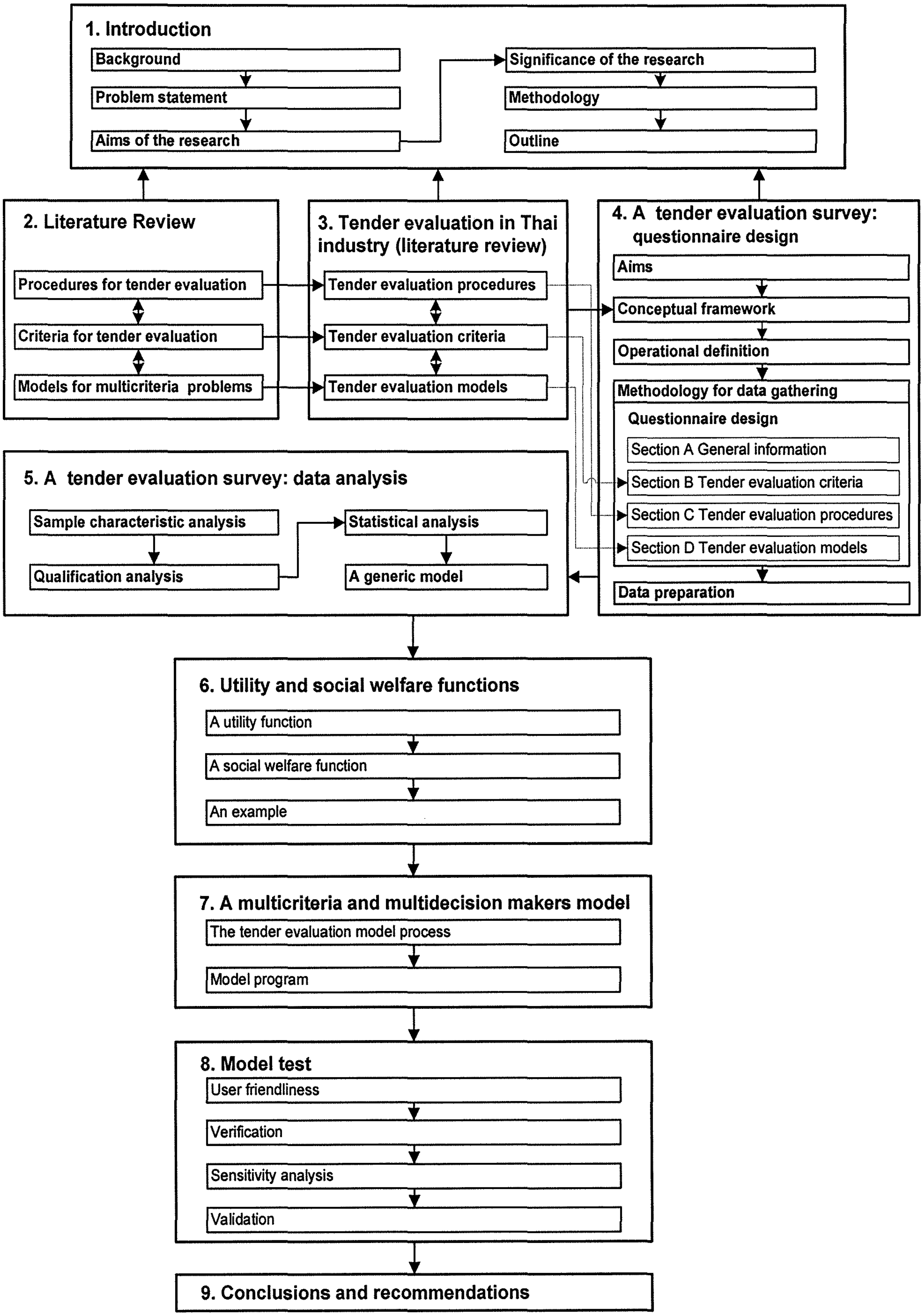

Figure 1 Structure and interaction of the research

1.7 Publication list

- Pongpeng, J. and Liston, J., "Multicriteria in tender evaluation: Thai construction industry," *Proc. Conf. on Real Research in Civil Engineering*, QUT, pp.20-49.

- Pongpeng, J. and Liston, J., "TenSeM: a multicriteria and multidecision-makers' model in tender evaluation," *Construction Management and Economics* (accepted for publication).

Chapter 2

Literature review

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2.1 Introduction

A large body of literature on multicriteria (or multiobjective) decision-making problems exists in various areas such as water resources (see Cohon, 1978; Haimes and Chankong, 1979), industry, transportation, finance, academia, land use (see Goicechea *et al.*, 1982), airport development (see de Neufville and Keeney, 1974), nuclear power plants (see Keeney and Nair, 1977), and forest problems (see Bell, 1977). This is possibly because there is an increased need to consider multiple criteria during peace periods, whilst during war periods a single criterion tends to be considered. This is also true for the problems of tender evaluation. Historically, when times were hard, cost was the sole criterion in tender evaluation problems because of the long usage of competitive bidding concepts (see Herbsman and Ellis, 1992). However, recently when times are favourable, multiple criteria have been introduced to solve the problems, which can be seen in, for example, Hatush and Skitmore (1997abc), Herbsman and Ellis (1992), Holt *et al.* (1993, 1994abc), Liston (1994ab, 1999), Russell (1990, 1992), Russell and Skibniewski (1988, 1990).

To study tender evaluation (as a multicriteria decision-making process), three main components were reviewed: (1) procedures for tender evaluation, (2) criteria for tender evaluation, and (3) models for multicriteria problems. The following is a review of the literature structured according to these three components. This structure permits an insight study of tender evaluation that addresses the important issues and can lead to an improvement of current practice.

2.2 Procedures for tender evaluation

2.2.1 Introduction

Where an owner/client wants to complete a facility (eg, a construction, a project or a product) by engaging outside companies, binding contracts are formed. There exist a number of contract strategies, delivery systems or procurement systems, which allow the engaging parties to exchange their resources and experience such as *traditional,* *design and construction, novation, and BOOT.* The selection of any delivery system is dependent upon the owner's needs, types and size of the projects, and a specific situation (Love and Skitmore, 1995), and reflects a variety of meaningful criteria for each delivery system. This means a set of meaningful criteria is suitable for a delivery system, an owner's needs or objectives and a specific condition. In other words, only selecting a suitable delivery system for a project does not mean selecting the *best* contractor to complete the project. Therefore, to select the *best* contractor, a set of meaningful criteria, a form of gathering data according to these criteria and a rational approach for evaluating abilities of contractors are necessary. In this section, tender evaluation procedures are studied to identify any issues and limitations.

Tendering can be expressed from two points of view. Firstly, from an owner's viewpoint tendering is a process of selecting the best contractor from many contractors for executing a specified project. Some investigators have researched from this viewpoint (Hatush and Skitmore, 1997abc and 1998; Herbsman and Ellis, 1992; Liston, 1994ab, 1999; Russell, 1990; Russell and Skibniewski, 1988, 1990; Russell *et al.*, 1990, 1992). Secondly, from the contractors' viewpoint, tendering is a process of selecting a project(s) to bid for and of preparing for executing work on stated terms. The work of Ahmad (1990) and Shash (1993) is an example of research in this area. Only the owner's viewpoint was focused on in this research.

This review of tender evaluation procedures was divided into prequalification (a process of evaluating contractors to examine *contractor ability*) and tender evaluation (a process of evaluating contractors to select the *best* contractor). Lastly, issues related to multiple criteria and multiple decision-makers in tender evaluation were discussed; this led to the development of a realistic working model.

2.2.2 Prequalification

2.2.2.1 Aims of prequalification

Prequalification aims at separating out between qualified (competent) and unqualified (incompetent) contractors, and at ranking the ability of the contractors to complete a specified project or class of work. Only the qualified contractors will be invited to bid for a specified project. Prequalification and tender evaluation also involve the owner/client in screening contractors according to a given set of criteria. The criteria selected/developed should be such that the decision-maker can reduce the risk in selecting a low qualified contractor and have a higher probability that the contract will be completed either within time, cost and quality (Liston, 1999).

Russell *et al.* (1988) explained prequalification by interpreting the interaction amongst three components, namely:

- **The decision-maker or owner.** The characteristics of the owner effects the decision strategy used and the criteria selected. Various criteria and sub-criteria describing the owner include:

  - Type of owner: Private and public owners select different criteria. That is, when selecting criteria for prequalification, the private owner is more elastic. Whereas, the public owner performs that selection of criteria under certain regulations no matter what the type of project is.
  - Owner's objectives: The objectives and their weights of relative importance affect the criteria selected. In addition, many objectives within each type of owner are involved in prequalification. These objectives are presented in the order of their descending priority: global objectives of the organisation, project objectives of a specific project, contractor prequalification objectives for obtaining the tenderers and contractor selection objectives for satisfying specific objectives. Amongst these objectives however, the project objectives, varying between projects and owners, are dominant. These objectives include minimising cost, minimising time, improving quality and improving safety.
  - Scope of work: The scope of work diagnoses both the types of construction and the relative sizes of the project. The types of construction considered are money demanded, labour or material concentrate, quality and type of equipment demanded, specialised trades or subcontractors implicated, the technology being executed and construction technology applicable. The

relative sizes of projects influence the degree of detail in the prequalification process.

- Resource demand: Resource plans are made before a project launches. Different resources are demanded for different projects. Therefore, different criteria are applied to different projects. The criteria securing a project consist of financial affairs, equipment, materials and man power.
- Constraints on the implementation of the project: Before a procurement strategy is selected, the sub-criteria affecting the implementation of the project are contemplated including government regulations (eg, cannot obtain a planning permit), resource availability (eg, labour, construction financing), geographic location of the project (eg, mobilisation) and public issues (eg, environmental impacts).
- Procurement strategy: The different procurement strategies influencing the characteristics of the owner are, for example, lump sum, reimbursable cost, design and build, construction management, time and material and unit price.

After all criteria meaningful to the process are selected, a hierarchy of the criteria describing the prequalification is developed. The hierarchy systematically supports the measurement of each criterion.

- **The contractor.** After the criteria important to the prequalification process are chosen based on the characteristics of the owner, the data pertinent to the criteria from the contractors who are willing to be qualified are gathered. The data may be obtained from inside or outside the contractor's organisation. The inner data consist of monthly progress reports, performance evaluation reports and comments from other owners.

The outer data are gathered by a questionnaire completed by the contractor providing the information: the company organisation, a list of past projects executed, a current balance sheet, a list of current projects under construction, experience of key personnel and references such as banks, trades, insurance companies, previous clients.

By asking several questions from the above references, the weaknesses and strengths of the contractor can be assessed. However, if the above references are biased and if the list of references is limited to the advantage of the contractor, careful consideration must be taken. Other sources include:

- credit rating sources (eg, a credit rating service company report)
- inspection of the contractor's home office and current sites. The inspection can reveal the operation of the contractor and the legitimacy and stability of the contractor in the business.

- **The decision.** A decision is made based somewhat on currently used techniques and on the bias of the decision-maker as follows.

  - **Decision techniques.** There exist five techniques in the USA.

    (a) Dimensional weighting

    - After the decision criteria and sub-criteria are determined based on the characteristics of the decision-maker, their weights of relative importance are stated.
    - Then, the selected criteria of each contractor are measured, and scores are used to communicate their amounts.
    - Next, the scores and their corresponding weights for all the criteria are multiplied together.
    - After that, the results of the multiplication for each contractor are aggregated into one overall score. Then, the abilities of the contractors can be ranked according to their scores.
    - Lastly, a simple rule is set up by specifying a number as a *threshold* that each contractor's score must reach in order to pass the prequalification.

    This technique can compensate for a contractor's scores amongst all criteria. That is, even if a contractor gets a low score from a criterion, the low score can recompense his high scores obtained from other criteria. As a result, this contractor may be qualified even if they obtain a rather low score from an important criterion.

(b) Two-step prequalification

- The first step is to select crucial criteria that must be satisfied. If contractors do not satisfy any of these criteria, they will be rejected from the tendering process. However, if successful at the first step, the contractors will continue to be qualified in the second step.
- The second step does the same as the dimensional weighting technique.

This technique can quickly exclude unqualified contractors, and then the decision-maker concentrates only on the qualified contractors. On the other hand, this technique may exclude some outstanding contractors. This is because some outstanding contractors may have good characteristics in the criteria which are not considered in the first step (Russell and Skibniewski, 1988).

(c) Dimensionwide technique

- After the prequalification criteria are selected, they are formulated as a hierarchy with respect to their descending order of relative importance.
- Next, the highest criterion in the hierarchy (reflecting the most importance) is qualified by using the last step of the *dimensional weighting* technique.
- After that, the next highest criterion is qualified. This repeats until all the selected criteria are qualified.

This process stops whenever the contractor does not satisfy any criterion in the hierarchy.

(d) The prequalification formula. The aim of the formula is to diminish the bias of the decision-maker against any particular contractor. In using this

technique, the decision-maker sets up a formula to quantify the maximum capability of the contractor. This capability (based on the financial criterion) indicates the maximum amount of a job or project that the contractor can execute at a specific time. However, the final formula may be tailored by other criteria such as organisation and key personnel, planning and equipment, credit and past performance.

(e) *The subjective judgment.* Performing subjective judgment is a rather unstructured approach. The bias of the decision-maker may affect the final decision. This possibly leads to bias in qualifying the contractors.

- **Decision bias.** Besides the previous five techniques, many biased items influence the final decision in the prequalification process. The explanation of the causes and effects of such bias makes the practical prequalification decision-making understandable. The causes of the bias come from either inside or outside the owner's organisation as follows:

    - Owner's preference: The previous working relationship between the owner and a contractor guide the preference of the owner. That is, if the contractor understands the owner's needs and how the owner performs work, trust or distrust between the two parties may develop. This trust or distrust possibly leads to bias in qualifying contractors.
    - Owner's risk attitude: The risk attitude of management influences the prequalification process performed and the rigour of the criteria employed.
    - Organisation infrastructure: The more complex the organisation, the more the bias tends to occur. This may be because many individuals are involved reflecting many conflicting objectives.
    - Resource constraints: The lack of either financial capability or personnel expertise of the owners leads to bias in prequalification.
    - Owner's personnel. If the owner's personnel or representatives have not enough capability, assessment of contractor's ability may be improper perhaps resulting in an incorrect decision. On the other hand, if the

contractor's personnel form good relationships with the owner's personnel or representatives, this contractor tends to succeed in prequalification.

- Construction technology: The owner tends to prefer the contractor who uses technology that the owner trusts.
- Economic condition: The details of the prequalification process and the rigour of the criteria employed vary with market conditions.
- Government regulations: Failure to comply with government regulations makes the contractor unsuccessful in prequalification.

2.2.2.2 Advantages and limitations

There are several advantages and limitations of undertaking prequalification for both owners/clients and contractors (Hatush, 1996; Liston, 1994ab, 1999; Russell and Skibniewski, 1988).

- Advantages
  - Reducing owners risk by obtaining the qualified contractor to do a specified project
  - Ensuring the owners/clients' objectives are satisfied such as minimising cost, minimising time, improving quality, and improving safety
  - Reducing time and cost of the following process of tender evaluation
  - Saving expense in preparing bids of unqualified contractors
  - Preventing incapable contractors from being involved in tendering
  - Possibly reducing losses for the surety bonding companies due to contractor failure
  - Encouraging reputable contractors by increasing their chance of success
  - Reducing the chance of loss of suppliers resulting from contractors going into liquidation
- Limitations
  - Increasing additional cost and time in performing prequalification, which result from the preparation of prequalification documents.

- Possibly resulting in higher bid cost due to the reduced number of tenderers. This is perhaps because the more the number of tenderers, the more competitive in bidding. Two possible reasons why the bid cost is forced down when many competitors exist: "one being due to estimating variability and the other being price cutting" (Harris and McCaffer, 1983).
- Prohibiting new contractors who have little experience in a specified project, if past experience is considered important to the project.

2.2.2.3 Prequalification process

2.2.2.3.1 Selecting objectives

Different owners/clients use different techniques resulting from different objectives. The objectives also affect the selection/development of criteria and their weights of relative importance. However, the project objectives are the most influential to the prequalification process, which always differ between projects and owners/clients (Russell and Skibniewski, 1988).

2.2.2.3.2 Selecting/developing criteria

Criteria meaningful to the prequalification process can be developed by, for example:

- finding the degree of importance placed on the criteria from prequalification practitioners through a questionnaire or individual interviews; then statistically analysing their degree of importance to determine the most meaningful criteria.
- developing the criteria as a hierarchy based on the knowledge base of a group of prequalification practitioners. Then, the hierarchy of the criteria is verified by another group of practitioners.

However, there is no universal acceptance for a set of prequalification criteria. These criteria may be subdivided into lower criteria as a hierarchy, which aims at measurement. The meanings of these criteria become clearer when moving down through the hierarchy.

2.2.2.3.3 Gathering data from candidate contractors

The data relevant to the selected/developed criteria can be obtained from inside and outside the contractors' organisations, for example, monthly progress reports, performance evaluation reports, comments from other owners, a questionnaire completed by the contractors, credit rating sources, inspection of contractors' home office and current sites, banks, trades, insurance companies and previous clients. However, the level of difficulty for data acquisition varies largely with the desired level of information reliability of the decision-makers and with the accessibility of data sources (Russell and Skibniewski, 1988).

2.2.2.3.4 Evaluating the contractor data against the criteria

In this step, multiple decision-makers always involve (1) assessing the value of each selected criterion for each contractor and (2) assigning weights of relative importance to the criteria.

To assess the value of each criterion, the decision-maker has to deal with the issues of measurement difficulty, conflicting direction of improvement and non-commensurate ability for interrelating all criteria – the interrelation or modelling are reviewed in Section 2.4. To cope with these issues, various researchers (eg, Diekmann, 1981; Hatush (1996), Hatush and Skitmore (1998) and Liston (1994ab) suggest different models in which uncertainty is included.

The weights of relative importance are always assigned to the criteria. These weights depend on specific conditions of the project (Russell and Skibniewski, 1988) and the decision-maker's preference. These weights can be obtained by, for example:

- directly stating preference by asking subjective questions
- performing regression analysis by asking less subjective questions
- performing a *pairwise comparison* using *trading-off* between criteria.

2.2.2.3.5 Qualifying/ranking the contractors

As a result of the previous step, a contractor may be qualified or unqualified. The qualified contractors can be ranked according to their ability (outputs from the previous evaluation).

2.2.3 Tender evaluation

Tender evaluation is the process of selecting the *best* contractor from many invited contractors to complete a project specified by the owner or their representatives (Nguyen, 1985). This process may be performed with or without prequalification.

2.2.3.1 Tender evaluation procedures

If owners/clients wish to enter into contracts with contractors in order to obtain the construction of facilities, the owners have first to arrange to obtain tenders from the contractors. Tenders are invited in one of the three broad procedures (Liston, 1999).

- Open tendering. This procedure allows any contractors to submit a tender for a project. This procedure also involves an owner/client or their representatives placing a public advertisement in the national and/or technical press, giving a brief description of the project and inviting contractors to apply to the owner/client or to their representatives for the contract documents before making a bid. This invitation does not bind the owner/client to accept the lowest or any tender (Liston, 1999). In this procedure, tenders will be evaluated after all tenders are submitted. This procedure can be subdivided into the following steps:
    - inviting tendering
    - receiving tenders
    - evaluating tenders (usually based on the lowest bid)
    - pre-award meeting (including price negotiation)
    - awarding a contract.

- Selective tendering. This procedure consists of drawing up a short list of contractors that are known to have the appropriate qualifications to carry a project. Such a list can be drawn up from the experience of the owner/client and their advisers or from prequalification. This procedure can be subdivided into the following steps:
  - inviting contractors for entry to a short list
  - receiving contractors' data
  - prequalifying the contractors (optional)
  - having a short list of contractors
  - inviting tendering
  - receiving tenders
  - evaluating tenders (usually based on the lowest bid)
  - pre-award meeting (including price negotiation)
  - awarding a contract.

- Negotiated tendering. The essence of this procedure is that an acceptable tender is arrived at by negotiation between a client, consultants and a single contractor without necessarily obtaining competitive tendering. Because this procedure involves high subjective judgment, it will not be further investigated in this research.

2.2.3.2 Competitive bidding concepts

In the USA, the concept of competitive bidding is deeply rooted (Herbsman and Ellis, 1992). This concept has been in practice in New York since 1847 (Harp, 1988). Also in the UK, this concept is currently used (Holt *et al.*, 1993). The lowest bid system is the basic idea behind this concept. However, selecting the lowest bid price does not mean selecting the lowest cost for completing the work. The problems of unreasonably low bids, bid rigging, unqualified contractors and so on have happened during the last two centuries (Herbsman and Ellis, 1992). In response to such problems, modifications to this system have been introduced (Moselhi and Martinelli, 1990). These two (lowest bid and modified lowest bid) concepts are explained as follows:

- Lowest bid concept. The concept is to guarantee that the public obtain the high benefit of fair and free competitive bidding at the lowest price offered (Herbsman and Ellis, 1992 after Cohen, 1961; Netherton, 1959). Some advantages of this concept are (Hatush, 1996):
  - preventing mismanagement by officials
  - proving that money is spent as a consequence of fair and free competition
  - protecting the public from corruption by officials.

  However, disadvantages of the concept are:
  - the lowest bid prices do not mean the lowest cost at completion
  - the lowest bid prices might result from misconceived bid analysis
  - the lowest bid prices might not be the most realistic bid (Merna and Smith, 1988).

- Modified lowest bid concept. This concept suggests that the best bid is the most reasonable one, not the highest or lowest one, but the one closest to some average (Herbsman and Ellis, 1992). This concept is used in several countries in Europe such as France and Portugal (Herbsman and Ellis, 1992). Also, variations of this concept exist.

However, Wong *et al.* (2001) have conducted a survey in the UK to find the owner's preference for multicriteria or for lowest bid price in selecting the best contractor. The survey concludes that the UK construction industry is moving towards considering multicriteria as they perform tender evaluation rather than considering lowest bid price alone. This opens a way for developing multicriteria approaches in tender evaluation.

2.2.3.3 Types of tendering

In the UK, Hatush (1996) found that prequalification is deemed compulsory. All contractors have to be qualified before being awarded any contract. There exist two broad types of tendering according to time horizon.

- *Standing list tendering* where contractors are invited for a project from a standing list of competent contractors who wish to tender for the project; this is done every 1, 3, and 5 years.
- *Project tendering* where contractors are invited from a short list of competent contractors; this is done for every project.

Here, regardless of the timing of the prequalification, the two types of tendering function similarly to reduce the number of contractors and then the cost of unsuccessful tenders.

2.2.4 Discussion

Although several countries have modified the lowest bid system, the approach still focuses only on cost criterion. This possibly leads to the selection of an incompetent qualified contractor to complete a project. As a result, the problems of extensive delays in the planned schedule, cost overruns, low quality of work and an increase in the number of claims and litigation have still occurred (Herbsman and Ellis, 1992). Furthermore, workmanship suffers and more supervision from the owner is required (Antill and Farmer, 1991). Recognising these problems, several researchers (Hatush, 1996; Hatush and Skitmore, 1997abc, 1998; Herbsman and Ellis, 1992; Liston, 1994a 1994b, 1999; Nguyen, 1985; Russell, 1990; Russell and Skibniewski, 1988, 1990; Russell *et al.*, 1990; Russell 1996) have introduced multicriteria such as cost, time, quality, safety, past performance, resources, and procedure, to evaluate tenders. However, the use of these multicriteria models is still at the academic level and is not available to normal practitioners.

Moreover, in practice multiple decision-makers participate but few existing models for tender evaluation can handle multiple decision-makers. These decision-makers have different interests and judgments regarding the relative weighting due to their different experience, background, and attitude towards risk and uncertainty. Sometimes, the problem of selecting a contractor changes to the problem of arguing between these multiple decision-makers about what weights should be given to the selected criteria.

In conclusion, tender evaluation is faced with two main issues:

- multiple criteria which have:
    - measurement difficulty, conflicting direction of improvement and non-commensurate ability
    - different weights of relative importance
- multiple decision-makers which assign different
    - weights of relative importance to the same criterion
    - values to the selected criteria for each contractor.

However, there is a limitation in considering the involvement of multiple decision-makers in existing models. Therefore, the limitations of these tender evaluation models will be further analysed (in Section 2.4) to enable a survey of the tender evaluation procedures, criteria and actual models that industry employs to develop a realistic working model for tender evaluation to be determined.

2.3 Criteria for tender evaluation

2.3.1 Introduction

As mentioned in Section 2.2, tender evaluation is a decision-making process concerned with a variety of criteria. The key criteria suggested by the NPWC/NBCC joint working party (No Dispute, 1990) in the selection of a contractor are: (1) the selection must be fair and equitable, (2) the competition must be fair to all parties, (3) the tenderer should meet a predetermined minimum standard before tendering, (4) the tender document should be clear and concise, and (5) a system should be available whereby a contractor can demonstrate ability to perform. The last statement leads to development of a model which is concerned with a range of criteria.

The criteria developed should support the success of the project, or at least support the screening of the candidate contractors. In practice, the criteria are subdivided into lower criteria, and then further subdivided into lower criteria and so on. This subdivision creates a hierarchy of criteria. However, the criteria selected by various owners are different. Furthermore, when these criteria are subdivided into lower criteria as a hierarchy, the hierarchy is rather diverse – that is, for example a criterion may be located on different levels of the hierarchy developed by different owners. This diversification of hierarchies has been shown in various works of, eg, Hatush (1996), Hatush and Skitmore (1997b), Liston (1994ab, 1999), Russell and Skibniewski (1998), Russell *et al.* (1990, 1992).

Consequently, a main question arises. Is it possible to develop common criteria for industry in order to achieve the same objectives? If yes, repetitive effort will be reduced. This section will review the published work on prequalification criteria and tender evaluation criteria including measurement issues relating to these criteria. This section also introduces some of the theory of *hierarchy, multilevel, systems* to be used as a basis for developing a hierarchy of criteria for tender evaluation, which then enables the development of a hierarchy of tender evaluation criteria for the following questionnaire survey.

2.3.2 Prequalification criteria

In some countries, investigators have suggested prequalification criteria to evaluate the ability of contractors to satisfactorily complete a contract if it is awarded to them.

In Japan, there are 5 ranking levels for contractors that will dictate the value of a project that the company is allowed to bid for. The factors affecting the ranking are average of the annual construction volume, stockholders' equity, number of engineers, current ratio (liquid assets: current liabilities), fixed assets to stockholders equity, net profit of total assets, number of years in business (Liston, 1999).

In the USA, Russell and Skibniewski (1990) suggested two different sets of criteria for public and private owners. The set of criteria for public owners consists of:

- Performance looking at record of failure on past projects, past performance, quality performance, project management capacities, staff available, control procedure over work performance, safety performance
- Type of contract looking at experience record, company organisation, equipment resources
- Capacity for assuming new projects looking at capacity of firm, capacity to add to this project, manpower resources
- Location looking at location of home office, experience in geographical location of the project
- Percentage of work performed looking at amount of work performed with own work force
- Third party evaluation looking at evaluation of references, bonding capacity
- Financial capacity looking at financial stability

The set of criteria for private owners is as follows:

- Management looking at control procedure over work performed, staff available, project management capacities, company organisation
- Safety looking at safety performance and substance abuse policy
- Location looking at location of home office, experience regarding geographic location of the project
- Performance looking at evaluation of references, past performance, quality performance
- Resources looking at manpower resources, equipment resources, amount of work performed with own forces
- Financial and experience looking at financial stability, experience record
- Failed performance looking at record of failure on past projects
- Bonding looking at bonding capacity
- Capacity for assuming new projects looking at capacity of firm, capacity to add to this project.

Later on, Russell (1990) and Russell *et al.* (1990) developed an expert system which suggested different criteria:

- References/Reputation/Past performance. This criterion (group of criteria) is of the highest priority. That is, the complete data to evaluate a contractor on this criterion have to be given by the contractor, if not, the contractor is disqualified from tendering. The criterion is subdivided into numerous lower criteria including reference evaluation; debarment; engagement in fraudulent action; failed contract; length of time in business; type of project performed in the past; the biggest project performed; capacity of contractors; bonding decision; bond cost as a percentage of project cost and union/open-shop consideration.
- Financial stability. The construction industry commonly operates under uncertainty. Therefore, the criterion of financial stability is crucial in that it secures the proposed project against unfavourable events. However, the nature of the industry is that there is often a limited amount of cash to deal with unfavourable events. In addition, some contractors run their business without knowing their financial stability. They only know they have financial problems if their business experiences difficulties. This criterion considers lower criteria as follows:

    - Credit rating: The sub-criterion shows the level of external financial requirements and the experience of cash-flow difficulties of the contractor. The information from trade suppliers, agents of credit-rating service, and credit reports helps to estimate this sub-criterion.
    - Banking arrangements: When the contractor does not have sufficient operating costs due to the lag between expenditures and payment received, the banking arrangements can supply financial resources for the contractor to continuously execute the project. Often, the contractor is not given credits to supply a loan. This causes the contractor to experience difficulties in continuously executing the project.
    - Financial statement: This sub-criteria is further described by:
        - Items related to the preparation of the financial statement of the contractor: the items, for example, are estimated by measures such as the number of accounting partners in the last 5 years, and the length of the relationship between the contractors and accounting agents.
        - Items impacting on the evaluation of a financial statement: the items, for instance, are estimated by measures such as adequate insurance coverage,

litigation in progress, unpaid union dues, and engaging in business ventures unrelated to construction.

- The financial data contained within the statement: The data are described by ratio analysis. This ratio analysis is subdivided into: solvency, reflecting the contractor's ability to satisfy short and long term obligations; efficiency, reflecting the manner in which the contractor employs and controls their assets; profitability, reflecting the success of the contractor in business.

- Status of current work program. This criterion estimates the existing work program as to whether it affects the achievement of the project being prequalified for. To further describe this criterion, two sub-criteria are selected: work under contract and bids waiting for award.
- Technical expertise. This criterion estimates candidate contractors' key management of their personnel and companies, and project management. This estimation shows both the availability of the basic technical knowledge, and experience and understanding of the requirements of the proposed project. This criterion is described by:
  - Company officers and key personnel
  - Work experience
  - Past performance
  - Company procedures consider company planning, estimating/bidding practices, staffing and managing projects, subcontractors administration, equipment maintenance program, purchasing and union agreements
  - Project control procedures consider the following sub-criteria: scheduling techniques, cost reporting and control systems, quality control systems and safety programs.
- Project-specific criteria. This criterion should be clearly understood by the decision-maker because this criterion can be used to investigate the consensus between the decision-maker and the contractor on:
  - location consideration
  - special equipment required
  - long lead items (special heating, ventilating, and air conditioning equipment)
  - construction of a plant that requires technology unfamiliar to contractors

- percentage of minority participating (disadvantaged business enterprise) on the project
- difficult working conditions
- labour or material intensive projects
- union-labour-agreement abnormalities
- performance standards demanded
- union-labour contract renewal date, considered future labour rate growth and its effect on cost
- hazardous materials
- project constraints such as schedule, environment, traffic, and weather.

Another work by Russell *et al.* (1992) proposed a set of criteria for prequalification:

- Financial stability looking at credit rating, banking arrangements, bonding capacity and financial statement
- Experience looking at success of completed projects, size of completed projects, number of similar completed projects and types of projects completed
- Information obtained from references looking at review of reputation and ethics of contractors, willingness to resolve conflicts and problems, change order frequency, schedule performance and number of times claims having gone to litigation
- Past performance looking at actual quality achieved (within specifications), actual schedules achieved, the number of times contractors have met the cost, quality and schedule
- Capacity of firm looking at last year's construction volume in dollars, construction volume dollars averaged over the last 3 years, current backlog of work in dollars, percentage of current backlog that an additional job represents, this year's employment (number of people), employment averaged over the last 3 years, employment trends and fluctuations, staff available for this specific project and the number of professional personnel
- Project control procedure looking at type of control procedures, type of safety program, type of cost control and reporting system, type of scheduling system, type of quality program, sophistication of control procedures, previous

experience with these procedures, and 'your' judgment as to whether management is able to use the procedures effectively

- Location of home office looking at home office location relative to job site location
- Geographic location of project looking at contractor's familiarity with weather conditions, contractor's familiarity with local labour agreement, contractor's familiarity with local politics, market conditions of the geographic area and contractor's familiarity with subsurface characteristics
- Safety looking at the existence of a contractor safety program and director, contractor's experience modification rate (EMR) for the last 3 years, information from OSHA log 200 accident reports, apparent management awareness of safety issues in the contractor's organisation, and contractor's faithfulness in conducting tool box meetings
- Project management capacities looking at key personnel experience including the number of years in construction and the projects worked on, complexity of past projects, appropriateness of project organisational chart, track records of quality of job (length of punchlist), track record-schedule, track record-cost, ability to deal with unanticipated problems, amount of decision-making authority in the field and amount of work performed with own forces on past projects
- Labour resources looking at the amount of labour available, quality of labour, existence of effectiveness of company training program and whether the contractor is union or non-union
- Company organisation looking at type of ownership (eg, partnership, corporation, sole owner...), number of years in construction, contractor's licenses held (by state and/or by category of work), number of failures to complete a contract and appropriateness of company organisational structure
- Company resources looking at type of equipment, size of equipment, condition of equipment, availability of equipment and suitability of the equipment for this project.

In the UK, Hatush (1996) and Hatush and Skitmore (1997b) proposed five criteria for prequalification:

- Financial soundness considering financial stability, credit rating, banking arrangement and bonding, and financial status
- Technical ability considering experience, plant and equipment, personnel and ability
- Management capability considering past performance and quality, project management organisation, experience of technical personnel and management knowledge
- Health and safety considering safety, experience modification rating, occupation safety and housing administration OSHA incidence rate and management safety accountability
- Reputation considering past failure, length of time in business, past client/contractor relationship, and other relationships.

In Australia, *proformas* have been developed by CIDA (1993) to collect information from contractors with respect to the criteria: technical capacity, financial capacity, quality assurance, time performance, occupational health and safety, human resource management and skill formation.

On the other hand, NPWC/NBCC (No dispute, 1990) suggests that to qualify contractors requires the information for initial acceptance which should then be updated annually: a minimum of two years' profitable operation, financial details, technical capacity, plant, machinery and staff resources, a list of current contracts.

In order to attempt to undertake the investigation in some realistic manner, seven criteria and proformas to collect information with respect to these criteria are provided by Liston (1994ab, 1999). These criteria are:

- Past performance considering the contractor's reputation within the industry, the reputation with unions, subcontractors and suppliers, the past performance for "your" company and others, the completion record, communication ability and specialist knowledge base
- Business considering the location of the contractor's offices, the business activities both base and ancillary, geographical knowledge, sibling relationships,

the ability to joint venture successfully, and joint ventures

- Capacity considering current contract values, previous contract values, outstanding tenders and personnel resources
- Financial considering legal entity, credit rating, financial ratios and banking arrangements
- Resources considering management, personnel ability, equipment availability and peak loading capacity
- Procedures considering overall procedures, responsibility matrix, control procedures, procurement procedures, engineering procedures and contract procedures
- Quality Assurance considering company procedures, audit capacity and company experience.

The review shows that although several hierarchies of criteria for tender evaluation and prequalification have been proposed, there is no consensus on which hierarchy should be used for prequalification or tendering evaluation. It is believed that this is because those hierarchies have not been developed corresponding to the hierarchy of an organisation.

2.3.3 Tender evaluation criteria

Various criteria used for prequalification are reviewed in the previous section. In this section, the criteria used for tender evaluation will be analysed. Practically, tender evaluation criteria just add cost criterion to prequalification criteria in order to select the best contractors.

In selection of contractors for a hybrid unit price cost-plus contract, Diekmann (1981) looked at four criteria, namely, cost exposure, company stability, quality of product, and management capacity. These criteria were subdivided into lower criteria as a hierarchy. Here utility is used to communicate the value of these criteria.
In addition, three criteria: cost, experience, and performance, were selected by Nguyen (1985). In his study, the non-commensurate issue is handled by *fuzzy sets*.
Furthermore, in the selection of a contractor in highway construction contracts,

contract cost and time are suggested by Ellis and Herbsman (1991). In this work, contract time is converted to cost by a conversion factor (eg, $7000/day). Later on, Herbsman and Ellis (1992) explained the concept of multiple criteria in a bidding concept in order to select the best contractor. Based on their experience, they suggested four criteria: cost, time, quality, and safety. To handle the non-commensurate issue amongst criteria, the last three criteria were converted to monetary value through the weights derived from trading off between these criteria and cost.

Although these researchers suggest different criteria, in common, cost received the highest priority.

2.3.4 Measurement of criteria

Measurement clarifies the meanings of criteria (Keeney, 1982). This usually leads to the creation of a hierarchy of these criteria. Also, the measurement is concerned with how to obtain information related to these criteria which is not focused on by this research.

When the criteria are subdivided into lower criteria, it may be that these criteria are rather loose or variously interpreted so they need to be described by lower criteria or descriptions for unambiguous communication. Practically, the criteria are subdivided until they are measurable (Keeney and Raiffa, 1976). If "too much" subdivision happens, finding the interrelation amongst a number of these subdivided criteria is difficult for modelling. However, if the lowest criteria being measured are still unclear, misinterpretation may occur. How much subdividing is proliferated depends somewhat on the sufficiency of the lowest criteria (in the hierarchy) to describe the higher criteria or the problem, the ability to analyse all the lowest criteria or to formulate a model, the decision-maker's judgment.

To conclude, the criteria can be measured by:

- themselves. That is, the criteria are objective (eg, cost and time) so they can be easily measured.

- a hierarchy of criteria. That is, the decision-maker wants to more clearly describe the higher criteria by proliferating them into lower criteria.
- subjective indices such as scores and utilities. That is, the decision-maker directly assigns *constructed* scales to the criteria in order to quantify them.
- proxy attributes. That is, the decision-maker indirectly measures the qualitative criteria by measuring the attributes that possibly closely describe the criteria.

2.3.4.1 Issues of multicriteria measurement

A previous review of the literature shows that the three main issues of multicriteria measurement in tendering evaluation are:

- Measurement difficulty. Some criteria have standard used scales that are widely accepted such as cost having "dollar" and time having "day." Whereas others have no standard scales such as quality and safety so they need constructed scales (eg, 1-10) for measurement. The idea of utility is helpful in handling this issue (review in Section 2.4.2.2.4).
- Conflicting direction of improvement. The directions of improvement of some criteria are opposite. For example, one wants to minimise cost and time but increase quality and safety. Again, using the idea of utility can solve this issue.
- Non-commensurate ability. Most criteria have different scales. To interrelate the criteria, assigning the same scale to all the criteria is necessary.

2.3.4.2 Scales

Before any scale is assigned to each criterion, the consciousness of measurement difficulty, conflicting direction of improvement and non-commensurate ability along with how to interrelate the criteria should arise. In practice, to solve all the issues a consistent scale is constructed and then assigned to all criteria. For example, in the problem of whether to bid or not, Ahmad (1990) assigned numbers between 0 and 100 to all criteria to avoid non-commensurate ability. To interrelate all criteria, weights were assigned to all criteria, which were derived from *pairwise comparison* through asking the subjective question – "How much less (or more) important is the second criterion than the first?" The pairwise comparison was simply done by comparing and asking the question between two criteria. Then, the weights of relative importance between the two were articulated. This was repeated until all criteria were paired off and compared.

On the other hand, Seydel and Olson (1990) introduced the concept of the tendering process as a continuous process until the percent mark-up selection. The purpose of this work was to select percent mark-up whilst multiple criteria were considered. They measured the multiple criteria by their weights – numbers between 1 and 9 – derived from the preference of the decision-maker.

In the selection of a contractor for cost plus contracts, Diekmann (1981) uses *utility* (ie, 0-1) to communicate the quantities of the selected criteria (ie, cost exposure, company stability, quality and management capacity). Here, these criteria are subdivided into two levels and weights are assigned to all levels to link these criteria.

2.3.5 Discussion

To support the success of the project or the screening of the candidate contractors, a set of meaningful criteria, a form of gathering data according these criteria and an approach for evaluating abilities of the contractors are necessary. In this section, the development of such a set of meaningful criteria is the main concern.

The review shows that although cost is still the most important criterion in tender evaluation, there is no consensus on a common set of (prequalification and tender evaluation) criteria. That is, different organisations/researchers use/suggest different sets of criteria. Thus, the first research aim is to develop a common set of criteria.

Nevertheless, what the criteria do have in common is that they are always in the form of hierarchy, in which the higher the levels of the criteria the more important they are. This is shown in the works of Hatush (1996), Hatush and Skitmore (1997b), Liston (1994ab), Russell and Skibniewski (1998), Russell *et al.* (1990, 1992).

Even though most researchers suggested the (prequalification and tender evaluation) criteria in a form of a hierarchy, all do not consider the physical hierarchy of organisations. This leads to a limitation of understanding potential success in designing hierarchical systems. These systems have been explained by the theory of *hierarchy, multilevel, systems* developed by Mesarovic *et al.* (1970), which suggests that any designed systems should be compatible with hierarchical organisational units and decision-making process.

An extension and application of the theory can be found in Anandalingam (1988), Dericx *et al.*, (1973), Jennergren (1974, 1976), Mahmoud (1977) Nachane (1984), Singh (1977), and Sundareshan (1977). The writer believes that if a hierarchy of the criteria is developed based on this theory, a common set of criteria will appear. This theory was used as a basis for the questionnaire design in Chapter 4. The following section is a discussion of the theory.

2.3.6 Theory of hierarchy, multilevel, systems

When a system is large and complex*, analysing it as an undivided system often involves great difficulty. This is partly because human capacities and tools such as computers and existing techniques are limited. To reduce the difficulty, therefore, the theory of *hierarchy, multilevel, systems* has been developed from organisational theory. This theory offers an alternative approach to analyse such large and complex systems.

The basic concept of the theory for solving multicriteria decision problems is applied by subdividing a (large and complex) problem into hierarchical subproblems. Each of the subproblems can be designed more simply and is easier to solve, eg, with less criteria or variables, than the original problem. However, to keep the subsolutions of the subproblems as a solution of the original problem, some parameters are selected always by higher level units to coordinate all the subproblems. If the appropriate

* Due to the difficulty of measuring the largeness and complexity, the largeness and complexity can be described by a number of components in the system, the coordination amongst each component, the existence of conflicting criteria amongst each component, and the uncertainty of environment (Mahmoud, 1977).

parameters are selected to capture this coordination, all the subsolutions of the subproblems will collectively comprise a solution to the original problem.

2.3.6.1 Characteristics

Some basic characteristics of the theory are:

- Vertical arrangement: any problem consists of a set of hierarchical subproblems, and decision units are assigned at every subproblem. The information such as parameters and feedback is always exchanged between any contiguous level.
- Right of intervention or priority of action: higher level units have the right to intervene in the activities of lower level units. This intervention, reflecting higher priority and higher objectives of the higher level units, may occur by modification of some parameters or procedures in the lower level units.
- Performance interdependence: the success of the original problem depends on all subsolutions of subproblems. To reach this success, the subsolutions of the subproblems must be evaluated with respect to the overall objectives of the original problem, and then send feedback to the higher level units. If the result of this evaluation does not satisfy the overall objectives, an adjustment of the parameters or procedures, or even the overall objectives, must be performed. This adjustment process is iterated until the overall, or adjusted, objectives are optimised/satisfied.

2.3.6.2 Success

Two main activities that make the systems succeed are: decomposition of the original problem into subproblems; and then coordination of the decomposed subproblems.

2.3.6.2.1 Decomposition

Decomposition means an original problem is subdivided into subproblems. The decomposition is a matter of design; for example, how many levels and subproblems should be generated and what the subproblems will be. However, it can be designed preliminarily based on, for example (Dirickx and Jennergren, 1979):

- Organisational hierarchy: the original problem is decomposed according to existing, organisational subunits. If the subproblems decomposed are not corresponding to the hierarchy of organisational subunits – possibly leading to the limit of cooperation, the subsolutions obtained from the subproblems tend to be meaningless for the original problem.

- Solution-searching or decision-making process: the original problem is decomposed in order to support the actual solution-searching process. If the subproblems are not compatible with this process – perhaps resulting in the acquisition of incorrect data, the original problem may not be able to be solved.

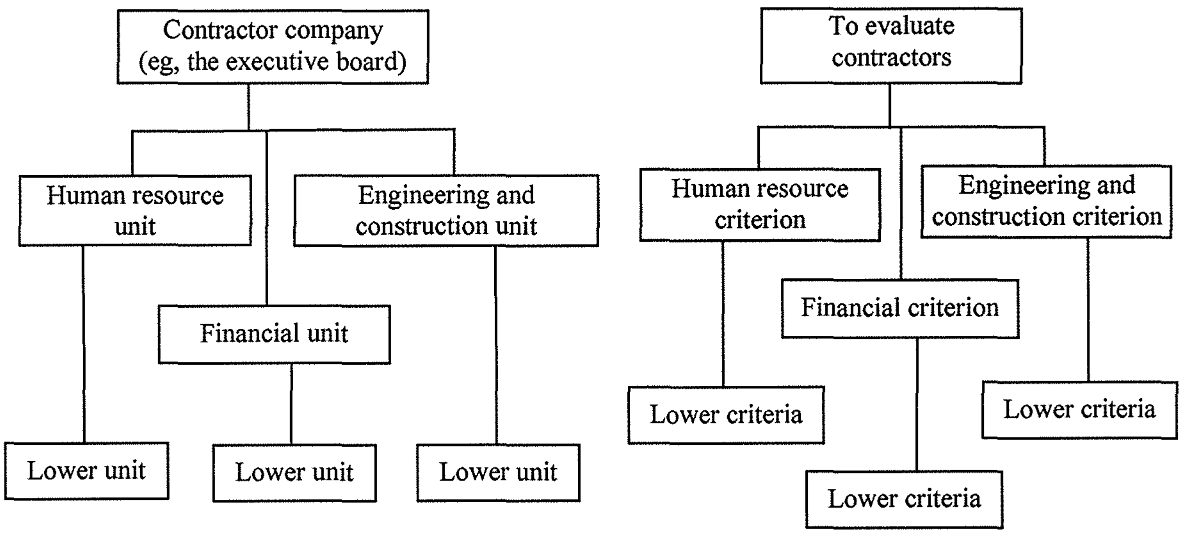
Most likely, the decomposition should be designed preliminarily according to both existing organisational hierarchy and the solution process. In other words, the subproblems decomposed and organisational subunits should correspond, and this correspondence is then employed in the actual solution process. This can secure the success of solving the original problem at a certain level.

2.3.6.2.2 Coordination

After the original problem has been decomposed into hierarchical subproblems being in charge of any organisational subunits, these hierarchical subproblems must be coordinated together by the higher level units in order to make them equivalent to the original problem – actually there are interdependences amongst these subproblems as described in section 2.3.6.1. Such coordination is done by finding parameters for the intervention and feedback for the response of the subunits. The success of the coordination depends primarily on whether the parameters and feedback can be found.

2.3.6.3 Application of the theory to this research

In the application of the theory to this research, the development of a hierarchy of criteria should be compatible with existing organisational units of contractors as is shown in the paradigmatic diagram in Figure 2. A main advantage of using this theory is that the hierarchy based on organisational units facilitates the tender evaluation if multiple decision-makers involve. For example, the evaluation of financial criterion can readily be given to the decision-maker from the financial unit and procurement criterion goes to one from the procurement unit.



A hierarchy of criteria

A hierarchy of contractors' organisational units

Figure 2 A diagram of a comparison between a hierarchy of contractors' organisational units and a hierarchy of criteria

However, this hierarchy may differ between contractors because they have different organisational structures. In the light of such differences, in this research the developed model was flexible enough to adapt itself to the different organisational structures of contractors. This adaptation also offers the opportunity to include multiple decision-makers' preferences resulting from, eg, delivery system selected, type and size of project and scope of work. This enables the decision-maker to adjust the hierarchy of criteria to a specific situation. Furthermore, a computer interaction can be extensively applied to this adaptation.

2.4 Models for multicriteria problems

2.4.1 Introduction

Where a decision has to be made regarding choices, decision-makers have to deal with multiple criteria. In the analysis of multicriteria problems, a number of models have been suggested. The models have been developed from various fields including business, engineering, academia, planning and marketing (see Cohon, 1978; Goicoechea *et al.*, 1982; Haimes and Chankong, 1979; Haimes *et al.*, 1975; Saaty, 1982, 1994; Saaty and Alexander, 1989; Saaty and Kearns, 1985; Saaty and Vargas, 1991, Szidarovszky *et al.*, 1986). This is why so many models exist. All the models attempt to manage the issues of measurement difficulty, conflicting direction of improvement and non-commensurate ability, which require subjective inputs from decision-makers, in order to interrelate these criteria.

In this section, all the models are classified into two groups based on disciplinary area: (1) optimisation approaches which are subdivided into two groups namely, (1.1) *post-subjective input models* and (1.2) *pre-subjective input model*; and (2) interactive approaches which are subdivided into three groups namely, (2.1) interactive optimisation models, (2.2) decision support systems, and (2.3) expert systems. The purpose of this classification is to address the inherent similarities and identify a state-of-the-art model for developing a realistic working model to solve multicriteria problems. This section also includes some multicriteria models that exist in the tender evaluation area. The following are structured according to this classification.

2.4.2 Optimisation approaches

Most problems have been solved by considering only one criterion, for example cost or time, since the early development of operations research. However, there has been an increased need to simultaneously consider more than one criterion in analysing problems such as water resources (see Cohon, 1978; Cohon and Marks, 1974;

Haimes and Chankong, 1979; Haimes *et al.*, 1975; Major, 1974), industry, transportation, finance, academia, land use (see Goicechea *et al.*, 1982), airport development (see de Neufville and Keeney, 1974), nuclear power plants (see Keeney and Nair, 1977), and forest problems (see Bell, 1977). To handle several criteria, multicriteria optimisation (where an ultimisation is required for more than one criterion) exists.

Multicriteria optimisation (maximisation or minimisation) can be explained as a process of searching for a single measure of merit of a solution that is greater than those of other solutions. If, for example, a solution has the greatest utility when compared to others', the solution is optimal. However, knowledge and information are incomplete and limited. There are also cost, time, environment forces, technical advancement and implementation issues that constrain the effort spent in searching for the optimal solution. In addition, the capability of humans to formulate and solve complicated problems is usually, in reality, insufficient. Consequently, multicriteria optimisation can be achieved subject to constraints and limitations of a particular situation as shown in Figure 3.

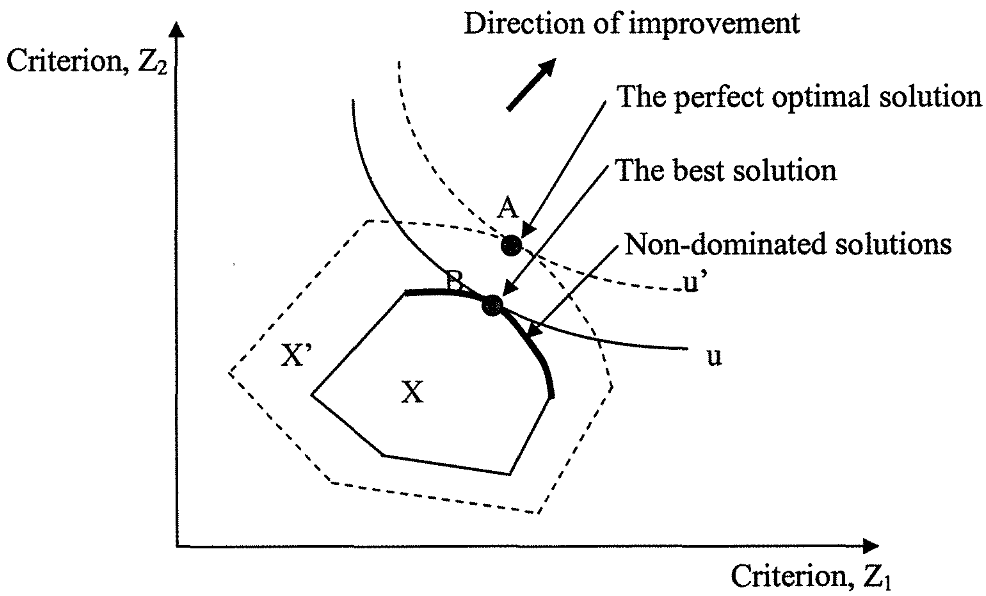


Figure 3 Multicriteria optimisation under constraints in criteria space (adapted from Zeleny, 1982: 65)

According to Figure 3, assume X' denotes the perfect set of solutions; then, maximisation of a constructed single objective (max $U(Z_1, Z_2)$) obtains the solution having the highest value at point A, *the perfect optimal solution*. In reality due to the constraints and limitations discussed earlier the perfect set of solutions will not exist. Then maximisation of a constructed single criterion will be done under the constrained set of solutions, X, and yield the new solution having the constrained highest value at point B, the *best* solution.

Nevertheless, the existence of the optimal solution for mulcriteria problems is rare, which means in general there will be more than one solution for multicriteria problems. Such solutions are termed *non-dominated solutions*, *non-inferior solutions*, *Pareto optimal solutions*, *productive efficient frontier*, or even *bargaining solutions* or *admissible solutions* (Zeleny, 1982). An increase in value of any one criterion of a non- dominated solution can be achieved by sacrificing the value of at least one other criterion, which leads to using value trade-offs that reflect subjective judgment and personal difference. Any non-dominated solution selected as the final solution is called the *best, best compromise, or preferred solution*. The selection of any non-dominated solution as the final solution requires subjective inputs from decision-makers whilst these inputs are not necessary for single criterion problems.

Many approaches have been suggested for finding a solution to multicriteria problems. All the approaches require subjective inputs although this occurs at different stages of the solution-searching process. What follows is a review of the literature classified into two groups according to the timing of stating subjective inputs: (1) *post-subjective input models* and (2) *pre-subjective input models*. This classification proposed by the writer permits us to address the similarities, differences, advantages and limitations of the various approaches, and leads to the identification of a state-of-the-art model.

2.4.2.1 Post-subjective input models

Here, subjectivity arises in *the trading-off process* as shown in Figure 4. That is, after all non-dominated solutions are obtained, the decision-maker trades off between these non-dominated solutions in order to select the best solution. These trade-offs require subjective inputs from the decision-maker about how much of a criterion they want to sacrifice to gain at least one of the other criteria.

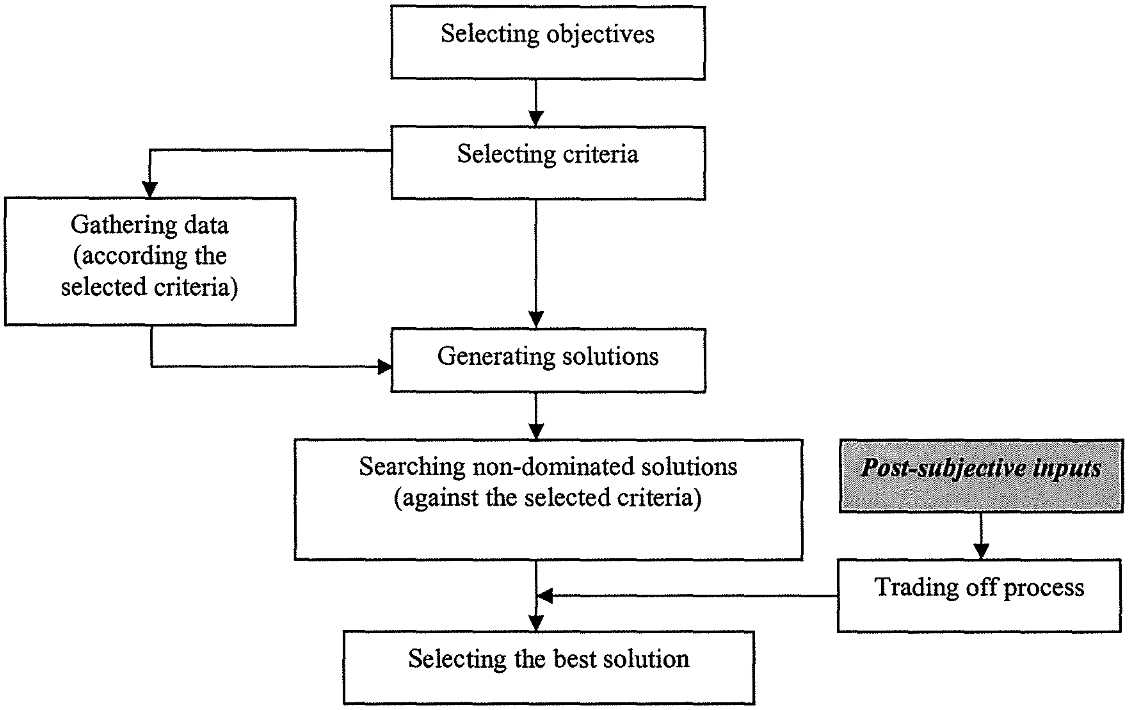


Figure 4 Solution-searching process showing *post-subjective inputs*

2.4.2.1.1 *Linear multiobjective programming*

Linear multiobjective programming attempts to find non-dominated solutions in association with the *multiobjective simplex method* (Zeleny, 1982). This programming operates directly on each objective to find whether an *extreme* solution is a non-dominated solution. This is repeated for all other extreme solutions until a set of non-dominated solutions are found. The preferred solution then is selected by *trading-off* the non-dominated solutions, which involves subjective judgment.

A linear form of this programming can be written as follows (see Zeleny, 1974, 1982):

$$(\min) Z = \sum_{i=1}^{L} \sum_{j=1}^{n} c_{ij} x_j$$

with constraints $g_r(x) = \sum_{r=1}^{m} \sum_{j=1}^{n} a_{rj} x_j = b_r$

where $Z = (Z_1, ..., Z_L)^T$ is a vector of criteria

$x = (x_1, ..., x_n)^T$ is a vector of decision variables

X represents the feasible value set for variable x ($x \in X$)

c_{ij} represents coefficients

a_{rj} represents coefficients, indicating how much of the r^{th} resource must be expended per each unit of increase in x_j

L is the number of objective functions

n is the number of decision variables

b_r is the values of the availability of the r^{th} resource

m is the number of constraint functions.

An algorithm of this programming is as follows:

- Linear multiobjective programming starts by exploring all extreme feasible solutions. This exploring can be accelerated by additional techniques such as *Multiobjective Simplex Method*, MSM, (see Zeleny, 1974, 1982). MSM is a mathematical technique that analyses only extreme feasible solutions.
- The MSM, then, tries to find non-dominated solutions from all the extreme solutions. That is, if the first non-dominated solution is found, the MSM technique will move to another extreme solution and analyse whether this solution is non-dominated or not. This will be iterated such that a set of non-dominated solutions are found.
- Lastly, as a set of non-dominated solutions are found, the decision-maker must trade off between these non-dominated solutions in order to select a final solution.

2.4.2.1.2 *Compromise programming*

Compromise programming (Zeleny, 1982) is a further development of linear multiobjective programming. The programming is basically similar to the linear multiobjective programming but the *ideal* solution as a point of reference is set to facilitate the trading-off process. However, the trading-off process is still subjective. A mathematical form of this programming can be written the same as that of linear multiobjective programming. An algorithm of this programming is as follows:

- Firstly, compromise programming performs the analysis of all feasible solutions by analysing only extreme feasible solutions, and then finds a set of non-dominated solutions.
- Secondly, the ideal solution is invented. It may be fuzzy in the early stage, but may become clearer later along the analysis. However, the ideal solution can be initiated by, for example, combining some extreme values from each non-dominated solution.
- Lastly, after a set of non-dominated solutions and the ideal solution are located, then the preferred solution is determined by selecting the non-dominated solution that has the shortest distance to the ideal solution. Any distance can be measured by, for example, Pythagorean measure.

For an understanding of the programming, Figure 5 from Zeleny (1982) with minor modification demonstrates an artefact example of two conflicting criteria.

According to Figure 5, assume the crosshatched area roughly indicates the bound of the conflict located between the ideal solution and non-dominated solutions. The larger the area, the more the conflict, when the area disappears, the conflict is resolved. The non-dominated solutions represented by the heavy line represent a region of compromise. If the final solution is selected from the non-dominated solutions, the conflict can be resolved. However, the conflict is not removed; it may not be reduced but it is suppressed by, for example, skills of (1) discussion, (2) negotiation, and (3) persuasion. The conflict may emerge again in the future. This means the conflict has not been resolved.

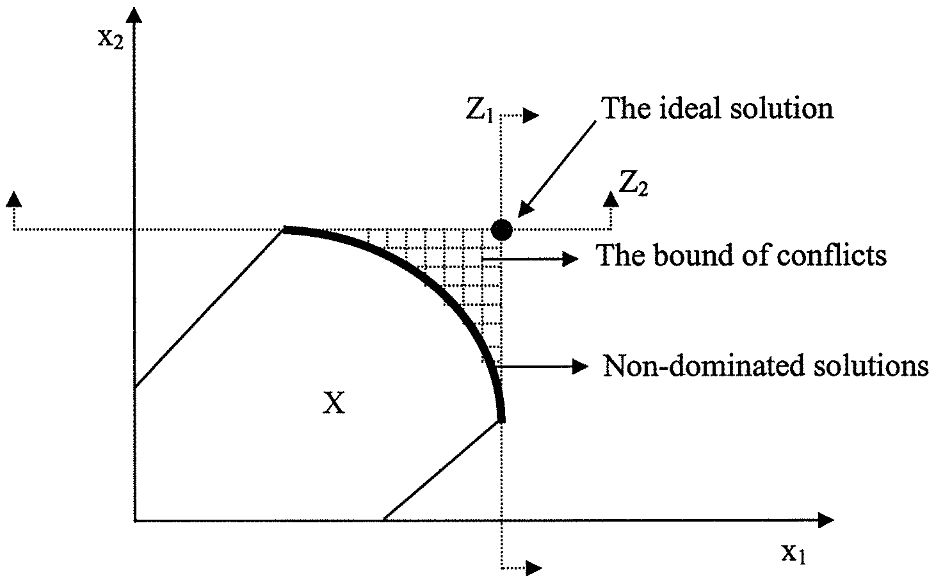


Figure 5 Using the ideal solution to handle two conflicting criteria in variable space (adapted from Zeleny, 1982: 118)

However, both types of programming perform on each objective directly. They do not pre-specify a set goal and assign weights to the objectives. As a result, the computations for non-dominated solutions are time-consuming if numerous variables are involved (Cohon, 1978; Goicoechea, Hansen and Duckstein, 1982). For example, in a problem where there are 7 criteria (objectives), 20 constraints and 50 variables the number of all extreme solutions can be up to $50!/(20! \times 30!) = 4.71 \times 10^{13}$ solutions. This represents a limitation resulting from a significant computational load in finding a set of non-dominated solutions. Hence, this makes these types of programming the least attractive.

2.4.2.2 Pre-subjective input models

Here decision-makers have to state their subjective inputs before the optimisation process as shown in Figure 6. The subjective inputs can be stated in various forms, namely, a pre-specified set goal, weights and a utility function. Each model requires different forms of subjective inputs.

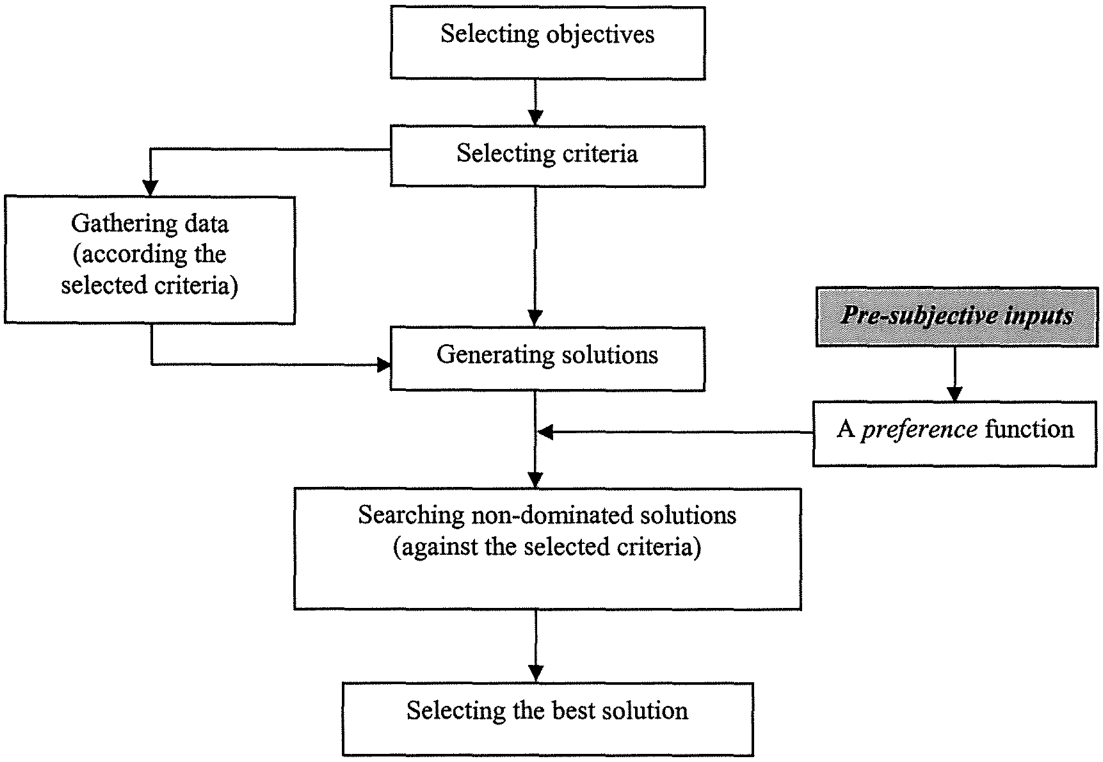


Figure 6 Solution-searching process showing *pre-subjective inputs*

2.4.2.2.1 Goal programming

Goal programming attempts to set levels of aspiration or points of reference for the decision-maker to strive for. This leads to fixing a specified set goal for each criterion and trying to achieve the specified set goal as closely as possible or to minimise deviations from the specified set goal.

In effect, all criteria are assembled into a constructed single criterion by fixing a pre-specified set goal for each criterion as a point of reference. The solution selected as the final solution collectively minimises deviations from a pre-specified set goal. A linear form of goal programming can be written as follows (see Daellenbach, George and McNickle, 1983; Lapin, 1991; Steuer, 1986; Zeleny, 1974, 1982):

$$(\min)\ Z \quad = \quad \sum_{i=1}^{L} (d_i^+ + d_i^-)$$

with constraints $x \in X$

where $d_i^+ = Z - \bar{z}$ denotes the deviations above a pre-specified set goal

$d_i^- = \bar{z} - Z$ denotes the deviations under a pre-specified set goal

$\bar{z}$ is a pre-specified set goal.

Goal programming can be broadly classified into two versions: pre-emptive goal programming and non pre-emptive goal programming.

The algebraic form of pre-emptive goal programming is basically the same as goal programming. The main difference is that dramatically different weights are assigned to the deviations implying vastly different weights of relative importance of criteria. To obtain a solution, higher weight criteria are satisfied first, and then the lower weight criteria may be considered. In this programming, the selection of the pre-emptive weights depends on the subjective judgment of the decision-maker. The constructed single criterion can be written in a linear form as follows (see Daellenbach, George and McNickle, 1983; Lapin, 1991; Steuer, 1986; Zeleny, 1974, 1982):

$$(\min)\ Z = \sum_{i=1}^{L} W_i(d_i^+ + d_i^-)$$

with constraints $x \in X$

where W_i denotes pre-emptive weights.

The other version is non pre-emptive goal programming which uses a similar concept to that of pre-emptive goal programming but non-dramatically different weights are given to the deviations; therefore all criteria are considered simultaneously. The solution selected as a final solution collectively minimises weighted deviations from a pre-specified set goal. Here again, selecting the weights depends on subjective judgment. In this version, the constructed single criterion can be written as follows (see (Daellenbach, George and McNickle, 1983; Lapin, 1991; Steuer, 1986; Zeleny, 1974, 1982):

$$(\min) Z = \sum_{i=1}^{L} w_i(d_i^{+}+d_i^{-})$$

with constraints $x \in X$

where w_i denotes non pre-emptive weights.

An algorithm of the goal programming is as follows:

- Goal programming starts by exploring all extreme feasible solutions. This exploring can be accelerated by additional techniques such as *Multiobjective Simplex Method*, (Zeleny, 1974, 1982) MSM.
- The MSM, then, tries to find non-dominated solutions from all the extreme solutions. That is, if the first non-dominated solution is found, the MSM technique will move to another extreme solution and then analyse this solution to determine whether it is non-dominated or not. This will be iterated such that all non-dominated solutions are found.
- Lastly, as a set of non-dominated solutions are found, the decision-maker must trade off between these non-dominated solutions in order to select a final solution.

Goal programming has several weaknesses. One of these is that it uses the idea of satisfying for analysing solutions. Simon (1976: xxviii) explains satisfying: *of the behavior of human beings who satisfice because they do not have the wits to maximize.*

This explanation is supported by Zeleny (1982:63): *an attempt to attain prespecified aspiration levels or goals with respect to given criteria when in fact, satisficing is the outcome or end result of an incomplete or unsuccessful attempt at optimization.*

These two explanations of satisfying, which the goal programming is based on, present some drawbacks of goal programming. Zeleny (1982) presents an artefact example to support his explanation as shown in Figure 7.

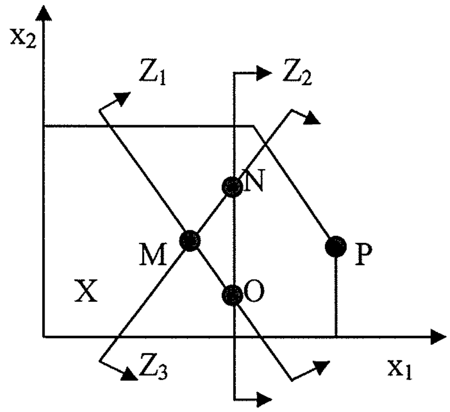


Figure 7 Goal programming may produce the final solution that is not a non-dominated solution in variable space (adapted from Zeleny, 1982)

As in Figure 7, three criteria, Z_1, Z_2 and Z_3, are fixed by a pre-specified set goal. By using goal programming to minimise d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, and d_3^-, the solution M can be obtained. At this solution, M, Z_1 and Z_2 are totally satisfied ($d_1^- = d_2^- = 0$), and Z_3 is moved towards as close as possible (d_3^- is minimised upon X). Clearly, this solution, M, is dominated by many solutions such as N, O and P. This shows that whether any solution selected as the final solution is a non-dominated solution depends largely upon the pre-specified set goal. In other words, the final solution may not be a non-dominated solution.

Furthermore, in this programming (either pre-emptive or non pre-emptive goal programming) the choice of a pre-specified set goal is frequently difficult to accept. Therefore, the pre-specified set goal may be adjusted during the analysis.

2.4.2.2.2 A weighting method

The weighting method manages to reduce multicriteria problems by transforming it into a series of single criterion problems, which are easier to solve. In this method, weights are assigned to individual criteria according to their relative importance to construct a new single criterion. Then the weights are varied in order to generate non-dominated solutions by solving (Cohon, 1978; de Neufville, 1990; Goicechea *et al.*, 1982; Haimes *et al.*, 1975):

$$(\min)\ Z = \sum_{i=1}^{L} w_i Z_i(x)$$

subject to $x \in X$.

An algorithm of this method is as follows:

- The weighting method explores all extreme solutions by optimising (eg, using *a simplex method*) each criterion one by one. This can be done by, for example, alternately adding the weight 1 to a criterion and the weight 0 to the remaining criteria.
- Next, two criteria with their weights are paired and then optimised under constraints. This process is repeated with varying weights until non-dominated solutions are found.
- Lastly, a pair of criteria is alternated. The above process is repeated until all criteria are paired off. A number of non-dominated solutions may be found, and then are traded off to select a final solution, which reflects subjective judgment.

This method may fail to find some non-dominated solutions, only if the surface of the non-dominated solutions is slightly concave; then may suggest no existing non-dominated solutions (de Neufville, 1990). This is illustrated in Figure 8 in which the portion AB is suggested as non-dominated solutions but on that portion feasible solutions do not exist.

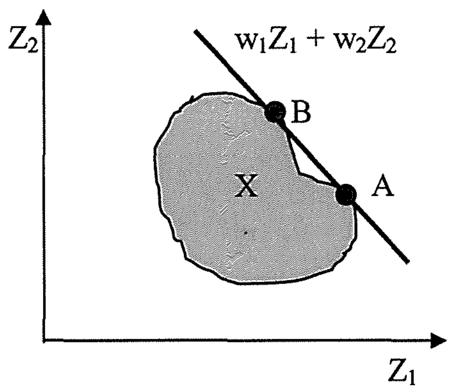


Figure 8 Portion AB is suggested as non-dominated solution in which feasible solutions do not exist in criteria space (adapted from de Neufville, 1990)

2.4.2.2.3 A constraint method

Like the weighting method, the constraint method analyses solutions against multicriteria by converting a multicriteria problem into a series of single criterion problems. In this method, a criterion is optimised first whilst the remaining criteria are converted into constraints by specifying values for the remaining criteria. Varying these values yields non-dominated solutions by solving (Cohon, 1978; de Neufville 1990; Goicechea *et al.*, 1982; Haimes *et al.*, 1975):

$$(\min) Z = Z_i(x)$$

$$\text{subject to} \quad \sum_{r=1}^{L} Z_r(x) \leq \varepsilon_r \qquad r \neq i$$

$$x \in X$$

where ε_r is a specified value.

Haimes *et al.* (1975) explain that, from a utility viewpoint, the benefit to society from criteria Z_r is constant as long as Z_r does not go above ε_r, but becomes eternally damaging below this level. That is, the utility function becomes additive with:

$$\text{utility of } Z_r(x) = \begin{cases} \text{a constant} & \text{if } Z_r(x) \leq \varepsilon_r \\ -\infty & \text{if } Z_r(x) > \varepsilon_r. \end{cases}$$

An algorithm of this method is as follows:

- The constraint method explores all extreme solutions by optimising each criterion one by one excluding any constraints on the other criteria.
- Next, a pair of two criteria is set. One criterion is optimised; the other acts as a constraint and vice versa. If there are more than two criteria, a triplet and more is

set. One criterion is optimised; the others are treated as constraints, and then another criterion circulates to be the sole criteria. This process is repeated until all criteria are paired off.

- Lastly, a number of non-dominated solutions may be found. The decision-maker, then, trades off to select a final solution, which subjectivity arises here.

Here, if the variations of the values are set in small increments, this causes a heavy computation load (Goicoechea *et al.*, 1982). Furthermore, if there are more than two criteria, the method consumes much computational effort to produce non-dominated solutions because the process of searching non-dominated solutions may involve infeasible solutions only if the surface of non-dominated solutions is slightly concave (de Neufville, 1990). Figure 9 illustrates this.

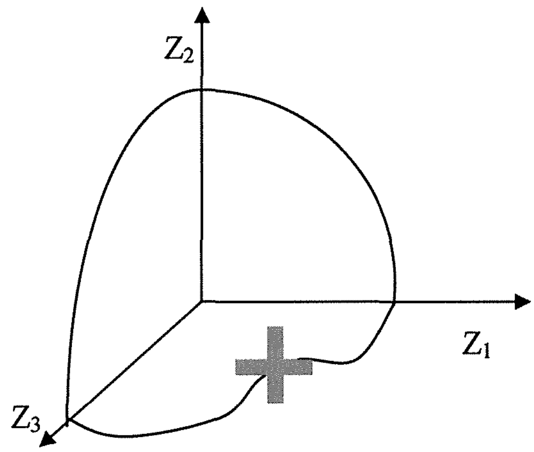


Figure 9 Shaded area is suggested as non-dominated solutions in which feasible solutions do not exist in criteria space (after de Neufville, 1990)

2.4.2.2.4 A utility function

The previous review of the literature has not considered risk arising from uncertainty in the analysis of multicriteria problems. However, "the only sure thing in this world is the past but what we have to work with is the future" (Moore and Thomas, 1976 after Auguste Detoeuf). To handle risk and uncertainty a number of studies have been undertaken (see Bell, 1977; de Neufville and Keeney, 1974; Farquhar, 1980ab;

Farquhar and Fishburn, 1981; Fishburn 1965, 1966, 1967, 1970, 1973, 1977; French, 1986; Keeney, 1974, 1978, 1982; Keeney and Nair, 1977; Major, 1974; Moskowitz and Bunn, 1987; Swalm, 1966; Yu, 1985). All these studies focus on *a utility function* which is a mapping of multicriteria values into a *constructed* scale, or a mathematical form of preference structure as shown in Figure 10.

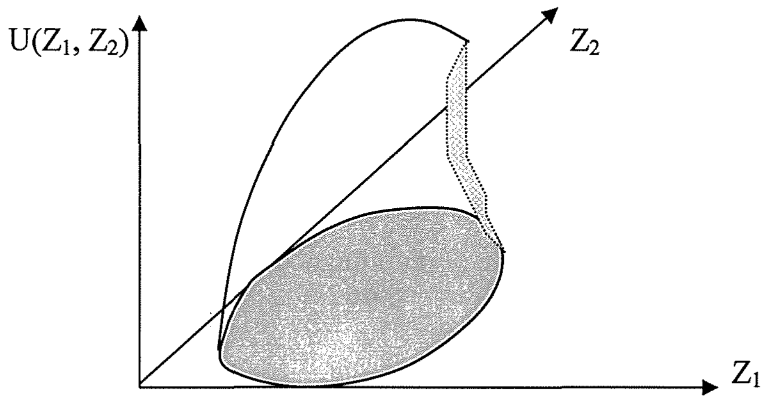


Figure 10 A (monotonically increasing concave) utility function, U, for two criteria

There exist two types of utility functions:

- *an ordinal utility function (or an indifferent function or indifference curves)*
- *a cardinal utility function (or a value function or a preference function).*

An ordinal utility function is a locus of the solutions that yields equal utility (Ferguson, 1972). That is, the solutions (under uncertain consequences) on this locus are equally preferred to the decision-maker. To find an ordinal utility function which does not specify the distance to which one solution is preferred to another, ordinal comparison between criteria is necessarily reflecting value trade-offs: how much increases in value of any one criterion are worth in terms of others. MacCrimmon and Wehrung (1977) suggest four procedures to find an ordinal utility function: *a line procedure, a square procedure, a diamond procedure and a circle procedure.*

The best solution selected as the final solution is the non-dominated solution at which an indifference curve is tangent to as shown in Figure 11.

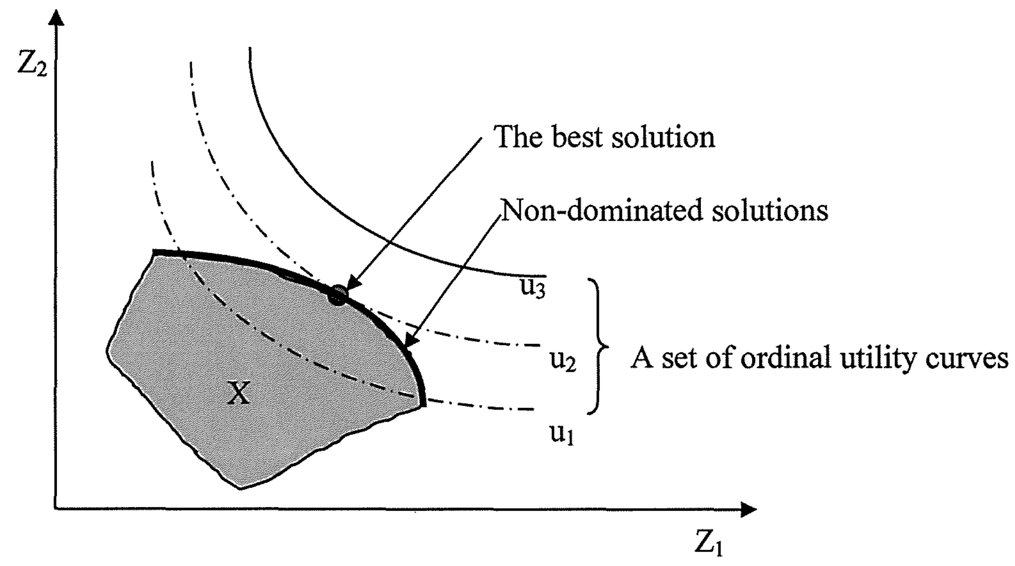


Figure 11 The best solution is the non-dominated solution tangent to an indifference curve

Finding an ordinal utility function is a fatiguing task which may lead to inconsistency by the decision-maker (see a procedure of constructing an ordinal utility function in MacCrimmon and Wehrung, 1977). Moreover, if more than two criteria are considered, finding an ordinal utility function is impractical

.

In contrast to an ordinal utility function, **a cardinal utility function** specifies the level of preference at which one solution is preferred to another. For example, solution X is 7 utilities preferred to solution Y. The cardinal utility function has played an important role in handling risk and uncertainty because it has the ability for mathematical operations (eg, +, −, ×, ÷) whilst the ordinal utility does not. For instance, to find a utility function for two criteria, a utility for each criterion can be added together. With such superior advantage, a utility function currently used and discussed further in this research is referred to only as a cardinal utility function.

The idea of a utility function for handling risk and uncertainty can solve the issues of measurement difficulty, conflicting direction of improvement and non-commensurate ability. The non-dominated solution that has the highest utility will be selected as the final solution by solving (Haimes *et al.*, 1975):

$$(\max)\ U(Z(x))$$

subject to $x \in X$

where U is a utility function. This is illustrated in Figure 12.

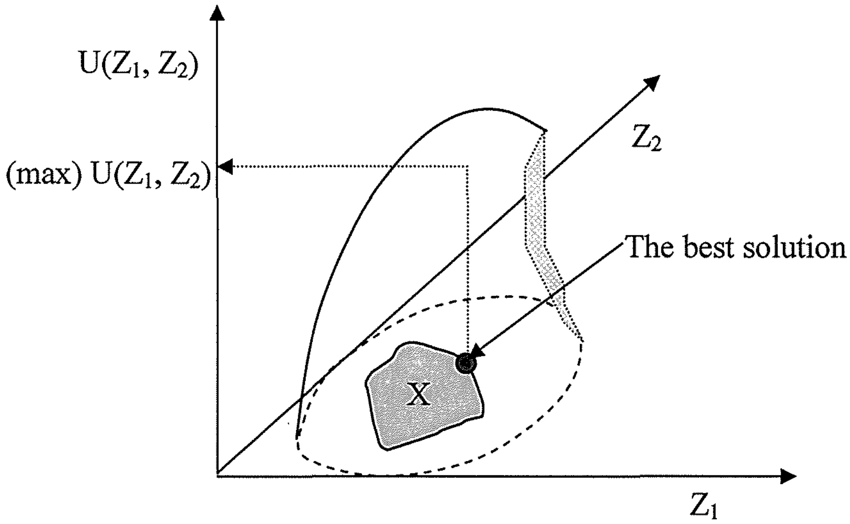


Figure 12 Maximising utilities of non-dominated solutions yields the best solution

The most superior ability of the utility function to other techniques is that it can include risk stemming from uncertainty and can totally rank the order of non-dominated solutions according to the utilities associated with them. A utility function will be used as a basis for modelling tender evaluation in this research.

2.4.2.2.5 A social welfare function

The literature review so far has assumed that only one decision-maker is involved in solving multicriteria decision problems. However, in most organisations individuals, stakeholders, or groups with different interests are involved. To cope with this, several approaches have been suggested such as (1) aggregation individual utilities (eg, *a social welfare function, Delphi, and Maximise the minimum individual utility*); (2) counselling an individual decision-maker (ie, the supremely authorised person), and (3) predicting political consequences (eg, *Paretian analysis, Game theory, voting* *procedures*) (for more detail see Cohon, 1978). Nevertheless, at present there is no universally acceptable analytical model dealing with multicriteria problems for all individuals (de Neufville, 1990). This does not mean that all suggested models cannot be applied but these models have some limitations and assumptions which cannot be accepted by all individuals participating in the problems.

In a democratic society, aggregation is based on public interest as the combination of individuals' interests, and has concentrated on theoretical work in welfare economics (Cohon, 1978). This concentration has led to the development of *a social welfare function* (*a real-valued function, a social decision function, a social preference function, or a group utility function*).

As an extension of a utility function, a social welfare function is a summation of utilities of individuals, which aims at searching the *best* solution for all the individuals by solving (see Cohon, 1978; de Neufville, 1990):

$$(\max)\mathbf{U}(\mathbf{w}) = \sum_{k=1}^{q} w_k U_k$$

where **U** is a social welfare function

w is a vector of weights

w_k is a positive weight on the utility function of each individual

U_k is a utility function of each individual

q is the number of individuals.

For this reason, a combination of the utility function and the social welfare function can be described as state-of-the-art and is developed further in this research (Chapters 6 and 7).

2.4.3 Interactive approaches

The literature so far has shown that certain optimisation models require *fixed* and *well-defined* subjective inputs (ie, weights, a set goal and a utility function) on the part of the decision-maker up front. This puts some cognitive strain on the decision-maker (Cohon, 1978). That is, they assume that all essential information for the subjective inputs can be obtained prior to solving an actual problem. However, in practice it is difficult to gain all necessary information before an actual problem is solved (Zeleny, 1982). In addition, the subjective inputs can change over time in relation to a particular circumstance. Also, the decision-makers may change their preference after some solutions are obtained. This is supported by Edgeworth and Ibrahim (1999):

Sigmund Freud was once asked by an interviewer how he made decisions. He responded by taking a coin out of his pocket and saying that he flipped it. The interviewer was agitated and said, "What! You, the great psychologist, toss a coin to make a decision?" Freud replied, "Yes, I toss the coin, and see if I like the way it turns up."

As the quote illustrates the decision-maker can change their subjective inputs (preference) to learn more about the problem ("... toss the coin, and see if I like the way it turns up.") until they get the best solution. For these reasons, interactive approaches are combined with other approaches to alleviate the difficulty in finding fixed and well-defined subjective inputs up front. The interactive approaches also provide an opportunity to change the subjective inputs during the solution-searching process, which in turn offers the decision-makers *sensitivity analysis*. However, these interactive approaches can still use the optimisation approaches as a basis for their development.

Having briefly considered the concept of interactive approaches, the following section is a classification of the interactive approaches as: (1) interactive optimisation models, (2) decision support systems, and (3) expert systems. They are discussed in more detail in the following section.

2.4.3.1 Interactive optimisation models

An algorithm of interactive optimisation models can help the decision-maker to arrive at the preferred solution. Broadly, the algorithm is (1) generating a non-dominated solution; (2) identifying the trade-offs between criteria in order to permit considering other non-dominated solutions; (3) asking the users to assess whether they prefer the first trade-off; (4) if not, identifying a new trade-off; and (5) repeating the previous steps until the decision-maker arrives at their preferred solution. Many interactive optimisation models have been developed including:

2.4.3.1.1 The *step method*, STEM

Here, in STEM (Benayoun, *et al.*, 1971), preference of the decision-maker is stated during the solution-searching process. STEM possesses the advantage of simple procedures.

However, the users have difficulty in determining the preferred trade-offs, which may lead to inconsistency of preferences and a high cognitive strain being imposed on the decision-maker. Also, STEM has no ability to handle multiple stakeholders.

A variation of STEM is found in Johnson and Loucks (1980), Fichefet (1980), Venugopal and Narendren (1990), Buchanan (1991), Ng (1991), Fonseca (1998), and Tappeta and Renaud (1999).

2.4.3.1.2 The *GDF method*

The *GDF method* proposed by Geoffrion, Dyer and Feinberg (1972) was developed from an ordinal utility function. The GDF method also has the advantages of simple procedures and reacception of any rejected solution.

However, the main drawback results from the difficulty in determining the preferred trade-offs. Also, multiple stakeholders cannot be handled.

A variation of the GDF method is found in Dyer (1973), Wehrung (1978), Hemming (1981), Rosinger (1981), Sadagopan and Ravindran (1986), Al-alwani *et al.* (1993), Seaman *et al.* (1993), Wallenius and Zionts (1977), Zionts and Wallennius (1976).

2.4.3.1.3 The *surrogate worth trade-off method*, SWT

The *surrogate worth trade-off method,* SWT, has been suggested by Haimes, Hall and Freeman (1975), and develops from a combination of an ordinal utility function and a constraint method. The SWT method ensures that any solution selected as a final solution is a non-dominated solution.

However, the difficulty for the users in determining preferred trade-offs and the inability to handle multiple stakeholders still remains.

A variation of the SWT method is found in Chankong and Haimes (1978), Haimes and Chankong (1979), and Yang *et al.* (1990).

Other interactive approaches have been proposed such as the *sequential multiobjective problem solving method* (Monarchi *et al.*, 1973), the *trade-off cutting plane methods* (Musselman and Talavage, 1980), and the *relaxation methods* (Lazimy, 1986). Again, in these approaches there are the difficulties in providing preferred trade-offs and no ability in handling multiple stakeholders.

2.4.3.2 Decision support systems

Decision support systems can be defined as interactive, flexible and adaptable computer-based systems, which permit using data and models to support a decision (Turban, 1995). The systems allow the decision-maker to include their judgments and data in analysing solutions to assist their decision.

In effect, the systems are designed to support the decision-maker from the step of identifying a problem to the step of evaluating solutions. However, they do not make decisions (Mcleod, 1988). They only give information such as periodic reports, special reports, and models to the decision-maker, who is assumed to have the intelligence, experience and common sense to arrive at a decision. For example, to arrive at a solution the systems provide a *well-defined* model but the decision-maker provides their subjective inputs for model processing.

The decision support systems can be subdivided into four major subsystems:

- Data management subsystem. This subsystem includes the database(s) for the whole system, which mainly holds pertinent data for a specific problem. The data comes from either internal or external systems. In tendering problems from an owner's viewpoint, previous reports of contractors are an example of internal data sources; whereas a questionnaire or forms completed by contractors are examples of data from external sources.
- Model management subsystem. This subsystem includes different kinds of models such as optimisation models and other qualitative or quantitative models that mainly offer the whole systems analytical capability.
- Communication or dialog management. This subsystem provides a channel for the decision-maker to communicate with and command the whole system, which is known as the *user interface*.
- Knowledge management. This is an optional subsystem which can provide the required expertise for solving some special aspects of a problem and/or providing special knowledge that can improve the operation of the other subsystems.

When compared to expert systems, decision support systems are more able to allow the decision-maker to combine their judgment with data for producing information to support a solution (Mcleod, 1988). However, as stated earlier decision support systems do not make decisions. They only support the decision-maker who has to have intelligence, experience and common sense in making their own decision (Mcleod, 1988).

2.4.3.3 Expert systems

Expert systems are computerised advisory programs that try to copy the rational procedures and knowledge of experts in solving specific problems, which are broken themselves from artificial intelligence, AI, (Turban, 1995). The idea of these systems is to convert the knowledge or expertise of *experts* into computer programmes. After the knowledge of many experts is converted and incorporated into the computer programmes, the decision-maker can consult these programmes for explanations and

inferences such that they arrive at a final solution, whilst the decision support systems do not. Such programmes, with the incorporation of the knowledge of many experts, could produce better results than that of only one *expert*.
The expert systems can be subdivided into subsystems as follows:

- Knowledge acquisition. This subsystem is made up of steps of aggregation, transfer, and transformation of expert knowledge (inputs) to a computer program for developing and expanding a knowledge base. The knowledge can be acquired for example through: literature including books, manuals, journal articles, databases; interviews with experts; questionnaires completed by experts.
- Knowledge base. This subsystem includes (1) facts such as theory, context of problems, (2) rules that determine the means of using knowledge in solving specific problems such as *if-then*. In effect, it comprises knowledge essential for understanding, formulating and solving problems.
- Inference engine. This subsystem is the control unit or rule interpreter, which is essential in a computer program. It offers a methodology for using the knowledge and formulating conclusions.
- Knowledge refinement. This subsystem is to analyse its own performance, learn from it and, improve it for future consultations. Its success and failure are analysed to improve the knowledge base and the methodology for using the knowledge and formulating conclusions.
- User interface. Similar to that of the decision support systems, this system offers the decision-maker communication with the whole system.
- Knowledge explanation. This subsystem gives reasons as to how and why conclusions are reached by answering questions in an interactive way as follows:
  - Why was a solution rejected?
  - How was a conclusion arrived at?
  - What is the procedure to arrive at a final solution?

A main advantage of expert systems is that the knowledge base can be incrementally developed over time (Turban, 1995). For example, any rules can be deleted or replaced by new rules that are more accepted. This offers the decision-maker flexibility. Furthermore, the systems relieve the decision-maker of the tedium of preparing rigidly formatted inputs, and then make suggestions to the decision-maker on the selection of criteria, particularly under risk and uncertainty (Barnwell *et al.*, 1988). However, the acquisition of knowledge of experts may be affected by some sources of biases such as limits in the number of experts and knowledge not always being readily available. This results in a flaw in the rules.

Another system that is akin to expert systems is the *artificial neural network, ANN.* Both the systems are in the branch of artificial intelligence. The main difference between expert systems and artificial neural network is the level of adaptability of these systems. That is, artificial neural networks can adjust themselves more readily (eg, in terms of criteria, variables) than expert systems.

2.4.4 Some multicriteria models in tender evaluation

This section discusses some multicriteria models existing in the tender evaluation area, namely, financial model, weighting method, fuzzy set theory, multiattribute utility function, and expert systems and artificial neural networks.

2.4.4.1 Financial model

The model is to evaluate the capability of the contractors based only on financial criterion. The idea behind this model is that the capability of a contractor to complete a project depends on the size of the project. The measure to indicate the capability is the difference between the contractor's maximum financial capability and the amount of ongoing unfinished work. As long as the project price is below this difference; the contractor is evaluated as enough capability and permitted to bid for the project. The model can be expressed as follows (see Russell, 1992):

$$\text{(max) Financial capacity} = (\text{Net current asset} - \text{Net current liability}) \times c \times S$$

where c is a constant

S is a subjective coefficient.

A main drawback of this model is that the evaluation is based only on financial criterion and this may not indicate the actual capability of contractors. Furthermore, the subjective coefficient (S) is always hard to be accepted.

2.4.4.2 Competitive model

The model was developed by Drew and Skitmore (1993) for use in prequalification. A competitive index, C, is derived from mean and standard deviation of bid prices. This index is used to determine a contractor's competitiveness. The scales of this combination range from "sensible," "non-serious," "harmless" and "suicidal." The decision to classify a contractor into one of these scales depends on the owners' attitude towards risk. However, here bid price is the sole criterion, which may not indicate actual contractor ability like the financial model.

2.4.4.3 Weighting method

The weighting method appears in tender evaluation area in various works.

Russell and Skibniewski (1990) introduce an interactive model, named *Qualifier-1*, using a weighting method as the basis for development, which aims to systematise the prequalification process. In this model, to prequalify contractors, the criteria selected are subdivided into two levels as a hierarchy; the first level is referred to as the lowest level criteria and the second level to the higher level criteria.

In this model, the weights of relative importance are derived from a regression technique to analyse the levels of impact of each criterion to prequalification. The model aggregates all the values of various criteria of each candidate contractor into an overall value using the following steps:

- Firstly, measure the lowest level criteria for a candidate contractor, and express in non-dimensional scores, ie, numbers between 0-4.
- Secondly, assign the weights of relative importance of all the lowest level

criteria. The weights are suggested by the model but the decision-maker can change them as required according to their subjective judgment.

- Thirdly, multiply all the scores and their corresponding weights within each higher level criterion together, and add them altogether. The results of this step are the weighted scores of all higher criteria.
- Fourthly, multiply all the weighted scores of each higher criterion (the result of the third step) and their corresponding weights, and add them altogether. The result is the overall score for one candidate contractor.
- Lastly, all the above steps are repeated until all candidate contractors are evaluated. Then, the contractors can be ranked according to their scores.

The advantages of this model are that it offers a systematic, structured approach for prequalification and reducing bias whilst the weights are elicited and stated. However, the limitations are the elicited scores depending largely on the decision-maker's judgment, and the algebraic formulas of this model are assumed to be linear (Russell and Skibniewski, 1990).

Another approach is suggested by Herbsman and Ellis (1992) where the concept of multiple criteria is used in a bidding system in order to select a contractor. Here, they manage multiple criteria by converting them into expected monetary value through trading off between criteria. The weights for all criteria, ie, cost, time, quality, and safety, come from past experience and judgment of the owner or the owner's representatives. This concept is presented as follows:

- Firstly, after all the criteria of contractors are obtained from tender documents and the owner, the criteria – ie, time, quality, and safety – are traded off in order to convert them to monetary value, ie, dollar. The trade-off is done by determining a ratio, eg, $7,000 per day, to convert time criterion to dollars. This ratio is based on past experience and subjective judgment of the owner.
- Lastly, the values (expressed in dollars) of all the four criteria for contractors are aggregated. Then, the contractor having the minimum value should win the contract.

Although the concept possesses ease and flexibility in its usage, its reliability may be questioned when the criteria and weights are repeatedly measured and stated because the acquisition of criteria's values and weights is based largely on the decision-maker's judgment.

In a problem of whether to bid for a project, Ahmad (1990) manages non-commensurate and conflicting criteria by converting them into a non-dimensional unit. Here, the criteria (ie, overall worth of the project, position and goals of the firm, resource constraints, and prevailing market conditions) are subdivided into two levels as a hierarchy.

The weights are assigned to all levels of criteria. These weights are derived from *pairwise comparison* through asking subjective questions – "How much less (or more) important is the second criterion than the first?" The *pairwise* comparison is simply done by comparing and asking the question between a pair of criteria. Then, the weight of relative importance between the pair is articulated. This is repeated until all criteria are paired off and compared.

Ahmad also uses the weights for a test of importance of each criterion. That is, if any weight of any criterion is lower than a *killed* value, which means this criterion is not important to describe the higher criterion, this criterion would be eliminated. Here again specifying the value is subjective. The steps of this model are as follows:

- Firstly, after the hierarchy of criteria is completed, all expected values of the lowest criteria are elicited – numbers between 0 and 100. Then the weights, obtained by *pairwise comparison*, are assigned to these criteria.
- Secondly, for a project, after all the expected values of these criteria and their corresponding weights are expressed, they are multiplied together; then added all together.
- Thirdly, minimum desirable values are assigned as *anchor* values by repeating the previous stage but substituting the minimum desirable values for the expected values. Again, these anchor values are subjective.
- Lastly, the overall expected value is compared with the overall minimum

desirable value. The amount of the difference shows a level of confidence on *bid/no-bid* decisions. That is, if the amount of the difference is high, the project should be bid for. Although, a table for converting the amounts of difference to the levels of confidence to bid is provided, how the converting table is derived is not demonstrated. Again, subjectivity arises here.

The main strength of this model is its flexibility in that some criteria can be appended or removed for a specific project. However, there is the difficulty in trading off during e liciting the expected values of the criteria. Also, the *anchor* values, *killed* values and converting table are still subjective.

2.4.4.4 Fuzzy set theory

Nguyen (1985) applies fuzzy set theory to the tendering process considering multiple criteria, ie, cost, experience, and performance, for selecting a contractor by transforming them into a non-dimensional unit. The fuzzy set is a set that has levels of membership called scores, of which scales were normally between 0 and 1 – a common set does not have levels of membership for each member. For example, a contractor had a membership level of 0.7 in a set of a criterion (e.g., experience); another contractor had a membership level of 0.8 in the set of the same criterion.

The weights of these criteria come from the subjective judgment of the decision-maker. The selection of a contractor using this model is done by the following steps.

- Firstly, for a contractor, scores of the three criteria, ie, cost, experience, and performance, are elicited based on the fuzzy set theory (which converts the values of these criteria into numbers between 0 and 1). This elicitation needs subjective inputs from the decision-maker.
- Secondly, after all the scores and the corresponding weights of these criteria are obtained, they are multiplied together.
- Thirdly, each score of each criterion is compared to select the minimum score. This is finding all minimum scores for all contractors.

- Lastly, amongst the minimum scores of all the contractors, the maximum of the minimum scores was chosen in order to select the preferred contractor.

As with the work of Herbsman and Ellis (1992), ease and flexibility is the main strength of this model. However, when the criteria's scores and weights are stated, inconsistency may occur because the derivation of criteria scores and weights is based largely on the decision-maker's judgment.

2.4.4.5 Multiattribute utility function

Several researchers have applied a multiattribute utility function to the tendering process. In contractor selection problems, Diekmann (1981) suggests a *weighted additive* model (representing the decision-maker's utility function) to evaluate contractors in cost plus contracts. The model is similar to *Qualifier-1* by Russell and Skipniewski (1990) mentioned earlier, except that here it uses utility for the value of each criterion and has no interactive nature. In this model, to select a contractor the criteria, ie, cost exposure, company stability, quality of product and management capacity, are subdivided into two levels as a hierarchy, and weights are assigned to all levels.

Similar to Diekmann, a *weighted additive* model is applied to tender evaluation by Hatush (1996) and Hatush and Skitmore (1997). However, they select different criteria for the modelling, namely, financial soundness, technical ability, management capacity, health and safety, and reputation. These criteria are also described by lower level criteria.

By using both the models, the difficulty of finding a utility function (see Section 6.2) is still inherent in these models. However, an advantage is that the model can incorporate risk stemming from uncertainty through the use utility theory.

Seydel and Olson (1990) introduced the concept of the tendering process as a continuous process including the percent mark-up selection. The purpose of this work is to select percent mark-up whilst multiple criteria are considered. The criteria selected for this model are maximising profit, minimising risk exposure, and work force continuity. Clearly, the first and third criteria are conflicting; the second and third are undoubtedly conflicting. Similar to the models proposed by Ahmad (1990), Diekmann (1981) and Russell and Skibniewski (1990), these three criteria are subdivided into lower criteria to provide a scale for measurement.

Here, the weights are estimated to consider all these three criteria simultaneously by *a matrix of pairwise comparison*, which is basically similar to the *pairwise comparison* used by Ahmad (1990) but the difference is that this comparison is done in the form of a matrix. The results of the matrix are a set of the weights for all the criteria. The weighting uses the technique of multiattribute utility function to capture preference of the contractor on the three criteria, which are expressed in weights or numbers. The steps of this model are as follows.

- Firstly, the weights of the criteria – expected profit, expected loss, and work force continuity – are expressed by the *matrix of pairwise comparison*.
- Secondly, several percent mark-up solutions are set up by the contractor's judgment. The infinite solutions are changed to discrete solutions by using the midpoints of the intervals of percent mark-up ratios.
- Thirdly, the weights for each of the solutions are expressed by the contractor's judgment using the *matrix of pairwise comparison*.
- Lastly, the weight of each percent mark-up solution and the weight of each criterion are multiplied together. The result is the overall weight of each percent mark-up solution. The percent mark-up solution with the highest weight (which reflects the highest utility) is selected as the final solution.

Like the model presented by Diemann (1981), the decision-maker can include their risk attitude to this model using utility theory. However, finding a utility function is still difficult.

2.4.4.6 Expert systems and artificial neural networks

Russell *et al.* (1990) developed an expert system, named *Qualifier-2*, for contractor prequalification. The development of this system is done by analysing many criteria in which data is obtained from four construction professions. In this system, five criteria are selected and ranked as a hierarchy namely, reference/reputation/past performance, financial stability, status of work program, technical expertise, project-specific criteria. Once again, these criteria are subdivided into a further two levels.

Here, the rules for prequalification applied at the lowest level ask "if-then" questions. If any criterion of a contractor does not reach its minimum level, the contractor does not qualify. Clearly, these rules reflect the subjectivity of these professionals. Another reflection of subjectivity is the weight assigned to criteria which are not explicit. They are implicit in the minimum accepted levels of these criteria. That is, the higher the minimum accepted levels, the greater the weight assigned to these criteria.

The algorithm of this system is as follows:

- After criteria are selected, as a hierarchy, the minimum accepted levels of these criteria are set up. These levels acted as *threshold* levels for establishing rules.
- Next, the rules for qualifying the contractors start from the top of the hierarchy. If any criterion of a contractor is not greater than the minimum accepted levels – done by asking "if-then" questions, the contractor is not qualified.

The main strength of this model is that the knowledge base can be progressively accumulated over time. Therefore, the decision rules can be improved, which shows the flexibility of the model. However, a major limitation is that the knowledge base in establishing the rules and the *threshold* values is possibly biased due to the small number (four) of construction professionals.

Other related models in this group can be seen in Taha *et al.* (1995), Hanna *et al.* (1997), Khosrowshahi (1999) and Lam *et al.* (2001).

Once again, all existing models in tender evaluation including prequalification so far have assumed that only one decision-maker participated.

2.4.5 Discussion

This review of the literature shows that in searching for a solution to multicriteria decision problems many approaches have been suggested. In contrast to single criterion problems, multicriteria problems require subjective inputs, ie, a set goal, weights, a utility function. As these multicriteria optimisation models are applied to solve the problem of tender evaluation, subjectivity is still inherent in the applied models.

Based on the timing of requiring subjective inputs, multicriteria optimisation approaches can be classified into two groups: (1) *post-subjective input models* and (2) *pre-subjective input models*. It is shown in the above literature review that the models in the first group (ie, linear multiobjective and compromise programming) are computationally intensive because each criterion is directly operated on, which means only computer calculations are practical for finding non-dominated solutions. However, this problem is reduced by using the models in the second group because multicriteria are transformed to a single criterion by for example constructing a new single criterion.

Within the various models in the second group, a utility function can include attitude towards risk from the decision-maker, and is the most useful in selecting the best solution from a large number of non-dominated solutions and in ranking non-dominated solutions. For this reason, a utility function has become one of the most active research areas (see, Russell and Skibniewski, 1990; Seydel and Olson, 1990; Hatush, 1996; Hatush and Skitmore, 1998). Thus this function is used as a basis for this research.

However, the utility function is difficult to find in practice and can change over time in relation to a particular situation. To decrease this difficulty, interactive approaches exist. Moreover in most real world problems, there are multiple decision-makers with different interests involved. To deal with these multiple decision-makers, there is a social welfare function, which is suitable for democratic organisations and represents the whole organisation preference. For this reason, a combination of the utility function and the social welfare function can be described as the-state-of-the-art and should be put forward.

This review of the literature also shows that development and application of an interactive approach that combines the utility function (to include risk and uncertainty) and the social welfare function (to include preferences of multiple decision-makers) has been very limited. This is because different models focus on different necessary features. Some include elements of risk and uncertainty but assume that only one decision-maker is involved. Others consider multiple decision-makers' involvement but there is no consideration of risk and uncertainty and no computer interaction.

In the light of this, the second main research aim is to contribute to the development of a more realistic working model using the combination of a utility function and a social welfare function with an interactive approach to solving the problems of tender evaluation.

The next chapter will continue to review tender evaluation focusing specifically on the Thai construction industry.

Chapter 3

Tender evaluation in the Thai construction industry

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3.1 Introduction

In conjunction with Sections 2.2, 2.3 and 2.4, this Chapter reviews tender evaluation procedures, tender evaluation criteria and tender evaluation models in the Thai construction industry. In this chapter, a great deal of limited sources exists. There are two main reasons why these sources are limited. One is that little research in the Thai construction industry has been undertaken in tender evaluation area. The other is that empirical techniques are not adequate in terms of tender evaluation criteria and their relation, resulting in using large subjective judgment. As such, the discussion in this chapter is developed from the limited sources and personal experience to enable a questionnaire survey to investigate the main findings from literature review.

3.2 Tender evaluation procedures

Similar to tender evaluation procedures in other countries, in the Thai construction industry the main aim of tender evaluation is to select the *best* contractor to complete a project within budget, time, cost and safety requirements (see Tharavijitkul, 1990).

The procedures used by government and private owners are rather different because government owners are under strict regulations whilst private owners are less regulated.

Government owners: Before any contractor can submit bids for projects, they have to register their desire to participate in public tendering for a specific type of project. Each government organisation establishes different standards on the qualification of contractors. Within the standards, commonly there are different ranking *classes* for contractors to register that will dictate, eg, (1) the maximum contract value for any one project that the contractor can bid for and (2) the maximum current contract value of all current projects in hand. Any contractors can go up a class when they have more experience on the type of project. Also, the class that a contractor registers in qualifies them for the work. A comparison of different ranking classes across different government organisations for road work is shown in Table 1.

Table 1 A contractor comparison of different ranking *classes* across government organizations for road work

Organisation	**Maximum contract value able to be bid for any one projects (million bahts)**					
	Exceptional class	Class 1	Class 2	Class 3	Class 4	Class 5
Bangkok Metropolitan Administration	-	Not limited	≤ 60	≤ 30	≤ 5	-
Department of Accelerated Rural Development	-	Not limited	≤ 30	≤ 15	≤ 7	-
Department of Highway	-	Not limited	≤ 300	≤ 150	≤ 60	-
Public Works Department	Not limited	≤ 150	≤ 60	≤ 20	≤ 10	-
Royal Irrigation Department	-	≤ 1000	≤ 300	≤ 100	≤ 50	≤ 25

Organisation	**Maximum current contract value of all current projects in hand (million bahts)**					
	Exceptional class	Class 1	Class 2	Class 3	Class 4	Class 5
Bangkok Metropolitan Administration	-	-	-	-	-	-
Department of Accelerated Rural Development	-	-	-	-	-	-
Department of Highway	-	-	≤ 600	≤ 300	≤ 120	-
Public Works Department	-	≤ five times capital register funds				-
Royal Irrigation Department	-	-	-	-	-	-

In most government contracts, the evaluation of tenders is undertaken on the concept of competitive bidding, where bid price is given the most priority. The selection of a competent contractor is then based on the lowest bid price and the *estimated* price, which determines the maximum budget.

Private owners: In contrast to government owners, there is generally no ranking class for private owners. Any contractor can bid for any project. The ability of each contractor is evaluated for every project where the concept of competitive bidding is usually applied to select a competent contractor.

Broadly, there exist three types of tender evaluation procedures in Thailand: (1) selective tendering with and without prequalification, (2) Open tendering, and (3) Negotiated tendering. For government owners, size of the project dictates the choice of tender evaluation procedures. For instance, in The Electricity Generating Authority of Thailand if any project has a contract value of more than 100 million US dollars, selective tendering is chosen (Tharavijitgul, 1990). Whereas for private owners any type of tendering may be chosen.

3.2.1 Selective tendering

Where selective tendering is chosen, a short list of contractors is drawn up with prequalification requirements or without prequalification by, eg, professional advisors, selection of some contractors listed from the same type of previous projects, or selection from Yellow Pages, trade magazines, etc. as shown in Figure 13.

In the case of the selective tendering with prequalification (based on Tharavijitgul, 1990), firstly, selection criteria are developed with the recognition of the project requirements including time, cost, quality and safety. Then, contractors are invited to register for prequalification. After the interested contractors have submitted their prequalification documents, a committee is appointed for evaluating the contractors' documents. The committee always includes different personnel from different sections in the owner's organisation. Next, the committee selects criteria to evaluate contractors' data. Then the committee gives scores on the selected criteria for each contractor based on their experience. The scores are combined in order to form a new single score which is used to qualify contractors. After that, a certain score is chosen as a *threshold* that any contractor's score must reach to qualify. If the contractor's score does not reach the *threshold* number, the contractor will be disqualified from tendering. Next, the owner informs the result of the prequalification to the contractors. Tendering documents are sold only to prequalified contractors. Lastly, the selection of any contractor to complete the project is based on the lowest bid price and the estimated budget including meeting technical specifications.

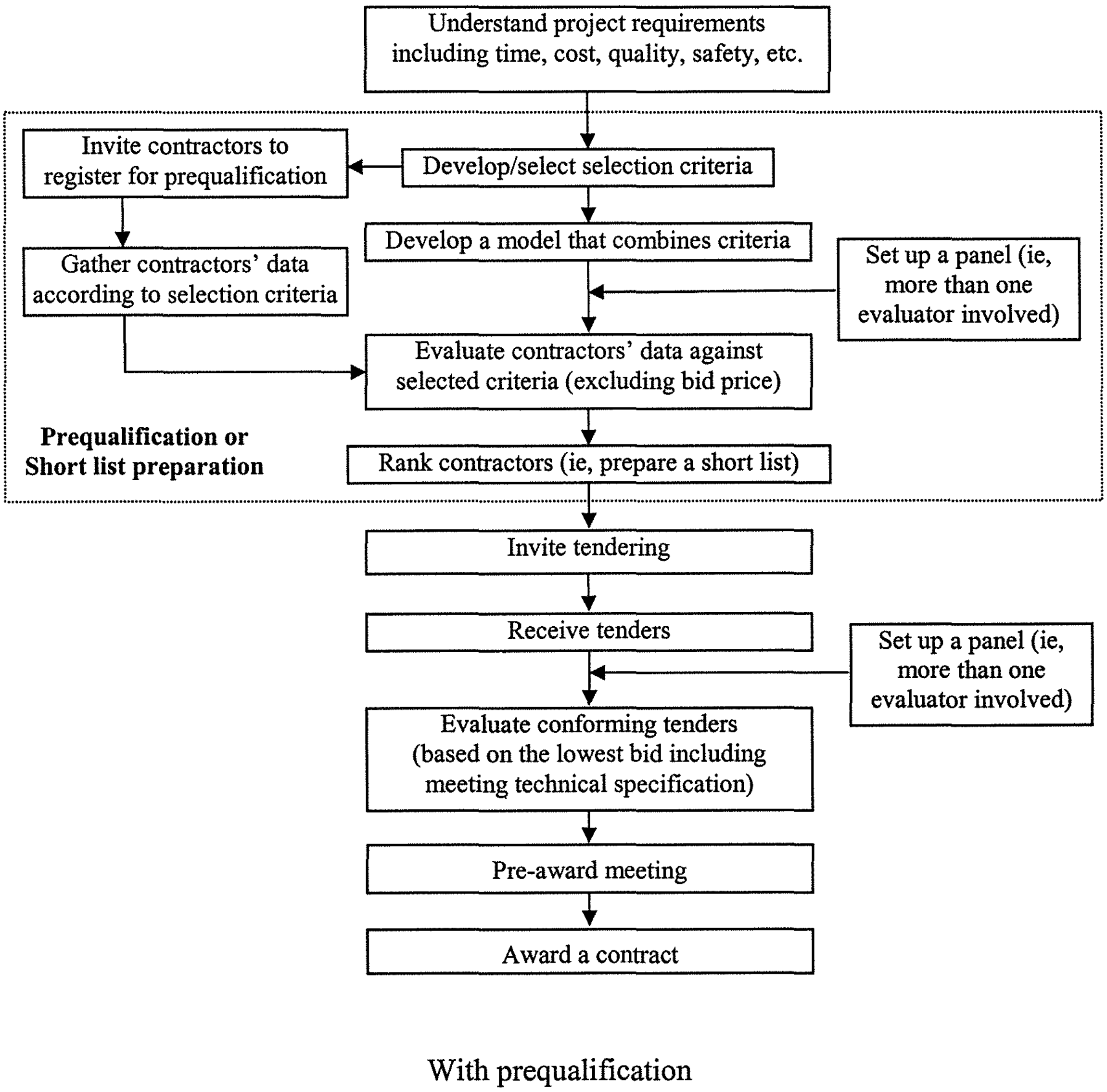
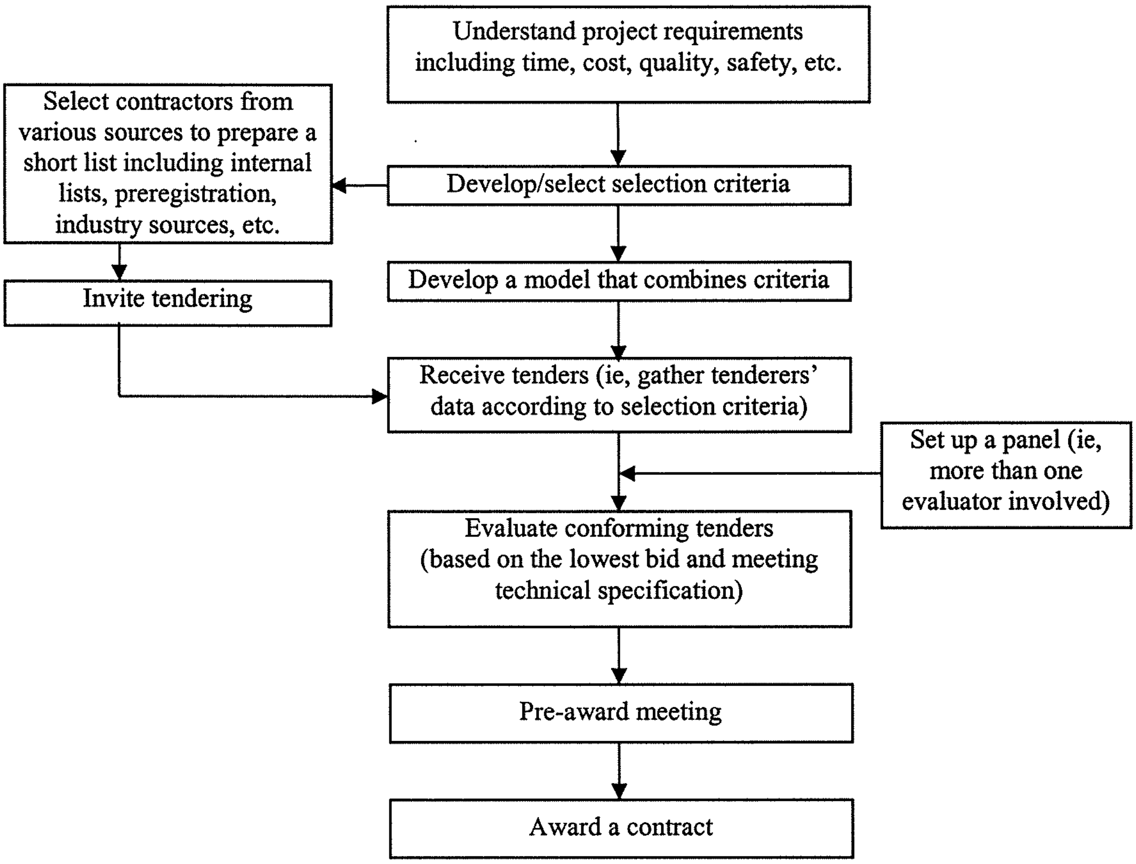


Figure 13 Selective tendering in Thailand with and without prequalification (adapted from Tharavijitkul, 1990)



without prequalification

Figure 13 (Continued)

In the case of selective tendering without prequalification, most steps are similar to that with prequalification except that here a short list is made by selecting contractors from, eg, internal (registration) lists or industry sources.

3.2.2 Open tendering

In open tendering, a number of contractors are invited to bid for a project. Tenders are evaluated after all tenders are submitted. Unlike the selective tendering, the selection of any contractor to complete the project is based on the selection criteria including the lowest bid price and the estimated price and meeting technical specification. The procedure is described in Figure 14.

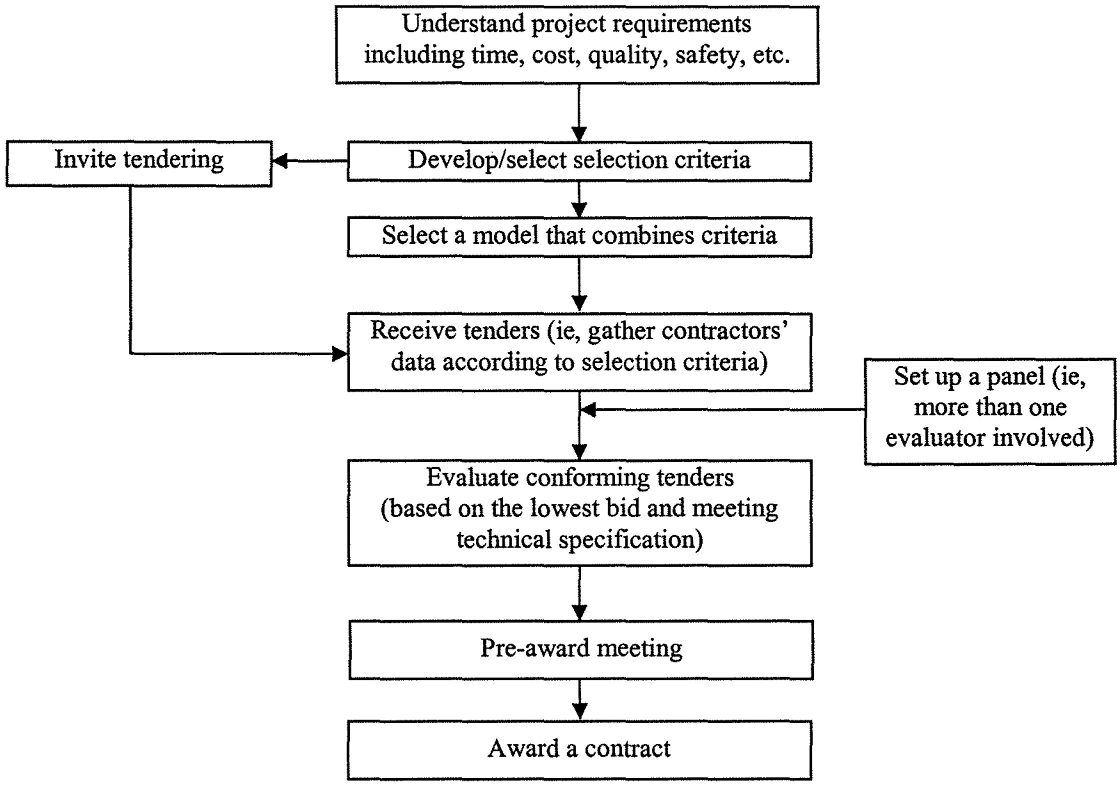


Figure 14 Open tendering in Thailand
(adapted from Tharavijitkul, 1990)

3.2.3 Negotiated tendering

Where negotiated tendering is chosen, low competitive tendering occurs. The selection of a contractor is reached by negotiation between the owner, consultants, and the contractor. Subjective decisions may have a strong bearing on this procedure.

As can be seen from Figures 13 and 14, in the Thai construction industry the main aim of tender evaluation is to select the *best* contractor to complete a project within budget, time, cost and safety requirements.

3.3 Tender evaluation criteria

In Thailand, there is no standard set of tender evaluation criteria for all government and private owners. Each has developed its own set of criteria. These criteria are also varied from time to time in relation to a particular situation. The following is a review on selective and open tender evaluation criteria.

3.3.1 Selective tender evaluation criteria

In practice, criteria and their weights of relative importance vary from:

- one owner to another due to their different objectives
- one project to another due to their different types and sizes
- one person to another due to their different background, experience, position and attitude towards risk and uncertainty.

For example, the Electricity Generation Authority of Thailand (EGAT) uses 4 criteria to evaluate *contractor ability*: financial capacity, bank guarantee, experience, and equipment and personnel (Tharavijitkul, 1990). Scores for these criteria for each contractor are given by a committee designated by the governor of EGAT. The aggregated scores explore the contractor ability. Only qualified contractors are invited to bid for the project. Then, the selection of any contractor to complete the project is based on the lowest bid price including the estimated price and meeting the technical specifications.

As another example, the Royal Irrigation Department (RID) considers these criteria for international projects where overseas loans are required, (Tharavijitkul, 1990; Weng, 1992):

- Financial conditions considering general company financial information and company records, local office and partners, assets, and financial ratios
- Personnel considering the number and experience of personnel, the number and experience of personnel in irrigation canal works

- Qualification and experience of the personnel responsible for the project
- Experience considering experience in Thailand, South-East Asia, elsewhere; experience in irrigation canal works; experience in highways and bridge works and other structures
- Current contracts considering current contracts in irrigation canals and other works
- Equipment for earthworks, concrete work, tunnels, and other equipment
- Subcontractors considering experience in tunnel work.

Whereas the following criteria are considered for local projects (Tharavijitkul, 1990):

- Financial status considering nominal capital, bank credit, and net worth
- Experience considering experience in construction work for 5 years continuously, approximate value of all contracts completed within last 5 years, and maximum value of contractors completed within last 5 years
- Equipment considering cost of total equipment
- Personnel considering engineers (ie, the number of senior civil engineers, number of associated civil engineers, number of junior civil engineers and number of other engineers.)
- Technicians considering the numbers of technicians having less than 5 years, between 5 to 10 years, and more than 10 years experience.

RID has developed tables for transforming contractors' data into scores (reviewed in Section 3.4). Like EGAT, the qualification of these contractors is determined by their scores. The invitation for bidding is limited to only qualified contractors. Then, again selecting the best contractor to complete the project is based on the lowest bid price including the estimated price and meeting technical specification.

3.3.2 Open tender evaluation criteria

In open tendering, the criteria are selected similar to selective tendering but all criteria (contractor ability criteria and bid price) are used as a one-step evaluation.

3.4 Tender evaluation models

3.4.1 Weighting model

In prequalification, a weighting model is adopted by RID (Tharavijitkul, 1990). In this model, the criteria are selected and the method of transforming the quantities of the criteria for each contractor is established before the evaluation is launched. The steps in this model are:

- Selecting criteria and breaking down the criteria. That is, a hierarchy of criteria is developed. The minimum scores for the lowest criteria may be chosen in order that the contractors' scores on these criteria must go above to pass the qualification.
- Measuring the criteria. This establishes how to convert quantities of criteria into scores. The conversion is done by using the conversion tables shown in Appendix 1. Subjectivity arises in these tables.
- Weighting the criteria. This is performed by distributing different maximum scores to different criteria. The higher the maximum score, the higher the weights of relative importance as shown in Appendix 1. The distribution of the maximum scores varies significantly from one project to another. For example, if the project is rather complex, experience receives a higher maximum score than that of the project with less complexity.
- Combining the weighted criteria scores. All scores of the criteria for each contractor are aggregated into an overall single score.
- Ranking the contractors. The ranking considers the overall single scores of the contractors.

In using the conversion tables, the model offers a rigid method. However, the specific numbers in conversion reflect subjectivity.

3.4.2 Subjective judgment model

Models using subjective judgment are rather unstructured. For example, criteria are selected *ad hoc*. How to interrelate these criteria may not be predetermined. The selection of a contractor may be based only on comparison of contractors' data against the *ad hoc* selected criteria. These models are prevalent within private owners.

3.5 Discussion

In the literature, tender evaluation has been subdivided into three sections: tender evaluation procedures, tender evaluation criteria and tender evaluation models. This subdivision permits a study of tender evaluation procedures and criteria in order to identify any limitations and a study of tender evaluation models in order to identify the-state-of-the-art model put forward in this research. The following is a discussion of each of the subdivisions.

3.5.1 Issues of procedures for tender evaluation

In the Thai construction industry, as in other countries, the selection of a competent contractor to complete a project within budget, time, quality and safety requirements is the main aim of tender evaluation. The literature review shows that there are three types of tender evaluation procedures: (1) selective tendering with and without prequalification, (2) open tendering and (3) negotiated tendering. Due to the involvement of high subjectivity, negotiated tendering will not be investigated further in this study. It was also found that two main issues are important to tender evaluation procedures:

- multiple criteria which have
  - measurement difficulty, conflicting direction of improvement and non-commensurate ability
  - different weights of relative importance
- a committee or multiple decision-makers who assign different:
  - weights of relative importance to the same criteria
  - values of selected criteria for each contractor.

The two main issues will be used as a framework to enable a survey of tender evaluation procedures and actual models that the Thai construction industry employs to develop a realistic working model for tender evaluation to be determined.

3.5.2 Issues of common criteria for tender evaluation

It is shown in the literature review that there is no consensus on a common set of criteria to evaluate contractor ability and tenders for all organisations, projects and decision-makers (each has its own set of criteria). In addition, different researchers suggest different criteria to evaluate contractor ability. However, a common feature is that the criteria are in the form of hierarchies but these hierarchies are not developed based on the phenomena of hierarchies discussed in Section 2.3.5 and Section 2.3.6.2. That is, the development of the hierarchy of criteria should agree with existing organisational units of contractors. This hierarchy is different between different contractors because they have different organisation structures. Furthermore, if multiple decision-makers are involved, different decision-makers may develop different hierarchies of criteria, which reflect subjective judgement and personal differences.

Recognising the difference, in this research the model developed for tender evaluation will be flexible enough to adapt itself to the changes of situations (eg, type of project, scope of work and delivery system). Here, the decision-maker can modify the hierarchy of criteria as required. Furthermore, a computer interaction can be widely applied for this modification.

The hierarchy of criteria developed based on the theory of *hierarchy, multilevel, systems*, is shown in Figure 5 as a paradigm in Chapter 2. This hierarchy will be used as the basis for designing a questionnaire survey in order to find a common set of criteria.

3.5.3 Issues of models for tender evaluation

In the literature on multicriteria models for tender evaluation, there are no objective models that can evaluate multiple criteria. All multicriteria models require subjective inputs from decision-makers in various ways, for example:

- determining a set goal or number
- stating weights of relative importance
- finding a utility function
- setting up a conversion table to transform quantities of criteria to scores
- distributing the maximum score for each criterion.

As a statement of subjective inputs, a utility function is the most superior because it can completely rank the order of contractors and include risk into the analysis as discussed in Section 2.4.2.2.4. In addition, in the Thai construction industry a panel (or multiple decision-makers) is normally set up to evaluate contractor ability and tenders. As an extension of a utility function, a social welfare function can cope with the involvement of the panel and is believed suitable for democratic organisations. However, the utility function is difficult to find in practice (Liston, 1999), as is the social welfare function. Also, the utility function changes over time in relation to a particular situation. This difficulty can be reduced and these changes can be absorbed by adding an interactive nature to the modelling.

However, it is shown in the literature that, like in other countries, in the Thai construction industry very little work has been done in the area of combining a utility function and a social welfare function with computer interaction to solve the problems of tender evaluation.

In conclusion, the main findings in this chapter are similar to Chapter 2. That is, (1) consensus on a common set of criteria does not exist and (2) no model can simultaneously take into account preferences of multiple decision-makers, elements of risk and uncertainty and a flexibility to absorb changes of preference in relation to a particular situation via computer interaction. The findings will lead to the design of a questionnaire to survey the actual models within the Thai construction industry and then to develop a realistic working model for tender evaluation. The design of the questionnaire will be discussed in the next chapter.

Chapter 4

A tender evaluation survey: questionnaire design

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4.1 Introduction

The previous two chapters reveal that there are three broad procedures in tender evaluation (excluding negotiated tendering): the selective tendering process with prequalification, selective tendering process without prequalification and open tendering process. All these procedures involve multiple criteria and multiple decision-makers. However, a universal commonality of selection of criteria (to evaluate contractor ability and tenders) does not exist. Moreover, existing models cannot simultaneously consider preferences of multiple decision-makers, risk stemming from uncertainty and interactive nature.

To further investigate the findings from the literature so as to develop a common set of criteria and develop a realistic working model capable of simultaneously (1) compiling multiple decision-makers' preferences, (2) incorporating risk stemming from uncertainty, and (3) offering computer interaction that makes a model flexible to any change in situation, the Thai construction industry was surveyed. Participants were in both government and private sectors. A hand-delivered questionnaire survey was selected to gather data on tender evaluation procedures, the criteria influencing the selection of a contractor and tender evaluation models in the Thai construction industry.

The development of the questionnaire was based on the findings of the literature in Chapters 2 and 3. However, the questionnaire distributed in the Thai construction industry was translated into Thai because the official language is Thai. A coding manual was also made in order to prepare data for analyses using the SPSS package.

4.2 Aims

The main aim of this survey was to test the hypotheses on (1) tender evaluation procedures, (2) the criteria influencing the selection of a contractor, and (3) tender evaluation models currently used by industry. The following section will establish a conceptual framework as a system of the hypotheses of the research.

4.3 Conceptual framework: a system of hypotheses

4.3.1 Tender evaluation procedures

There are three broad procedures (excluding negotiated tendering) in tender evaluation: (1) selective tendering with prequalification, (2) selective tendering without prequalification and (3) open tendering as shown in Figures 15, 16 and 17.

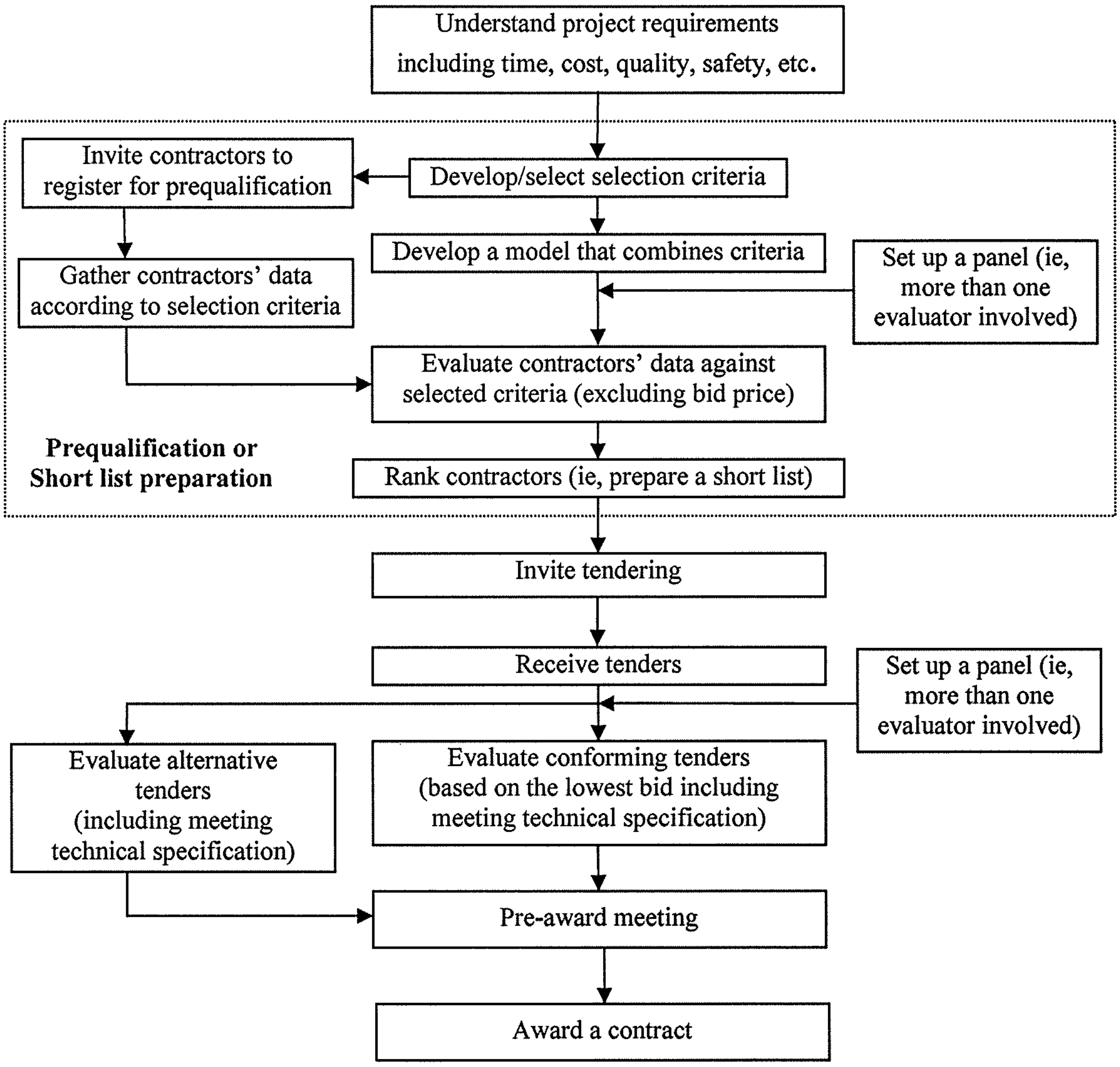

Figure 15 A selective tendering process with prequalification

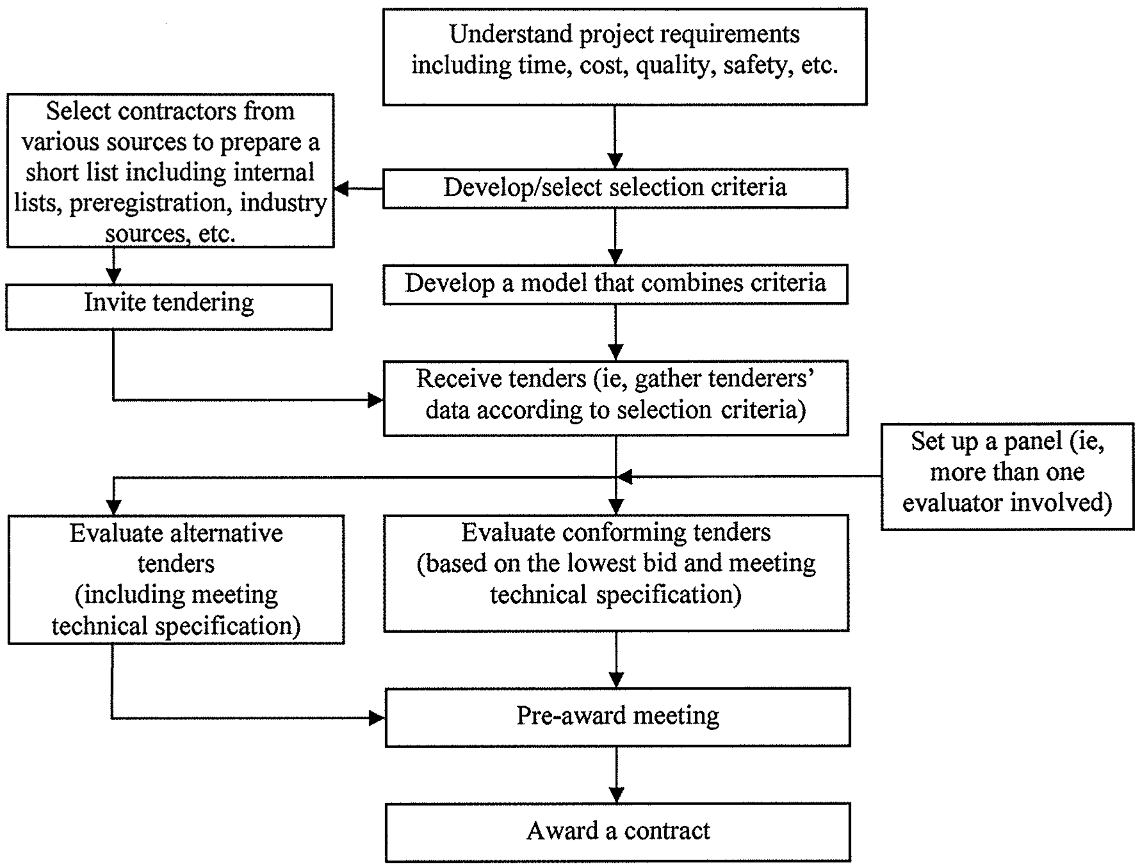

Figure 16 A selective tendering process without prequalification

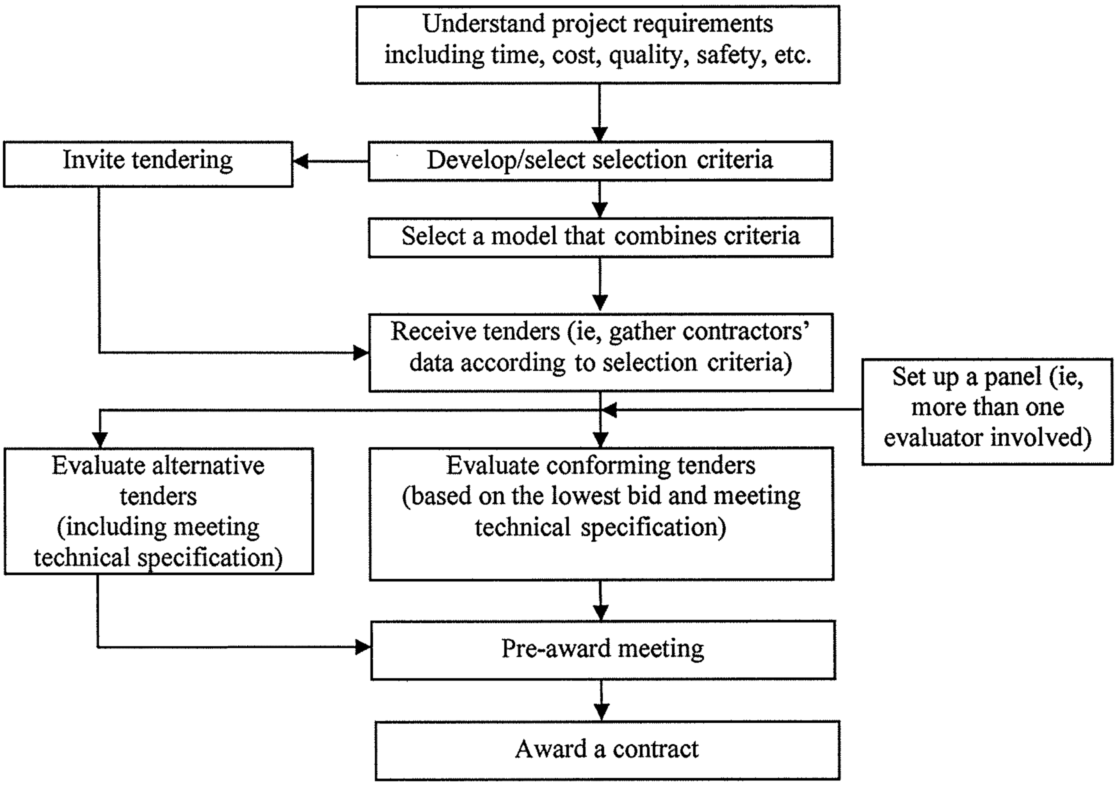

Figure 17 An open tendering process

4.3.2 Tender evaluation criteria

A variety of criteria are suggested to evaluate contractors' abilities. These criteria are always in the form of a hierarchy. The hierarchy of criteria should be developed according to existing organisational units of contractors, which makes this evaluation rational and practical. There is a strong belief that this development results in the success of project requirements/objectives, if the project requirements have been understood.

4.3.3 Tender evaluation models

Existing models in tender evaluation are:

- personal judgment
- weighting models
- utility models
- computer programs.

4.4 Operational definition

The selective tendering processes with and without prequalification and the open tendering process refer to Figures 15, 16 and 17.

Based on the existing organisational units of contractors, the criteria for tender evaluation are broken down into financial strength, quality management systems, human resources, public relations, procurement/contract, plant/equipment, engineering/construction and project managers as follows.

4.4.1 Financial strength

No contractor can operate their business without the management of a supply of money. How well a contractor manages (plans, monitors, controls and adjusts) this supply indicates their financial strength. Because of the prevailing uncertainty in the construction industry, unexpected events may incur unexpected cost to the contractor. Also the nature of the industry has limited the amount of cash to handle such events (Russell, 1990). If the contractor has low financial strength, they may fail. This failure is costly to owners, suppliers, subcontractors and the industry. To avoid engaging a low financial strength contractor, the question then arises "How does the owner measure a contractor's financial strength to identify its financial position?"

To answer this question, Russell (1990) suggested three subcriteria to measure financial capacity: credit rating, banking arrangements, and financial statement. Later, Liston (1999) added legal entity but this criterion is not as important. On the other hand, financial ratios were suggested by Diekman (1981) to measure financial stability. Whereas Ng and Skitmore (1998) found the four most commonly used methods in financial assessment were: ratio analysis, annual turnover, formulae and predictive models. Amongst these, the most commonly used in Australian industry are ratios analysis and annual turnover (Skitmore, 1999). The last two methods face problems of accuracy and reliability (Ng and Skitmore, 1998). Clearly, some suggested criteria indicating financial strength overlap.

Therefore to extract these suggested criteria, only three criteria are considered: (1) financial ratios, (2) banking arrangements and (3) credit ratings. To evaluate financial strength, data required from a contractor are banking arrangement statements and financial statements (balance sheets and profit and loss accounts).

4.4.1.1 Financial ratios

Financial ratios serve two main purposes: analysis and interpretation of financial statements (Liston, 2000). As an analytical tool, financial ratios are beneficial information extracted from financial statements, which aims at exploring trends and relationships in a contractor's finance. On the other hand, as an interpretative tool, financial ratios explain the information revealed by the analysis, which aim at synthesis to identify strengths and weaknesses of a contractor's finance. Most of the ratios are calculated from balance sheets and/or profit and loss statements.

Various financial ratios are used as a convenient means to serve the two purposes. Collectively they give a whole picture of financial strength not obtaining by just one or two. However, using too many ratios may lead to confusion as the ratios are conflicting (Liston, 2000). Different researchers may use different ratios to measure financial strength reflecting different judgments. For this research, the groups of ratios investigated are (Liston, 2000):

- Profit margins. The margins are an important factor indicating the success of a contractor's business. To make a satisfactory net profit margin, a contractor must have a sufficiently high gross profit and then keep its expenses down to a reasonable level. The higher the ratios, the more the profit margins received. The ratio for evaluating contractor margins is:

    - Gross profit on sales $= \dfrac{\text{Sales revenue} - \text{cost of sales}}{\text{Sales revenue}} \times 100\%$

- Turnover. Turnover ratios show the efficiency with which assets are used to produce sales. The higher the ratios (indicating the lower risk), the lower the profitability. There are a variety of ratios measuring contractor turnover:

  - Asset turnover ratio $= \dfrac{\text{Sales}}{\text{Total liabilities} + \text{Owner's equity}} \times 100\%$

  - Asset turnover ratio $= \dfrac{\text{Cost of sales}}{\text{Stock}} \times 100\%$

- Financial structure. It is critical for the long run success of a contractor that the financial structure most suits to the nature of its activities and that its affairs are conducted so it achieves and maintains that structure. The profitability of a contractor to its owners can be improved through prudent use of debt. This is referred to as using leverage or gearing. A common way of measuring the degree of leverage of a contractor is:

  - Financial leverage ratio $= \dfrac{\text{Return on owner's equity}}{\text{Return on total funds employed}} \times 100\%$

  If the financial leverage ratio is equal to or greater than 1, the contractor is using leverage successfully.

- Liquidity. Liquidity management is about managing cash. Therefore, there really is no substitute for a carefully prepared cash budget and continuous monitoring of cash balance and bank account. Certain financial ratios are widely used to measure liquidity.

  - Working capital ratio attempts to measure how easily a contractor can meet its current liabilities from its current assets which are expected to turn into cash in the normal course of business.

  Working capital ratio $= \dfrac{\text{Current assets}}{\text{Current liabilities}} \times 100\%$

- Quick asset ratio is a stricter measure of liquidity with a much shorter time horizon. It attempts to show how easily a contractor can meet its current liabilities which are due for payment in the immediate future out of those current assets which can be readily turned into cash.

$$\text{Quick asset ratio} = \frac{\text{Current assets} - \text{Stock} - \text{Prepayments}}{\text{Current liabilities} - \text{Bank overdraft}} \times 100\%$$

4.4.1.2 Banking arrangements

Most contractors use outsourcing money to run their business. The money often comes from banks. When a contractor does not have sufficient working capital due to the lag between expenditures spent and payments received, banking arrangements can supply cash for the contractor to continuously execute the project (Russell, 1990). Some contractors may not be given credit to supply a loan. This makes it difficult to continuously execute the project.

To measure the banking arrangements in this research, Liston (1999) suggests the requirements to be considered are: which banking organisation, length of time with that bank, has the bank been prepared to back the contractor, does the bank provide a line of credit to the contractor, what interest rate does the bank charge the contractor, and what security has the contractor provided for the bank as collateral.

4.4.1.3 Credit ratings

The credit ratings show the preference level of outside organisations to the performance in meeting external financial obligations of a contractor. The information from suppliers, subcontractors, and credit reports helps to estimate the ratings.

4.4.2 Quality management systems

Quality management systems, termed Total Quality Management (TQM), aim at continuous improvement of the quality of products and services to satisfy customers' needs based on the integration of all processes inside and outside an organisation. Due to its origination in the manufacturing industry, the concept of TQM may not be fully understood by construction industry. Also, the meanings of quality are various and usually lead to conflict amongst parties. An owner may interpret the quality as the level of excellence whilst a contractor the level of compliance with the specification (Mouatt, 1997). Clearly, both interpretations are conflicting.

According to the former interpretation, Mazda is unlikely to be a quality car in comparison to Mercedes. This is open to much criticism. However, based on the latter, Mercedes and Mazda may both be quality cars if both satisfy different customers' needs/wants thereby forming different specifications. This example shows satisfying customers' specifications means achieving their quality. This interpretation is more appropriate for this research.

As a management philosophy, quality management systems provide an outline procedure, which incorporates all the activities affecting quality, for *quality assurance* and *control* to be implemented in an organisation to ensure that the products and services meet customers' specifications. Several widely accepted standards for design and implementation of quality management systems are available, for example, ISO 9000 series; AS 3900 series; NZS 9000 series.

In order to identify the quality performance position of a contractor for this research, three main activities based on the development of a quality system are considered: quality systems selection, implementation and audit.

4.4.2.1 Quality systems selection

Most owners accept international and local quality standards as an indication of specified quality achievement. Depending on a contractor's objectives and the scope of its business, examples of standards to select from are Joint AS3900/NZS9000 series and ISO 9000 series. These standards are ready to be installed in a contractor's organisation as the basis for establishing a Quality Assurance system. In the installation, a contractor has to satisfy requirements/elements of the selected standard. As measures of this selection, the full requirements of Joint AS3901/NZS9001 or ISO9001 (suitable for *design and construct* contractors) are:

- management responsibility
- quality system
- control review
- design control
- document and data control
- purchasing
- control of customer-supplied product
- product identification and tractability
- process control
- inspection and testing
- control of inspection, measuring and testing equipment
- inspection and test status
- control of non-conforming products
- corrective and preventative action
- handling, storage, packaging, preservation and delivery
- control quality records
- internal quality audits
- training
- servicing
- statistical techniques.

To ensure the level of compliance with the standard (ie, all the above elements), a contractor has to identify noncomplying elements and what plans or actions are taken against them.

4.4.2.2 Quality systems implementation

After a particular standard is selected and installed, a contractor has to undertake necessary documentation to prove that standard elements are complied with. However, implementation of a quality system takes time because it requires the involvement of all personnel in all work processes inside and outside a contractor company. Three progressive steps of the implementation are acceptable (Hammond, 1998):

- Basic implementation. As a starting point, a policy that a contractor will commit to conduct a quality standard is announced.

- Substantial implementation. By accreditation evaluation, a contractor may receive official substantial implementation position, if he can show:
  - policy statement and approved quality manual
  - organisational structure supporting the quality standard
  - documentation and implementation of the majority of the standard elements
  - documentation and implementation of associated work manuals and processes
  - a plan for full implementation of the standard.

- Full implementation. Now, a contractor conducts full documentation and implementation (ie, satisfies all standard elements) at auditable standard. That is, the contractor receives an official certificate (eg, AS3901).

How far the standard has been implemented is identified by the above three steps.

4.4.2.3 Quality systems audit

When a contractor receives an official certificate by a registered third party accreditation body (a Quality Assurance system have been installed), Quality Control will then be conducted to ensure that:

- the documented processes are in place ready to address the standard elements
- the documented processes are being followed by a contractor
- the documented processes are effective and suitable.

By examining the mentioned documented processes, the level of the Quality Control of a contractor are identified.

4.4.3 Human resources

Any contractor cannot achieve its objectives without human resources. A contractor needs appropriate personnel to effectively and efficiently operate its business and projects. Also, the availability of necessary personnel affects the successful execution of projects. This is a matter of personnel management. Personnel management (indicating the approximate number of personnel and availability) are identified by investigating personnel management functions: personnel planning, development and maintenance.

4.4.3.1 Personnel planning

The planning provides information on what types of personnel will be needed, the number required, and when they are needed. To make the plan, a contractor has to consider the personnel demands for current and future projects and the current available personnel. An example of the plan that measures how well a contractor manages its personnel is:

- A personnel chart which shows the personnel demands and supplies of a contractor along with a time horizon (Liston, 1999).

4.4.3.2 Personnel development

Due to environment changes and technology advancement, personnel ability should be developed in order to keep constant or higher *productivity*. Personnel development can be gauged by:

- Training such as job-centered training and training conferences by outside contractor organisations
- Supervisor coaching.

4.4.3.3 Personnel maintenance

Highly talented personnel should be kept in a contractor company. A contractor should be able to provide motivation to these personnel. Such a motivation is identified as the ability of a contractor to maintain its personnel. This motivation looks at:

- Competitive income/welfare. The higher the income/welfare, the greater the chance of keeping personnel.
- Social status of a contractor company reflecting acceptance from outside the contractor organisation and people.
- Promotion showing opportunities for personnel to go up the ladder of the organisational hierarchy.

4.4.4 Public relations

As a *marketing* technique, three main activities of public relations are (1) finding out a contractor's reputation, (2) planning to improve or maintain the reputation and (3) using communication skills to positively change public (including employee) opinion on the reputation (Starr, 1968). Clearly, all the activities focus on a contractor's reputation. The last two activities are used to build a good reputation, which mainly aims at creating demands in engaging the contractor. However, in order to examine a contractor's reputation, only the first activity is relevant to tender evaluation as this indicates what publics (ie, owners, suppliers, subcontractors and union or even community) think about the contractor. Recurrent criteria used by different researchers (Liston, 1999; Russell, 1990; Russell et at, 1990) to measure public relations (indeed measure reputation) are performance, and health and safety.

4.4.4.1 Performance

Performance describes behaviours of a contractor in executing projects and operating its business. Based on time, indicators of level of a contractor's reputation to owners, suppliers, subcontractors and union can be:

- Past performance. Liston (1999) suggests only performance within the last five years should be considered. As minimum measures for past performance, the following behaviours are investigated:
  - meeting time, budget and quality requirements
  - having the intention of chasing claims
  - having payment affairs to suppliers and subcontractors
  - having fraud scandals.

- Current performance including any current conflicts with unions and within the contractor company, and any current litigation cases.

4.4.4.2 Health and safety

Although an owner does not necessarily have to be involved in a contractor's health and safety program, there is a move in the health and safety legislation to bring the health and safety under the responsibility of the owner (Liston, 1999). This is because health and safety issues affect the *productivity* of the whole community, not only that of the owner and contractor. They incur two major costs:

- Economic costs of, for example, compensation, rehabilitation and accidents
- Social and psychological costs of, for example, emotional trauma due to delays in compensation payments and long term emotional impacts of major disasters (Quinlan and Bohle, 1991).

Different contractors may have different methods for dealing with health and safety issues due to the unique nature of a project and their policies. However, a common structure is investigated:

- Health and safety plans including a health and safety policy statement, safety training of employees, work place rules, accidence recording and reporting, and emergency preparations (CCH, 1996).

- Health and safety controls. After the plan has been set up and then implemented, health and safety performance has to be controlled. Frequency of safety training, site safety meetings and inspection can be used as measures of these controls.

4.4.5 Procurement/contract

From a contractor's view, procurement is the processes of acquiring materials, products, services and subwork from outside sources (eg, suppliers and subcontractors). Materials, some products and services may be acquired by using purchase orders whereas some subwork may be acquired by using subcontracts. In accepting any form of acquisition, there is a binding enforceable contract.

Because price, quality and timing of delivery are important factors to acceptability under specification (Antill and Farmer, 1991), a contractor needs procurement plans, and delivery and subcontract controls to smoothly execute their projects.

4.4.5.1 Procurement plan

Before work begins on any project, a contractor should have detailed materials, products and subcontract schedules. These schedules will link engineering/construction, procurement/contract and financial/accountant departments together to provide an adequate flow of materials, products and subcontracted work. The position of a contractor's procurement plan is identified by the:

- material schedule
- subcontract schedule.

4.4.5.2 Delivery control

As mentioned, quality and timing of materials, products and work are vital. Their quality has to meet the owner's specification and not be damaged. Also, they have to reach the site at the right time and in the correct sequence (Liston, 1999). As a measure of delivery control, several activities are investigated:

- warehousing to prevent materials and products from being damaged and lost
- distributing to keep records of the quantities used
- receiving to verify the quality and quantity delivered.

4.4.5.3 Subcontract control

After a contractor wins a head contract to do a project, they may subcontract out parts of the project due to, for example, resourcing constraints and specialist requirements. As a result, the contractor loses some control over these parts. To keep control by the contractor, they have to send some parameters to subcontractors. The parameters used as measures of the level of the control are (Antill and Farmer, 1991; Birrell, 1985):

- General conditions of subcontracts looking at subcontractors' rights and responsibilities, variations to subcontract work, method and time for payments, retention money, alternation of the subcontract price with changes in basic costs of labour and materials and dispute procedures.

- Special conditions of subcontracts looking at the time allowed for execution of subcontracts, damages payable for the late completion and special restrictions on subcontractors.

- Trade interaction between the contractors and subcontractors looking at work, services and facilities provided and charged by the contractor, and without charge.

- Methods of reviewing drawings and change orders looking at participants and time of notifications to participants.

- Communication lines looking at the way that subcontractors know when they are needed on the project and site meetings for subcontractors.

- *Power leverages* looking at the way that the contractor deals with extra work done by subcontractors and the way that the contractor deals with their or others' mistakes affecting subcontractors' cost.

4.4.6 Plant/equipment

Plant/equipment provides services to facilitate working operations. Potentially, it increases productivity (eg, lower cost, shorter time and larger scale of work) of construction workers (Harries and McCaffer, 1982, 1991).

However, plant/equipment may increase significant liability possibly resulting in financial difficulties. Only seeing a list of plant/equipment may be insufficient to identify a contractor's ability on overall asset management. Appropriate management activities will also need to be considered. Two essential activities to be considered are: plant/equipment acquisition and maintenance.

4.4.6.1 Plant/equipment acquisition

Broadly, plant/equipment is acquired by buying, renting, leasing methods or a combination of these. All the methods have advantages and disadvantages. A contractor may select one of these methods or a combination of them by balancing their advantages and disadvantages together with considering its policy (eg, tax deduction, maintenance responsibility, disposal and renewal), company and market situations, and type of work. No matter which method is selected, the end results are:

- a list of plant/equipment showing its numbers and conditions
- a plan of renting or leasing plant/equipment.

These results can be used as indicators of the success of the acquisition.

4.4.6.2 Plant/equipment maintenance

Not only does a contractor have items of plant/equipment but also the contractor has to maintain them in order to guarantee their being available, meeting safety requirements, working properly, increasing lifetime. Cost/benefit analysis is necessary to determine the level of maintenance. However, this level depends on contractor policy which shows in:

- Programmed maintenance involving a regular schedule of inspection/repair or replacement of plant/equipment by the workshop staff.

- Spare parts stocking involving inventory to prevent shortage and non-timing delivery of the spare parts. This can reduce work-disruption time for plant/equipment.

The two factors are considered to be a measure of the success of plant/equipment maintenance.

4.4.7 Engineering/construction

From a contractor's view point, projects are the smallest units of development to meet its objectives (eg, profit maximisation). Projects generally require extraordinary resources and management in a limited period of time. Therefore, most contractors have arranged their organisational units and their tasks to meet these objectives.

Due to complexity, a project may be subdivided into subprojects, subsubprojects, tasks, subtasks and so on as a hierarchy, termed *Project Breakdown Structure* (*PBS*), to make the project more *manageable*. This PBS facilitates the management of time, resources, and budgets, which are always done at the lowest level. How well the management performed is identified by main project management activities: project planning, executing, monitoring and adjusting.

4.4.7.1 Project planning

As a preparation for action, planning involves deciding (1) what tasks from PBS will be done in what way, at what time and in what sequence, (2) what resources in what amounts are called for, and (3) what objectives are to be achieved. Different contractors have different ways of planning due to the different ways of their executing work. However, all should have the following plans to facilitate their work:

- Master plans showing main activities (eg, foundation and structure), milestones, and main resources required (eg, main plant/equipment and subcontractors) for the whole period of a project.

- Detailed plans showing operating tasks in detail (eg, foundation and structure formwork) for monthly, weekly, and daily tasks.

- Resource plans including manpower plans, material plans and plant/equipment plans.

- Budgeting showing cash inflow and outflow of a project such as *S curves*.

4.4.7.2 Project executing

After the project plans are finished, the project is ready to start. To evaluate a contractor's project executing ability, the following factors are investigated:

- Communication of the plans to those involved. This illustrates the communication skills of a contractor. Tables, pictures and diagrams support the communication.

- Technical ability showing basic technical knowledge and understanding of construction projects by considering length of experience, complexity and scale of projects done, type of projects done and in-house knowledge/technology currently used.

4.4.7.3 Project monitoring

Whilst a project is being executed, some assumptions may change and unexpected events may occur. This leads to the difference between planned and executed work. Monitoring the difference is measured by:

- Continuous reporting including daily, weekly and monthly reports.
- Analysed reporting for example a comparison between planned and executed S curves.

These two reportings gives a good indication of the monitoring efficiency of a contractor.

4.4.7.4 Project adjusting

The difference between planned and executed work needs some adjustment. Budget, time and/or resources may be adjusted to narrow such differences. Actions taken based on time are:

- monthly actions
- quarterly actions
- half yearly actions.

4.4.8 Project managers

It is widely agreed that one of the keys to a project's success is the Project Manager, the PM. All the main activities are led and/or performed by a PM. Most PMs carry out these functions:

- the development of master and resource plans in order to draw up budgets
- the assurance of the attainment of master plans and budget plans
- the investigation of plans, cost and technical results to ensure the attainment of project objectives and contractual reporting
- the changes of controls (eg, monthly actions) to ensure configuration accountability affecting the project is success.

As project managers play an important role in a project's success, evaluating the ability to manage projects involves evaluating the project managers of a contractor company. To do this, several factors to consider are suggested by Einsiedel (1984):

4.4.8.1 Project management experience

Experience can guarantee the success of carrying out the above functions at a certain level. When the project is more complex, the experience of project managers is necessary. This experience reflects the ability of project managers in:

- Problem solving skills. These skills support the implementation of solutions involving human interactions and relationships such as allocating project resource requirements and surviving company constraints.

- Management of conflict. The main cause of conflict is the imbalance of jurisdiction between functional departments and projects. How well the balance managed represents the ability of PMs by, for example, developing contingency plans with and without consultation with functional department managers and the regularity of meetings to review master project plans.

- Previous or current position. It is vital for a PM to be accepted by functional department managers and to be allocated with enough resources to implement any project. Creditability, social status and authority are also important when a PM is to command personnel assigned from functional departments.

4.4.8.2 Communication skills

Good communication skills mean that a PM can effectively and efficiently deliver plans, controls, tasks and standards to personnel who will be (are) carrying them out. These skills involve:

- Observing information skills. Actively listening, reading and organising messages are good indicator of a PM's ability to facilitate the control-delivery process.

- Analysing information skills. These skills show the intelligence of a PM to separate between the relevant and related information. Then only relevant information is used to solve a particular problem.

- Persuasive skills. When ideas have to be promoted and accepted for implementation, persuasive skills are vital in selecting an effective presentation method and the right time to suitable personnel.

4.4.8.3 Adaptability

Some projects operate under ambiguous and changing circumstances. Finding the best solution and implementing a solution within the constraints of time, cost and quality may not be enough. The way and time to do this are also important to the success of a project. The PMs have to be adaptable and able to handle ambiguity and change. The level of adaptability looks at the ability to balance between conserving and challenging traditional operations and behaviours in order to avoid conflict.

4.5 Methodology for data gathering

To test the hypotheses, survey research – eg, mailed questionnaires including hand-delivered questionnaires, telephone and interview surveys – was considered. To receive a high rate of return, a hand delivered questionnaire survey was selected to gather the data. This survey was chosen as it can cover a wide range of professionals.

4.6 Questionnaire design

Several methods can be used to acquire the necessary data, for example: survey, observation, and quasi/experiments. The selection amongst the three methods is based on three criteria: the purpose of the research, the characteristics of samples proposed, and limitations of time and resources. The last two methods do not comply with the last two criteria. In addition, some phenomena (data) cannot be accessed by observation (Nachmias, 1976) or by experiments. Therefore, survey research was chosen.

Within survey research, there are a variety of methods such as mail (or *self-administered*), telephone, and interview surveys. Erdos (1970) provides some advantage of mail (or self-administered) surveys compared to the others: (1) Wider distribution; (2) Less distribution bias; (3) No interviewer bias; (4) Better chance of truthful and thoughtful reply; and (5) Time and cost saving. Thus, a self-administered (hand-delivered) survey was selected to gather data from the samples.

4.6.1 Characteristics of questions

The basis of the interview is questions (stimuli). The major characteristics of the questions designed were:

- Sections were made to effectively communicate areas of interest.
- The major responses were a tick or circle over a number.

- To retain high attention of the respondents, the length of time respondence was arranged at around 20-30 minutes.
- Leading questions – ie, the questions are anticipated to get definite answers – were carefully used in order to avoid biased answers.
- Threatening questions – ie, question asking "why" and "how" – were avoided.
- Wording of the questions aimed at understanding of the respondent. Words that may be variously interpreted were avoided but, if necessary, they were explained as a frame of reference.
- Sequence of questions started form simple to complex to develop interest letting the respondent move onwards.

4.6.2 Purpose of asking questions

There were only seven main questions with subquestions. The questions were divided into four sections as shown in Appendix B1:

- **Section A:** General information consisted of two main questions (Q1-Q2) aimed at gathering some characteristics of the respondents and their organisations and at probing the validity of the sources of data.

- **Section B:** Criteria influencing the selection of a contractor (Q3) was aimed at eliciting the criteria and their degree of importance and at seeking other criteria potentially influencing tender evaluation.

- **Section C:** Tender evaluation procedures comprised three main questions (Q4-Q6) aimed at exploring tender evaluation procedures currently used by industry.

- **Section D:** Tender evaluation models consisted of one main question (Q7) aimed at finding state-of-the-art models for evaluating contractors.

Due to the qualitative nature of criteria, particularly in Section B, a hierarchy of subcriteria was developed based on the existing hierarchical organisational units as discussed in Section 4.4. However, to assign a scale to the criteria there is a dilemma between ordinal and interval scales: Do the criteria have interval scales? or do they have only ordinal scales? (Nunnally, 1978). There is no universally acceptable answer for these questions. Practice suggests that interval scales are easier to analyse because of more available analytical procedures but more difficult to answer by the respondent. As a result, a trade-off arises in the selection between the two scales. That is, selecting an interval scale puts the onus on the respondent whereas choosing an ordinal scale puts the onus on the investigator (as the analyst). Therefore, a combination of *Likert scale* (an ordinal scale) and *bipolar adjective scale* (an interval scale) were applied. The *Likert* scale was used to verbally explain the pre-specified points within the range of the scale (1 = very low importance, 2 = low importance, 3 = medium importance, 4 = high importance and 5 = very high importance) for the sake of identically communicating meanings of the scale between the respondent and investigator; hence reducing the onus on the respondent. Whereas, a bipolar adjective scale (1 = very low importance .... 5 = very high importance) was applied for the use of parametric analysis, ie, factor analysis; hence decreasing the analytical burden. In addition, Lehmann (1989) suggests "... at best the scale is somewhat in between an interval [scale] and an ordinal scale." This combination is a compromise between the practical reality of data gathering and the methods of analysis, and is expected to render "a" most suitable measure.

4.6.3 Confidentiality

The data from the respondents were kept confidential. Confidentiality was emphasised to the respondents in order to increase the level of reliability of data possibly resulting from biased responses.

4.6.4 Questionnaire test/modification

Before distribution, the questionnaire was tested, as a pilot study, with seven postgraduate students (with widely diverging cultural backgrounds) at the school of civil engineering, QUT in order to make sure that the data could be validly collected and the questions were able to be understood. Following modification, the questionnaire was tested again with one Australian and two Thai practitioners in tender evaluation. This resulted in the questionnaire being further modified to reduce the obscurity of the questions and to increase the clarity and conciseness of the questions.

4.6.5 Distribution

To receive cooperation in answering the questionnaire, a covering letter was sent to the organisations sampled. The need for cooperation and the purpose of data collection were presented. The questionnaire was distributed (hand delivered) to 103 government and 107 private agencies in Bangkok, Thailand. All questions were translated into Thai to increase the level of validity of data as shown in Appendix B2. A verification of the translation is provided in Appendix B3.

4.7 Data preparation

The necessary data were prepared for analysis in three main steps:

- Coding; that is, data (variables) were transformed into number. Appendix B4 shows coding manual.
- Editing; that is, after the completeness and discrepancy of the data was inspected, the data were rectified by referring to the original questionnaire.
- Transforming; that is, all the coded data were transformed into an SPSS file.

4.8 Conclusions

The findings from chapters 2 and 3 show that worldwide commonality in selecting criteria (to evaluate contractor ability and tenders) still does not occur. In acknowledgment of the non-existing commonality, the *theory of hierarchy, multilevel, systems* was applied, as a conceptual framework, to develop the hierarchy of criteria. The hierarchy of the criteria was designed to correspond to contractors' organisational units. By using this concept, it was believed that a common set of criteria would appear.

To test the belief, a hand delivered questionnaire survey was chosen. In addition, the questionnaire was designed to investigate tender evaluation procedures and tender evaluation models currently used by the Thai construction industry.

The next chapter will analyse the questionnaire in terms of its quality and statistics to draw a conclusion regarding the belief and investigation.

Chapter 5

A survey of tender evaluation: Data analysis

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5.1 Introduction

In conjunction with chapter 4, after being prepared, the data were analysed using SPSS in relation to (1) sample characteristics, (2) data quality and (3) statistics.

For the data characteristic analysis, the overall response rate is 68%. The government sector returned a 77% rate whilst that of the private sector was 59%. Both the sectors have a total annual contract value of AUS$24,932 million with minimum and maximum values of AUS$0.01 million and AUS$10,000 million.

The quality of the data was tested in terms of validity and reliability. After that, three major statistical analyses were undertaken to (1) determine similarities and differences in selecting contractor ability criteria between government and private sectors by using comparison of importance index and ranking order and hypothesis tests, (2) examine relationships between all the criteria and measures by using correlation coefficients, and (3) apply factor analysis to group all correlated measures together.

5.2 Sample characteristic analysis

Types of organisations with their response rates are summarised in Table 2. The total rate of return was 68% (142). The government sector returned 79 questionnaires and had the highest return rate of 77%, whilst the private sector returned 63 questionnaires at a return rate of 59%. This overall return rate is considered good as Babbie (1989) suggests that any rate over 50% can be reported, over 60% is good and over 70% excellent. The expected time for completing the questionnaire was 20-30 minutes; but a comment from some respondents indicated that double this time was needed. Where organisations preferred to give 1 hour to complete a questionnaire, the importance of the subject to the industry is indicated.

Table 2 Sample characteristics in the Thai construction industry

Sector	Organisation	Number of questionnaires		Percent return
		Sent	Returned	
Government	Bangkok Metropolitan Administration	20	16	80
	The Department of Accelerated Rural Development	3	3	100
	The Department of Highways	14	11	79
	The Royal Irrigation Department	20	13	65
	The Public Works Department	20	15	75
	The Electricity Generating Authority of Thailand	25	20	80
	The Airports Authority of Thailand	1	1	100
	Subtotal	103	79	77
Private	Consultant	29	15	52
	Contractor	52	33	64
	Others (eg, owners and engineering)	26	15	58
	Subtotal	107	63	59
	Total	210	142	68

Note: The government organisations are large. They have a number of multiple decision-makers for tender evaluation.

The sectors involved have a total annual contract value of AUS$ 24,932 million with the minimum and maximum values of AUS$ 0.01 million and AUS$ 10,000 million. In terms of annual average, the government sector has a higher contract value (AUS$ 306.9 million) than the AUS$ 138.3 million of the private sector. The government sector engaged in maintenance works totalling 11,205 contracts annually, followed by civil works with 6,186 contracts, services with 2,240 contracts, building works with 564 contracts and others works with 264 contracts. The results from the private sector indicated that there were 590 contracts in civil works, followed by 160 contracts in services, 132 contracts in building works, 41 contracts in other works and 20 contracts in maintenance works. A summary of the results is presented in Table 3.

Table 3 A summary of characteristics of the respondents' organisations

Sector (Q 2.1)	Approximate average annual contract value (M$) (Q 2.4)	Contract values (M$) (Q 2.5)	
		Minimum	Maximum
Government	306.9	0.01	10,000.0
Private	138.3	0.01	1,304.0

Sector	Average annual number (Q 2.3)				
	Building works	Civil works	Services	Maintenance works	Other works
Government	564	6,186	2,240	11,205	264
Private	132	590	160	20	41
Total	696	6,776	2,400	11,225	305

Note: Bahts were converted to Australian Dollars using the exchange rate of 23 Bahts/Dollar.

5.3 Qualification analysis

Measurement has long been being used as the linkage between concepts and reality. Various measurement instruments can be constructed for this linkage such as experiment sets, simulations, observations and survey questions. As the measurement instrument for studying the tender evaluation problem, the questionnaire was constructed to link conceptual and realistic criteria. Many criteria together with their measures were developed based on the theory *of hierarchy, multilevel, systems* (see Mesarovic *et al.*, 1970) and the related previous research works (eg, BMA, DARD, DOH, PWD and RID standards for contractor registration; Hatush and Skitmore, 1997; Liston, 1994, 1999; Russell, 1996; Russell and Skibniewski, 1988, 1990; Russell *et al.*, 1992). The quality of the constructed questionnaire (ie, criteria and measures) needed to be assessed. To qualify the constructed questionnaire, the gathered data was tested in terms of validity and reliability.

5.3.1 Validity

Validity means measuring what is expected to be measured. Several authors (Babbie, 1989; Mertens, 1998; Nachmias, 1976) discuss various types of validities such as criterion-related, content and construct validities. The criterion-related validity needs criteria/standards to test. On the other hand, the content validity demands high understanding of meanings of the studying objects (eg, problems and projects). The construct validity needs other *parallel* theories to test.

Because criteria/standards are not available to tender evaluation and understanding of tender evaluation is limited, the criterion-related validity and the content validity are difficult to test. As such, a pilot study was carried out with postgraduate students in School of Civil Engineering, QUT, tender evaluation practitioners in Australian and Thai construction industries. Then the questionnaire was modified to reduce the obscurity of the questions and to improve the clarity and conciseness of the questions. This test provided a certain level of confidence in the criterion-related and content validities.

The scant existence of other *parallel* theories does not easily allow testing the content validity. Thus correlation analysis was used to examine whether relationships amongst all criteria and their measures existed (cf, Nunnally, 1978). The results shown in Section 5.4.3.2 ensured that all criteria and measures were correlated and hence relevant to the evaluation of contractor ability.

5.3.2 Reliability

Reliability means the measurement instrument yields the same result over time. Many techniques can be used to test reliability such as *test and retest*, *parallel forms*, *split-halves*, and *internal consistency* methods (Babbie, 1989; Mertens, 1998; Nachmias, 1976). Each of the methods has its advantages and disadvantages. For example, although the test and retest and the parallel forms are easy to understand, the former suffers from repetitive measurement whilst the latter confronts a problem of constructing parallel measure. On the other hand, the split-halves can rectify the problems of the previous two methods but it faces the inconsistent results of different splitting. The limits of the three methods can be improved by the internal consistency method such as Cronbach's Alpha and Kuder-Richardson formulas. However, the Kuder-Richardson method is used only for 0-1 scales. Thus Cronbach's Alpha was performed to test the internal consistency reliability of the questionnaire. In this study, the Alpha of 0.981 for the questionnaire test indicated a good internal consistency reliability (the Alpha should be greater than 0.7 (SPSS training, 1998)).

5.4 Statistical analysis

There are a number of statistical methods for analysing data. Some require normal distribution of data. Others do not. This requirement affects the accuracy of those statistical methods' results (or the quality of prediction). As such, before any statistical method was selected to analyse data, the shape of the distribution of data was examined. It was found (by using Skewness and Kurtosis) that a majority of data were not normally distributed. Thus, statistical techniques that do not require normality of data were selected to analyse the data in this section.

5.4.1 Question 1

"1. Please give some personal details, namely:

1.1 Current position ....

1.2 Working duration in the position (yrs) ....

1.3 Current function

☐ Contract preparation ☐ Tender evaluation
☐ Contractor selection ☐ Other.................................

1.4 Your educational background

☐ Architect ☐ Civil engineer
☐ Quantity surveyor ☐ Other................................"

The question was asked to obtain characteristics of the respondents in terms of their current positions, duration in the positions, current functions and educational background. A summary of the characteristics is shown in Table 4.

Table 4 A summary of characteristics of the respondents

Level of current Position (Q 1.1)	Number in the level	Percent in the level	Working duration in the position (yrs) (Q 1.2)		
			Minimum	Maximum	Mean
Operations	62	43.7	1.0	28.0	5.6
Middle management	70	49.3	0.5	30.0	4.8
Top management	10	7.0	2.0	20.0	10.5
Total	142	100.0			

Current function involved in (Q 1.3)	Number of the respondents involved with the function	Percent of the respondents involved with the function (out of all respondents)
Contract preparation	13	9.2
Tender evaluation	111	78.2
Contractor selection	68	47.9
Other function	19	13.4

Education background (Q 1.4)	Number of the respondents	Percent of the respondents
Architect	4	2.8
Civil Engineer	97	68.3
Quality surveyor	8	5.6
Other	32	22.6
Missing	1	0.7
Total	142	100.0

Table 4 shows that all respondents are valid persons within the parameter of this survey in terms of current positions, duration in their positions, current functions involved in tender evaluation and educational background. Furthermore, the respondents have experience in their functions between 0.5 and 30 years.

5.4.2 Question 2

"2. Please give some details of your organisation, namely:

2.1 Sector

☐ Public ☐ State enterprise ☐ Private ☐ Other............

2.2 Business

☐ Owner ☐ Consultant ☐ Architect
☐ Project manager ☐ Engineering ☐ Contractor
☐ Other...................................

2.3 Type of work and average number of annual contracts

☐ Building works and number........... ☐ Civil works and number........
☐ Services and number...................... ☐ Maintenance and number......
☐ Other..

2.4 Approximate annual contract value (only your sole company) $M.................

2.5 Minimum and maximum contract values $M..................to $M.............."

The question was asked to gather characteristics of the respondents' organisation. Table 5 presents the characteristics. The sectors involved have a total annual contract value of AUS$24,932 million with the minimum and maximum values of AUS$0.01 MILLION and AUS$10,000 million. In terms of annual average, the government sector (public and state enterprise) has the higher contract value (AUS$306.9 million) compared to AUS$138.3 million for the private sector. The government sector engaged in the maintenance works totalling 11,205 contracts annually, followed by civil works with 6,186 contracts, services with 2,240 contracts, building works with 564 contracts and others works with 264 contracts. The results from the private sector indicated that there were 590 contracts in civil works, followed by 160 contracts in services, 132 contracts in building works, 41 contracts in other works and 20 contracts in maintenance works.

Table 5 A summary of characteristics of the respondents' organisations

Sector	Approximate average annual contract value (AUS$M)	Contract values (AUS$M)	
		Minimum	Maximum
Government	306.9	0.01	10,000.0
Private	138.3	0.01	1,304.0

Sector	Number of business category of the organisation (Q 2.2)					
	Owner	Consultant	Project Manager	Engineering	Contractor	> one business
Government	50	-	1	-	-	7
Private	3	15	-	1	33	11
Total	71	15	1	1	33	21

Sector	Average annual number				
	Building works	Civil works	Services	Maintenance works	Other works
Government	564	6,186	2,240	11,205	264
Private	132	590	160	20	41
Total	696	6,776	2,400	11,225	305

5.4.3 Question 3

"3. There are criteria important to the success of project requirements. What are the degrees of the importance? And what are other criteria together with their degrees of the importance not written down?..."

The question required the respondents to determine the degree of importance of listing criteria and to specify other criteria influencing the selection of a contractor. The main aim of the analysis was to find selection criteria for evaluating contractor ability and their weight of relative importance. To achieve this aim, three major analyses were undertaken to (1) determine similarities and differences in selecting contractor ability criteria between government and private sectors by using comparison of importance index and ranking order and hypothesis tests, (2) examine relationships amongst all criteria and measures by using correlation coefficients, and (3) apply factor analysis to group all correlated measures together.

5.4.3.1 Test of similarities and differences

To find similarities and differences between government and private sectors, means and standard deviations of all criteria and their measures were explored. However, means may not well represent data if the data have high standard deviations. Thus, a *standardised* ratio (making the standard deviation equal 1) of mean and standard deviation was constructed for the use of comparative purposes (cf, Lehmann, 1989), which was written as:

$$\text{Importance Index} \quad = \quad \frac{\text{Mean}}{\text{Standard deviation}}.$$

To draw a conclusion as to whether government and private sectors consider criteria differently as they evaluate contractor ability, mean importance of each criterion and measure was compared using Mann Whitney U test.

5.4.3.1.1 Comparison of ranking order and importance index across sectors

A summary of the comparison is presented in Table 6. Overall, the five most important criteria were:

- "project planning"
- "project monitoring"
- "project management experience"
- "ability to adjust a project"
- "performance."

The five most important measures were:

- "master plans"
- "continuously reporting"
- "a list of plant/equipment"
- "past performance"
- "problem-solving skills."

Table 6 Comparison of the five most important criteria and measures

Sector	5 most important criteria		5 most important measures	
	Criteria	**Index**	**Measure**	**Index**
Overall	Project planning	5.81	Master plans	5.22
	Project monitoring	5.70	Continuously reporting	4.93
	Project management experience	5.45	A list of plant/equipment	4.82
	Ability to adjust a project	4.73	Past performance	4.82
	Performance	4.69	Problem-solving skills	4.80
Govern-ment	Project planning	6.07	Master plans	5.06
	Project monitoring	6.07	Past performance	5.06
	Project management experience	5.27	Continuously reporting	4.93
	Performance	5.01	Problem-solving skills	4.78
	Ability to adjust a project	4.78	A list of plant/equipment	4.67
Private	Project management experience	5.74	Technical ability	6.34
	Subcontractor control	5.65	Budgeting	6.06
	Project planning	5.53	Master plans	5.57
	Project monitoring	5.25	Observation skills	5.36
	Financial ratios	5.15	Analysis skills	5.18

Clearly both sectors considered "project planning," "project monitoring," and "project management experience" as very important. Therefore, these three criteria should be considered when contractors are evaluated.

"Performance" and "ability to adjust a project" were indicated by the government sector as important. These two criteria largely affect the timeliness of a project, which guarantees that the fiscal year is not violated. On the other hand, the private sector indicated "subcontractor control" and "financial ratio" as important because these two criteria extensively affect the cost of a project. This, in turn, ensures economic viability of private organisations in business.

It is interesting to look at the criteria on quality and safety. As shown in Tables C1 and C2 in Appendix C, both sectors rated criteria "quality system selection" (importance indices of 2.94 and 3.64 by public and private sectors, respectively), "quality system implementation" (importance indices of 2.98 and 3.60) and "quality system audits" (importance indices of 3.44 and 4.32) as being of medium-to-high importance. Based on these results, the quality system selection, implementation and audits are not of major concern to either sector. On the other hand, although health and safety performance can block the execution of a project and lead to an additional cost to a project, it is rated as semi-important by the government sector (an importance index of 3.56) but as rather important by the private sector (an importance index of 4.79). This reinforces the belief that any criteria possibly affecting project cost can be of great importance to the private sector. This is not true for the government sector: the major factor that affects this sector is time.

On measures as shown in Tables C3 and C4, only "master plans" was indicated as highly important by both sectors but the government sector put a higher priority (ranked 1st) on "master plans" than did the private sector (ranked 3rd). This factor explains the belief that time is of more concern to the government sector. In contrast, the private sector expressed "budgeting" as very highly-important (ranked 2nd) because this measure helps to establish financial viability. However, the government sector ranked "budgeting" 26th, from which it can be concluded that financial viability is not a major concern for this sector.

Other measures amongst the five most important for the government sector were "past performance," "continuously reporting," "a list of plant/equipment" and "problem-solving skills." The main reason why the first three measures are considered as important is that all these measures are prescribed by the government sector, and cannot be breached. Also, having "problem-solving skills" as a project manager is of major concern because most government organisations require contractors who have the ability to solve their own problems (eg, allocating project resource requirements, surviving company constraints and managing risk associated with the project) and to correct errors/mistakes that occur in the specifications and drawings.

For the private sector, the remaining five most important measures were "technical ability," "observation skills" and "analysis skills." These three measures reflect the aim of the private sector, which is to make a profit from constructing the facility. To achieve this aim, the private sector wants contractors who have high technical ability, show basic technical knowledge and understand construction projects. Also, the contractors should have a project manager who has good communication skills and is therefore able to effectively and efficiently deliver plans, controls, tasks and standards to other colleagues. This then secures the completion of the facility on a pre-specified budget.

Of interest are measures describing quality, and health and safety. Both the public and private sectors rated "AS 3900 series" as being of low importance, (1.85 and 1.86, respectively) whereas "ISO 9000 series" was of medium importance (2.54 and 3.03, respectively). The comments from some respondents were that they were more familiar with standard ISO than with Joint standard AS/NZS. "Progressive steps of implementing a quality system" was rated by public sector as being of medium importance (an importance index of 3.09) but of rather high importance by the private sector (an importance index of 3.98).

Another interest was that "documented processes being followed by contractor," "documented processes in place ready to address standard elements," and "documented processes being effective and suitable" were rated as being of medium-to-high importance with an importance index range between 3.53-3.16 by the government sector, and as rather-high-to-high with an importance index range between 4.15-3.76 by the private sector. Also "health and safety plan" and "health and safety control" were rated as of medium importance with an importance index range of 3.16-3.06 by the government sector and as rather-high-to-high with an importance index of 3.95-4.08 by the private sector.

The comparison of ranking order between government and private sectors has shown that 3 out of the five most important criteria, 60%, are selected in agreement. However, only 1 out of the five most important measures, 20%, is similarly selected. In addition, when importance indices of criteria and measures on quality and health and safety are compared, the overall statistical figures show that the government sector places a lower priority on these criteria (importance indices of 3.23 and 4.09 by government and private sectors, respectively) and measures (importance indices of 3.26 and 3.97 by government and private sectors, respectively) than does the private sector. Furthermore, as discussed earlier, the five most important criteria and measures indicated by the government sector are directed towards time requirement whilst those of the private sector are directed towards cost requirement. Nevertheless, at this stage it cannot be concluded whether government and private sectors consider criteria/measures differently as they evaluate contractor ability. To explore this further, hypotheses on which criteria and measures make the two sectors different at specified statistical levels were tested.

5.4.3.1.2 Hypothesis test

In conjunction with the previous section, differences and similarities between the two sectors were further inspected. A nonparametric statistical test, Mann Whitney U test, was performed to compare the mean importance of each criterion and measure whether there was any statistical difference at the 95% level of confidence. Normality of population is not required. Hence this test was selected.

The aim of the Mann Whitney U test is to draw a conclusion on the existence of mean differences of variables between two population groups which are selected independently (for more details see Seigel and Castellan, 1988; Keller and Warrack, 1997). The test started with forming the null and alternative hypotheses:

H_0: The mean importance of each criterion and measure are equal for both government and private sectors

H_a: Some mean importance of each criterion and measure are not equal for both government and private sectors

The null hypothesis was then tested against the alternative hypothesis. All criteria and their measures for both sectors were compared as to whether any differences exist. The level of confidence used for the test was 0.95 (or the level of significance equalled 0.05). This means the results of the test can be 95% trusted or have 5% error. The result is presented in Table C5 in Appendix C.

Table 7 summarises the result. In the Table, only 5 out of twenty three criteria, 22%, were indicated as statistically different in terms of mean importance, namely, "financial ratios," "quality system implementation," "project execution," "communication skills" and "adaptability." Also, only 19 out of sixty three measures, 30%, were statistically different, including "gross profit," "progressive steps of implementing a quality system," "competitive incomes/welfare," "master plans" and "budgeting."

Table 7 Criteria and measures indicated as statistical differences between the two sectors

Mean criteria indicated difference*	**Mean measures indicated as difference***
Financial ratios	Gross profit
Quality system implementation	Current banking organisation
Project execution	Average length of time that the contractor pays subs/suppliers
Communication skills	Conditions in bank guarantee
Adaptability	Progressive steps in implementing a quality system
	Competitive incomes/welfare
	General conditions of subcontractors
	Communication line
	Master plans
	Budgeting
	Contingency plans
	Communication of the plans to involved people
	Technical ability
	Management of conflict
	Previous and current position
	Observation skills
	Analysis skills
	Persuasive skills
	Tolerance for ambiguity

* statistical difference at the 5% level of significance

Clearly, less than 35% of the number of criteria and measures are indicated as statistically different at the 95% level of confidence. Therefore, it can be concluded that both government and private sectors consider criteria/measures similarly in evaluating contractor ability.

5.4.3.2 Relationships between all criteria and measures

To identify that the criteria and measures were valid and relevant to the evaluation of contractor ability, the relationships between them were examined. The Spearman Rank Correlation method was selected to calculate the correlation coefficient, r, because normality of population is not required (for more details see Seigel and Castellan, 1988). The interpretation of the coefficient is:

- r value is minus, indicating a *negative* relationship. The more r approaches –1, the higher the *negative* relationship.

- r value is plus, indicating a *positive* relationship. The more r approaches 1, the higher the *positive* relationship.

- r value equals zero, indicating no relationship.

The coefficient was used to test the hypotheses:

H_0: There is no relationship between the two criteria or the two measures
H_a: There is a relationship between the two criteria or the two measures.

The level of confidence for the test was 95% or 99%. Almost all criteria and their measures were correlated except that the criterion "quality system selection" was not correlated to its measure "AS 3900 series."

For example, criteria considered of both high and low importance (resulting from the previous section) are shown in Table 8. In the table, the statistically significant relationships between the criteria and their measures are indicated by * (at the 5%

level of significance) or ** (at the 1% level of significance). Clearly "financial ratios" and "banking arrangement" had the weakest relationships with other criteria. That is, "financial ratios" did not correlate with "banking arrangement," "procurement plan," "delivery control," "project planning," "project execution," "project monitoring" and "ability to adjust a project." Also there were no relationships between "banking arrangement" and "financial ratios," "procurement plan," "subcontractor control," "project planning," "project execution," "project monitoring". However, "delivery control" was strongly correlated to "subcontractor control" as were "project planning" and "project monitoring." Similarly, there was a strong relationship between "project monitoring" and "ability to adjust a project."

Table 8 Spearman rank correlation coefficient, r, of ten example criteria

Criteria	**Financial ratios**	**Banking arrangement**	**Credit ratings**	**Procurement plans**	**Delivery control**	**Subcontractor control**	**Project planning**	**Project execution**	**Project monitoring**	**Ability to adjust a project**
Financial ratios	1									
Banking arrangement	0.145	1								
Credit ratings	0.386**	0.607**	1							
Procurement plans	0.127	0.219	0.247**	1						
Delivery control	0.123	0.298**	0.473**	0.349**	1					
Subcontractor control	0.209*	0.187	0.416**	0.479**	0.540**	1				
Project planning	0.168	0.160	0.337**	0.356**	0.234*	0.324**	1			
Project execution	0.033	0.137	0.214*	0.420**	0.225*	0.316**	0.484**	1		
Project monitoring	0.042	0.161	0.234*	0.415**	0.350**	0.336**	0.570**	0.561**	1	
Ability to adjust a project	0.092	0.309**	0.256*	0.369**	0.348**	0.356**	0.459**	0.510**	0.597**	1

* at the 5 % level of significance; ** at the 1 % level of significance

In the overall section, criteria and measures were correlated. This confirms the relevance of all the selected criteria and their measures to the evaluation of contractor ability. Moreover, some measures were strongly correlated as one shared group, whilst other measures were correlated as another shared group. This means the highly correlated measures share a common factor. Thus they can be grouped together for the sake of understanding and modelling tender evaluation (the fewer the number of factors/criteria, the easier the model can be created and understood). The next section presents the method of grouping the measures using factor analysis.

5.4.3.3 Factor analysis

In order to group together measures which are highly correlated, factor analysis was chosen. Two basic reasons for the grouping are (1) the simplification of modelling (common sense suggests that the smaller the number of criteria, the easier the creation of a model) and (2) the exploration of the underlying structure of measures whether the structure is compatible with hierarchical organisational units of contractors. The details of factor analysis can be seen in Aaker *et al.* (1998) and Lehmann (1989).

A condition required by the factor analysis model is that the number of observed samples must be greater than the number of variables/measures. The more the number of samples, the better the results. For this reason, any measures having an importance index of less than 3 (considered as of medium importance) were primarily removed. Accordingly, only 53 measures were used as input for factor analysis as shown in Table C6 in Appendix C.

The main aims of using factor analysis were to group those highly correlated measures together and then to find weights of relative importance amongst those groups.

5.4.3.3.1 Correlation coefficient examination

The coefficient, r, indicates the level of relationship between the two measures. The coefficient value ranges between –1 and +1. The coefficient is interpreted similarly to that in Section 4.3.2, namely:

- If r is nearly –1 or +1, the pair of the variables is highly correlated; the variables should be in the same factor.
- If r is nearly 0, there is a low correlation between the pair of the variables; the variable should be in different factors.
- If r is nearly 0 between a variable and the other variables, the variable has a low correlation to the other variables and is not relevant to the problem; the variable should be removed.

The coefficient values indicated that all measures were correlated. In addition, the coefficient values were used to test whether the data were appropriate for using factor analysis. The tests were:

- The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. The value of the measure ranges between 0 and 1 (1 indicates adequacy whilst insufficiency is 0).
- Bartlett's test of sphericity. The test was done against the null hypothesis: no relationship amongst variables/measures, at the 95% level of confidence.

Table 9 summarises the results of the tests. The KMO measure of 0.897 indicated adequacy for using factor analysis. Also, the Bartlett's test indicated relationships amongst measures (rejecting the null hypothesis), which was suitable for running factor analysis.

Table 9 KMO and Bartlett's test

Kaiser-Meyer-Olkin measure of sampling adequacy		0.897
Bartlett's test of sphericity	Significant	0.000

5.4.3.3.2 Factor extraction

As a result of examining correlation coefficients, the relationships for all measures are explored. Highly correlated measures were able to be grouped together. A variety of methods for the grouping are suggested. The most common method, the *Principal Components* was selected, because normality of population is not required. What the *Principal Components* does is to combine many correlated measures into a small number of components, namely:

- the first component which contains the maximum information in all the measures. That is, this component has the largest variance. Thus, it can explain the problem most effectively.

- the second component, which is independent of the first component, and contains as much of the remaining information in all the measures as possible, and so on.

The result from examining the *greater-than-one eigenvalues* (characteristic values) of the principal components suggested 12 components to retain as shown in Table C6 in Appendix C. Each row of the table contained factor loadings (a correlation-type coefficient between a measure and a component) that indicated which measures belong to each component (−1 or + 1 indicate the measure belongs to the component but 0 indicates it does not). From the table, the values of factor loading were still not clear in indicating which measures should belong to which components because the values of factor loadings of many measures on each component were close. In order to make a clear pattern of this, a modification of the factor loadings by rotating the principal components performed in the next step was necessary.

Another important result of this step is the total variance explained[†] by each component. Table 10 summarises the result. The 12 components together accounted for 75% of variance of all the measures. The first component explained 39% of variance of all the measures whilst that of the last component explained only 2%.

5.4.3.3.3 Factor rotation

The rotation of the components/factors was to adjust the values of factor loadings so that the new values were closer to –1, +1 or 0, which is the ideal result of the rotation. These new values make the grouping of measures easier if each variable has a high factor loading (close to –1 or +1) on a single component but small factor loadings (close to 0) on the other components.

Two main rotation types exist: *orthogonal* rotation (resulting in non-correlated components) and *oblique* rotation (leading to correlated components). To create non-correlated components for the sake of sequential modelling, *orthogonal* rotation was chosen. In this rotation, variations exist. The most popular one is *varimax* rotation which attempts to ease the grouping by maximising the variances of the factor loadings on each component. Based on popularity, *varimax* rotation was selected.

The rotated factor loadings are shown in Table C7 in Appendix C. This analysis has made it easier to clearly identify which measures belong to which components. Twelve components to retain were still suggested. The results are shown in Table 10 in the shaded area. However, the *prior* theory (ie, the theory of *hierarchy, multilevel, systems*) being applied to the problem suggests that the selection criteria should be primarily decomposed according to existing organisational units of contractors. Based on a combination of this result and the *prior* theory, nine components were adopted for simplifying sequential modelling.

[†] Percent of variance explained means how much each component/criterion can be explained by the original variables/measures.

Table 10 Total variance explained

Component	Extraction sums of squared loadings (eigenvalues)			Rotation sums of squared loadings		
	Total	Percent of variance	Cumulative percent	Total	Percent of variance	Cumulative percent
1	20.553	39	39	5.952	11	11
2	3.815	7	46	5.494	10	21
3	2.307	4	50	4.404	8	29
4	2.066	4	54	4.067	8	37
5	1.934	4	58	3.819	7	44
6	1.762	3	61	3.292	6	50
7	1.525	3	64	2.609	5	55
8	1.358	3	67	2.550	5	60
9	1.265	2	69	2.546	5	65
10	1.103	2	71	2.060	4	69
11	1.070	2	73	1.578	3	72
12	1.017	2	75	1.401	3	75

5.4.4 Question 4

"4. Which of the following procedures do you use for tender evaluation?

Procedures	How to make a short list?
☐ Selective tendering	☐ With prequalification (if you tick this box, answer question 6.1) ☐ Without prequalification (if you tick this box, answer question 6.2)
☐ Open tendering	(if you tick this box, answer question 6.3)
☐ Negotiated tendering	

"

The question asked for the procedures that are used in tender evaluation. A summary of the procedures used by the respondents is shown in Table 11.

From Table 11, 47.5% of the respondents use selective tendering with prequalification, followed by selective tendering without prequalification (29.5%) and open tendering (6.5%). This shows that selective tendering with prequalification is the most used in Thailand.

Table 11 A summary of procedures used in tender evaluation

Number and percent of each procedure used in tender evaluation									
Selective tendering with PQ		Selective tendering without PQ		Open tendering		Negotiated tendering		More than one procedure used	
No.	%	No.	%	No.	%	No.	%	No.	%
66	47.5	41	29.5	9	6.5	1	0.7	22	15.8

Note: 3 samples missing

5.4.5 Question 5

"5. How many people are involved in evaluating contractors in your company?

☐ One ☐ More than one ☐ Don't know"

The question was asked to confirm how many people were involved in tender evaluation. 94.7 % of the respondents said that more than one was involved. It can be inferred from this that more than one decision-maker is involved in tender evaluation. Table 12 provides the summary.

Table 12 The number of decision-makers involved in evaluating contractors

Number and percent of the respondents answered about the number of decision-makers involved in evaluating contractors					
Only one		More than one		Don't know	
Number	Percent	Number	Percent	Number	Percent
0	0	125	94.7	7	5.3

Note: 10 samples missing

5.4.6 Question 6

"6. The following procedures are shown as flow diagrams.

Within the diagrams, each block represents a step of the tendering process. If you do not agree with any step of the process, please change it, override it or show by a freehand sketch the modification you believe applicable...."

The question continued on from Question 4 to explore the processes of tender evaluation procedures. There were three broad procedures for tender evaluation: selective tendering with prequalification, selective tendering without prequalification, and open tendering. Most respondents agreed with the processes of the three broad procedures suggested but variations of the processes exist. Table 13 summarised the degree of adjustment to the processes of the three procedures.

Table 13 A summary of percentage of respondents making adjustments to the processes of the proposed procedures

Tender evaluation procedure	Percentage of respondents making adjustments to each proposed procedure		
	Not adjusted	Slightly adjusted	Highly adjusted
Selective tendering with PQ	88.4	11.6	-
Selective tendering without PQ	88.7	11.3	-
Open tendering	90.9	9.1	-

In the table, on the slight adjustment to all the three procedures, a comment was that both steps involving setting up a panel should move up ahead of the steps of "develop/select selection criteria" and "receive tenders." This possibly occurs where the owners develop or change selection criteria for every project. However, most of the respondents agreed with the positions of the two steps. Another comment was that the step of "evaluating alternative tenders" was rarely practised in Thailand (cf,

Appendix B1, Q6). More importantly, some respondents (especially from the private sector) commented that the lowest bid price was not the sole criterion for making the decision on selecting the *best* contractor. They said that the lowest bid price did not mean the lowest cost at completion. They included contractor ability in the decision. This presents a move for trading off between bid price and contractor ability to select the best contractor. After all the comments are considered, the three procedures (cf, Section 4.3) are modified in actuality as shown in Figures 18-20.

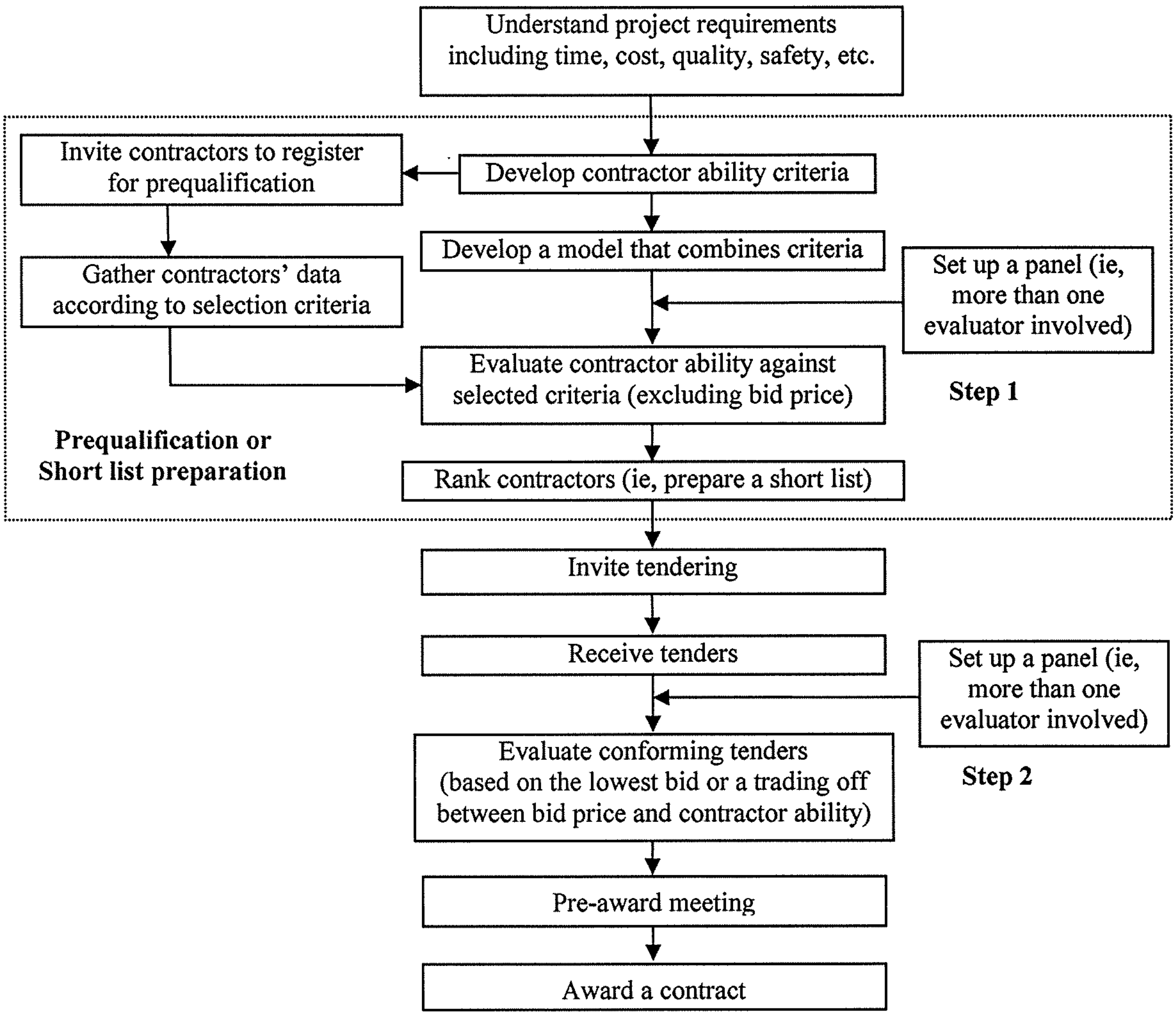

Figure 18 A selective tendering process with prequalification (showing a two-step evaluation)

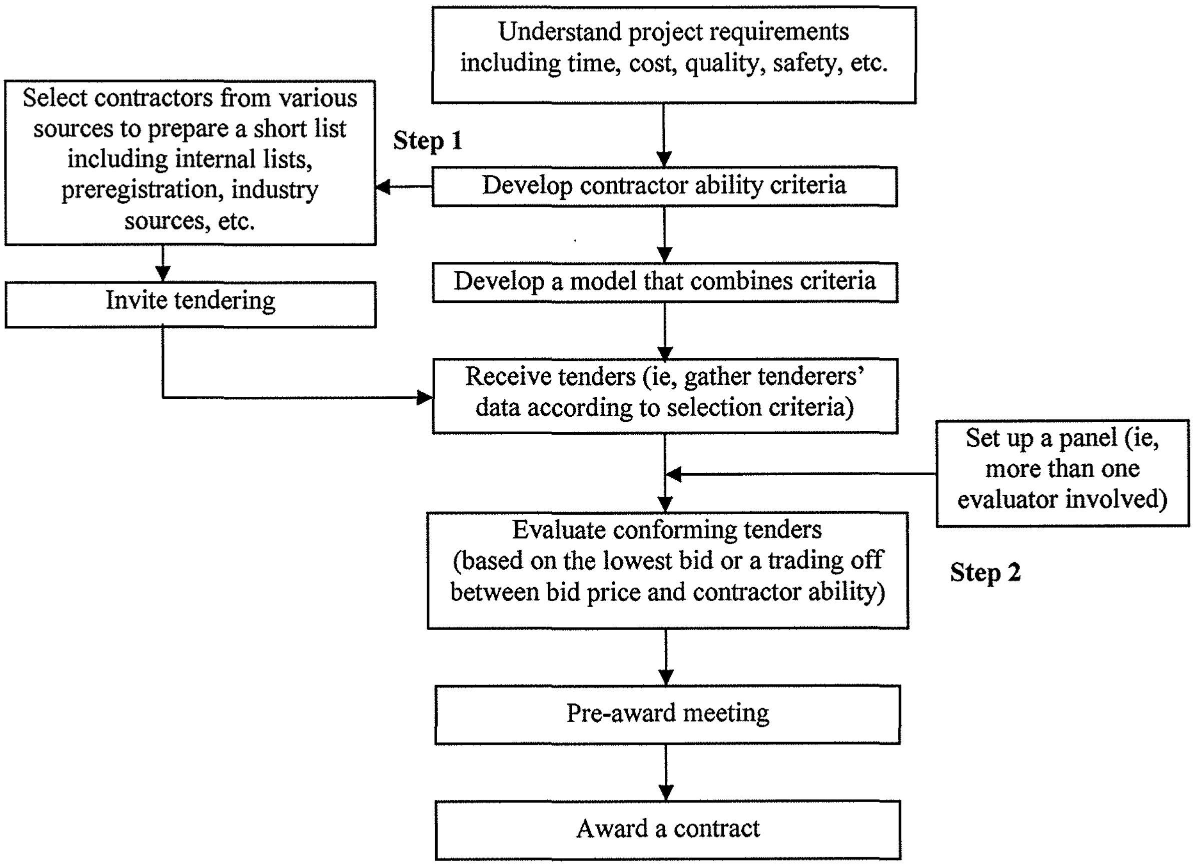

Figure 19 A selective tendering process without prequalification (showing a two-step evaluation)

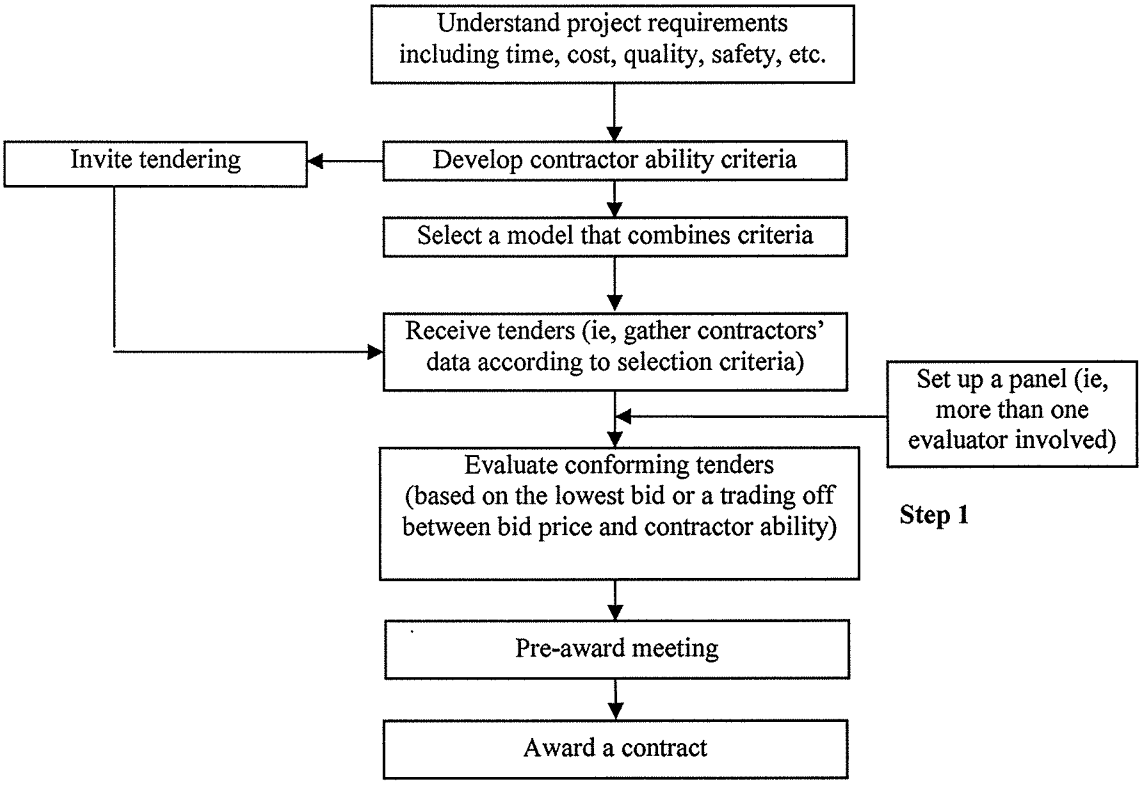

Figure 20 An open tendering process
(Showing a one-step evaluation)

Based on the side comments of respondents, the results of investigating tender evaluation procedures confirm the findings from the literature review that three broad procedures exist (excluding negotiated tendering): the tender evaluation process with prequalification, the tender evaluation process without prequalification, and the open tendering process. All of these procedures involve multiple criteria and multiple decision-makers. Also, most respondents used a weighting method (to evaluate contractor ability and tenders) in tender evaluation.

In addition, from Figures 18-20, the selective tendering processes with and without prequalification use a two-step evaluation to select the best contractor: step 1 evaluating contractor ability and step 2 evaluating tenders. Whereas the open tendering process uses a one-step evaluation to select the best contractor. That is, bid price and contractor ability are evaluated at the same time. The two-step evaluation is selected for developing a realistic working model because it allows the application of all the three procedures. This development will be discussed in the next chapter.

5.4.7 Question 7

"7. Which of the following models/equations do you use for evaluating contractors?

☐ Personal judgment

☐ Weighting models, like

Overall score = A summation of all of (weight × score of each criterion)

Score is the quantity of a criterion of a contractor, which has no element of risk and uncertainty.

☐ Utility models, like

Overall utility = A summation of all of (weight × utility of each criterion)

Utility is the preference (representing a quantity) of the decision-maker for a criterion of a contractor, which includes his/her attitude toward risk and uncertainty.

☐ Computer programs, like

Expert systems or Artificial Neural Networks

☐ Others, please specify..
....
...."

The question was asked to investigate the current models that the industry uses in tender evaluation. The result showed that most practitioners used weighting models for evaluating contractors (48.6%), followed by utility models (35.9%). Surprisingly, personal judgment was used at a high rate of 28.2%. A summary of tender evaluation models used is shown in Table 14.

Table 14 Tender evaluation models used in the industry

Models used in tender evaluation	Number of the respondents using the model	Percent out of all respondents
Personal judgment	40	28.2
Weighting models	69	48.6
Utility models	51	35.9
Computer program, eg, ES and ANN	21	14.8
Other	8	5.6

5.5 A generic model

As a result of the previous section, percent of variance explained, factor loadings and their normalised weights of relative importance are summarised in Table 15. The total percent of variance of nine criteria was 69%, indicated as "a" *normal* intercorrelations ("... the components accounting for 85 percent of the variance means unusually high collinearity, and ... accounting for 50 percent indicates atypically low intercorrelations amongst the original variables" (Lehmann, 1989).). The criteria "engineering/construction" accounted for the most variance (39%) followed by "procurement/contract" accounted for 7%. Surprisingly, "financial strength" accounted for only 3% of the variance because most contractors can use outsourcing funds to run their business.

The hierarchy/set of these criteria with their normalised weights of relative importance is shown in Figure 21.

Table 15 Percent of variance, factor loadings and normalised[‡] weights

Criteria and measures	Percent of variance	Factor loading	Normalised weight, %
(1) Engineering/construction	**39**		**57**
Project planning		2.790	41
Project execution		1.198	17
Project monitoring		1.633	24
Ability to adjust a project		1.253	18
(2) Procurement/contract	**7**		**10**
Procurement plans		1.245	21
Delivery control		0.711	12
Subcontractor control		3.954	67
(3) Human resources	**4**		**6**
Personnel planning		0.378	11
Personnel development		1.479	41
Personnel maintenance		1.747	48
(4) Project managers	**4**		**6**
Project management experience		0.602	15
Communication skills		1.899	48
Adaptability		1.500	37
(5) Quality management systems	**4**		**6**
Quality system implementation		0.600	21
Quality system audits		2.303	79
(6) Health and safety	**3**		**4**
Occupational health and safety		0.702	100
(7) Financial strength	**3**		**4**
Financial ratios		0.476	15
Banking arrangement		2.185	67
Credit ratings		0.570	18
(8) Plant/equipment	**3**		**4**
Plant/equipment acquisition		1.480	85
Plant/equipment maintenance		0.255	15
(9) Public relations	**2**		**3**
Performance		1.298	100

[‡] "Normalise" means making the summation of weights equal 1 or 100%.

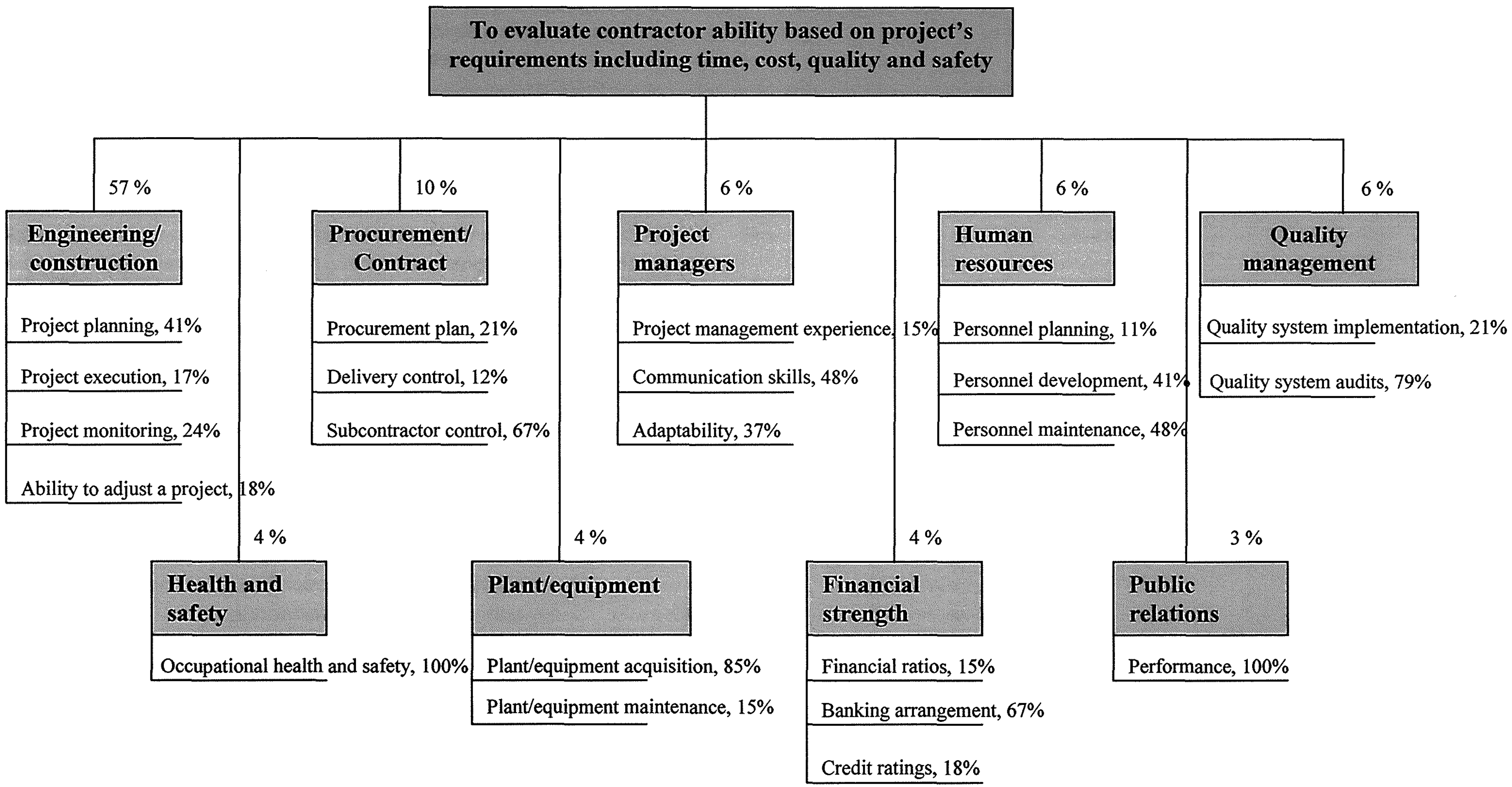

Figure 21 The hierarchy/set of contractor ability criteria with their weights of relative importance

To establish mathematical intercorrelation amongst the contractor ability criteria deduced from Figure 21, a *weighted additive* model can be written as:

Contractor ability's index = 0.57 ENC + 0.10 PRC + 0.06 PM + 0.06 HR + 0.06 QMS + 0.04 HS + 0.04 PLE + 0.04 FS + 0.03 PR

where

ENC denotes "engineering/construction"
PRC denotes "procurement/contract"
PM denotes "project managers"
HR denotes "human resources"
QMS denotes "quality management systems"
HS denotes "health and safety"
PLE denotes "plant/equipment"
FS denotes "financial strength"
PR denotes "public relations."

The model was used as a basis for the development of a realistic working model in tender evaluation. However, the model does not include (1) elements of risk and uncertainty and (2) preferences of multiple decision-makers involved. The next chapter will show how to combine the two issues into this model.

5.6 Conclusions

In this chapter, the data on (1) contractor ability criteria, (2) tender evaluation procedures, and (3) tender evaluation models were analysed.

The analyses of the data on the contractor ability criteria were performed in three steps:

- Discovering the similarities and differences using the comparison of importance index (mean/STD) and using hypothesis tests on mean differences of criteria/measures between the two sectors. The result of hypothesis tests using the Mann Whitney U test was that the government and private sectors considered similar criteria when they evaluated contractor ability. This infers that if contractor ability criteria are developed consistent with organisational units of contractors, types of owners do not affect the selection of criteria. There may be differences of organisational units between contractors but most contractors in any countries perform similar functions to run their business. Thus, this inference is still valid. Consequently, a generic model for both government and private sectors can be developed.

- Examining relationships between all criteria and measures using correlation coefficients. The result showed that the criteria and measures were correlated. These selected criteria and their measures were relevant to evaluating contractor ability.

- Structuring all the measures using factor analysis. The theory of *hierarchy, multilevel, systems* led us to infer that the contractor ability criteria should be developed to correspond to existing organisational units of contractors. The results of the factor analysis confirmed this inference. One possible reason is that a common characteristic of all contractors is the existence of their organisational units, which structure an organisation. This commonality then led to a common set of contractor ability criteria. Although differences in organisational units between contractors may exist, similar necessary functions of contractors are performed to operate their businesses. Thus, this reason is still valid. The results indicate a slight difference in the mean importance of criteria and measures between government and private sectors. Therefore, a generic tender evaluation model for both government and private sectors was suggested. These results are identified as important in providing a basis for further developing a realistic working model in tender evaluation.

On tender evaluation procedures, most of the respondents (47.5%) used the selective tendering process with prequalification (refer to Figure 18). Whereas the selective tendering process without prequalification (refer to Figure 19) was used at 29.5%. Both the procedures perform a two-step evaluation. That is, contractor ability is evaluated first and tenders are then evaluated based on the lowest price or bid price and contractor ability. It is important to note that sometimes practitioners did not use only the lowest bid to select the best contractor, because the lowest bid may not yield the lowest cost at completion. For this reason, they traded off between bid price and contractor ability before selecting the best contractor. This trade-off will be included in the developed model in Chapter 7. On the other hand, a one-step evaluation is performed in the open tendering process (refer to Figure 20). In this process, bid price and contractor ability are evaluated simultaneously. Due to the permission of the application of the three procedures, the two-step evaluation was selected to develop a realistic working model presented in Chapter 7.

Moreover, around 95% of the respondents said that more than one decision-maker participated in tender evaluation (the remaining respondents said "don't know" and did not answer). This confirms the findings from the literature review in Chapters 2 and 3 that in reality more than one decision-maker participates in tender evaluation decisions. Consequently, multiple decision-maker participation will be included in modelling the tender evaluation in the following chapters.

The investigation of the currently-used models showed that most government and private practitioners used weighting models for evaluating contractors. The weighting models do not allow the incorporation of risk arising from uncertainty and multiple decision-makers' preferences. Thus, the next chapter will develop a method using a combination of a utility function and a social welfare function, which provides this facility to decision-makers.

Chapter 6

Utility and social welfare functions

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6.1 Introduction

Uncertainty is always associated with tender evaluation decisions. This uncertainty then leads to the risk of unfavourable consequences/events when selecting a contractor as the best contractor to complete a project. To handle the uncertainty, a utility function is the *best* technique as discussed in Chapter 2 and recommended as a basis for modelling the tender evaluation. However, the determination of a utility function is a difficult task. To reduce this difficulty, a new method of utility measurement is proposed and used in this chapter. In addition, to facilitate the utility expression for bid price, percentile of bid price distribution is introduced and employed.

In reality, multiple decision-makers are always involved in tender evaluation decisions but the utility function has a limitation in dealing with the involvement. To handle this involvement, a social welfare function is introduced to aggregate all individual utilities so as to find the *best* contractor that satisfies the whole owner organisation.

This chapter aims at developing a realistic working method using a combination of the utility and social functions through an example. In the example, the stepwise procedure of combining both the functions to select the *best* contractor for the whole owner organisation is demonstrated.

6.2 A utility function

Developed from the belief that different people value the same thing differently and illustrated by the fact that one dollar to the poor has more value than it does to the rich, utility theory has proved itself as a rational approach in analysing risky solutions. The development of *cardinal* utility was started by von Neumann and Morgenstern in 1947. The theory has been used widely in various areas such as engineering, business and economics.

At present, utility theory suggests that the maximisation of the utility yields the best solution. By using the utility theory, two main types of preference of the decision-maker can include (cf, Kiangi, 1988):

- preference of a decision-maker about uncertain consequences of solutions within any criterion, which affects the value (utility) of the criterion

- preference of a decision-maker about the criteria selected, which reflects the weights of relative importance between the criteria.

Different decision-makers have different utility functions. The differences in the decision-makers' utility function then show the different degrees of their attitude towards risk. Broadly three different patterns of the utility function have been found: risk aversion, risk neutrality and risk propensity as shown in Figure 22 (see Gupta and Cozzolino, 1974; Keeney and Raiffa, 1976).

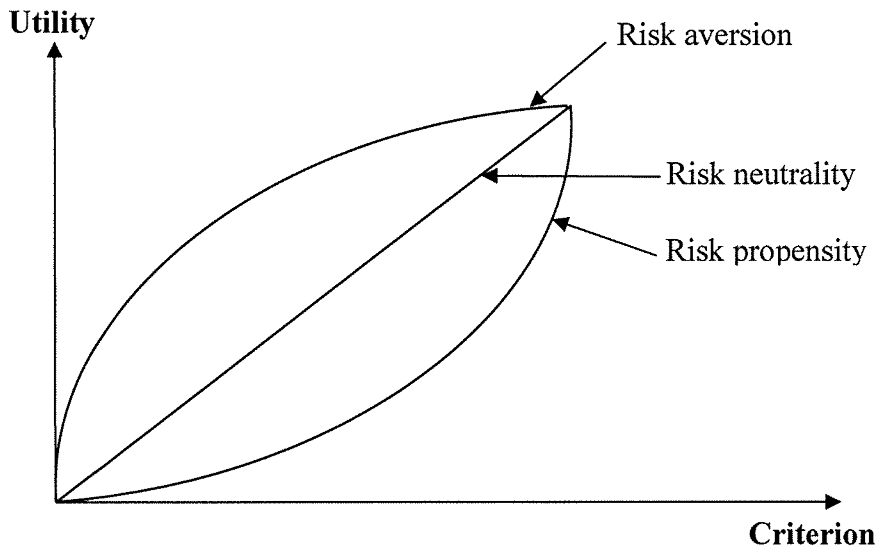

Figure 22 Three broad patterns of utility functions

In Figure 22, risk-neutrality-type people consider any value (utility) of any additional amount of any criterion linearly no matter what the amount is. On the other hand, risk-propensity-type people put higher values on any amount of any criterion. They prefer a small investment with small chances but possibly large returns. Conversely, less value is placed on any amount of any criterion by risk-aversion-type people.

Such persons are cautious about unfavourable events.

As discussed in Chapter 2, although a utility function has the most superior ability, finding the utility function requires *fixed* and *well-defined* subjective judgment from decision-makers up front, which puts some cognitive strain on the decision-makers (Cohon, 1978). That is, they assume that all essential information for stating the subjective inputs can be obtained prior to solving an actual problem. However, in practice it is difficult to gain all necessary information before an actual problem is solved (Zeleny, 1982), which means one does not know their utility function. Therefore, a *known* utility function is assumed. A simple *known* utility function, representing the preference structure of the decision-maker, is developed and termed a *multiattribute utility function*. Various forms of these multiattribute utility functions are developed such as: *additive, weighted additive, multiplicative or log additive, quasiadditive, multilinear functions*, and so on (see Keeney and Raiffa, 1976; Zeleny, 1982).

The multiattribute utility function combines the values (utilities) of all single attributes of each contractor into an overall utility. A contractor selected as the *best* contractor is the contractor with the highest utility. An algorithm of the technique of multiattribute utility function is as follows:

- Firstly, to convince the decision-maker that all this work is worth it, a meaningful assessment of this technique is introduced.

- Secondly, a form of multiattribute utility function is appropriately selected as a utility function for the decision-maker, which represents their preference structure. This is difficult to perform in practice (Zeleny, 1982). Thus, an assumption that a particular form is correct for a given situation is often used. The *weighted additive* form is usually selected because of its simplicity, and can be written in a linear form as follows:

$$U(x) = \sum_{j=1}^{L} w_j u_j(x_j) \tag{1}$$

with constraints

where x is an attribute such as engineering/construction and procurement/ contract

w_j is a weight of relative importance between the attributes

$u_j(x_j)$ is a utility function of attribute, x_j

U (x) is an overall utility function

L is the number of attributes

Using this form, two fundamental types of independence have to be analysed:

- preferential independence to show that the value trade-offs between two attributes is not affected by another attribute
- utility independence to show that, for example, the first attribute is utility-independent of the second attribute when the decision-maker's preferences amongst lotteries – as probabilistic equivalents in a decision tree, involving only the first attribute, with the second attribute fixed at a particular level – do not depend on the level of the second attribute.

To prove these two independences is a tedious task. Thus, an assumption for these two independences is usually made (de Neufville, 1990).

- Thirdly, the weights for attributes are stated by, for example, performing regression analysis, directly articulating the weights by asking less subjective questions, and employing a *pairwise comparison* through value trade-offs.

- Fourthly, each individual utility function for every attribute is searched by probabilistic elicitation, similar to the elicitation of a single-attribute utility function. That is, a series of two-choice questions (one is in certainty whilst the other is not) is asked to construct a utility function.

- Fifthly, once the utility function has been found, the evaluation of the form's *scaling constants* is necessary to secure internal consistency (Zeleny, 1982). For example, a utility of 10 years of experience to one contractor should be equal to that of another contractor. Again, it is a fatiguing task.

- Sixthly, to evaluate each contractor the value of each attribute is transformed to a utility by the utility function obtained from the fourth step. Then, each of the utilities and its corresponding weight are multiplied and aggregated into an overall utility. Any contractor having the highest overall utility should be selected as the *best* contractor.

- Lastly, the consistency of the overall utility must be tested against the decision-maker's actual preference. Even though the utility function is established by previous processes, the utility function may not represent the decision-maker's preference over all attributes, perhaps because of, for example, analyst error, decision-maker error, change in decision-maker's attitude, or change in situation. An artificial problem may be used to test this consistency.

Finding a utility function is time-consuming and fatiguing, if a number of attributes are involved. In addition, the utility function (including the choice of weights) can change over time in relation to a particular situation, which means a lot of effort is spent on finding the utility function but it can be used only once for the particular situation. As such, a utility function has to be developed every time for every situation. These considerations make utility approaches impractical for tender evaluation practitioners. To encourage the practitioners to use the utility idea, the theoretical method of finding a utility function as previously mentioned has been modified to be discrete.

6.2.1 Utility measurement

As shown in Figure 23, there are three main types of attitude towards risk: (1) risk neutrality, (2) risk aversion, and (3) risk propensity. The difference between the last two is deviation from the first, risk neutrality.

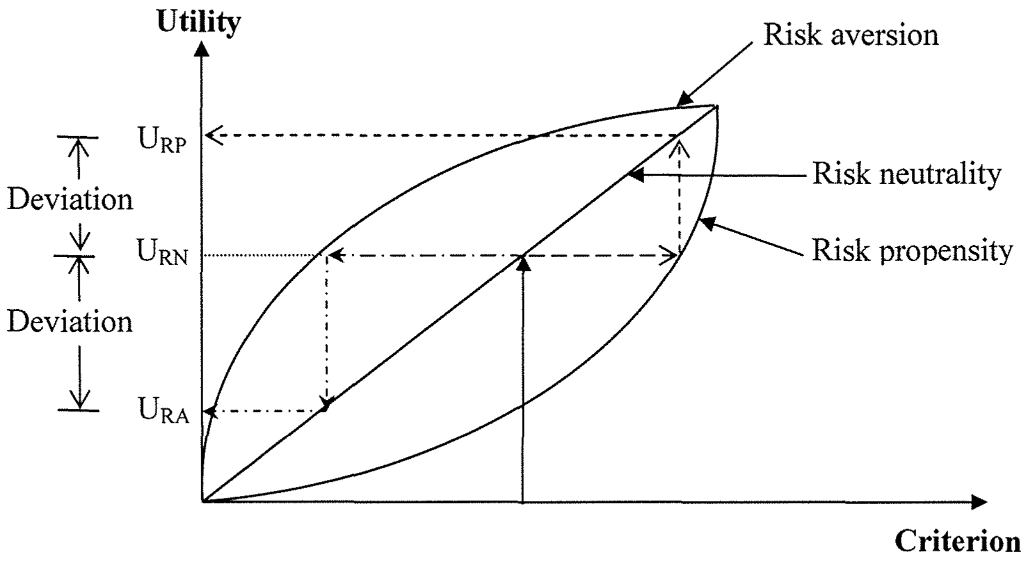

Figure 23 Utility measuring

Without risk and uncertainty, risk-neutrality utility (U_{RN}) will be expressed as shown in Figure 24, steps (1) – (2).

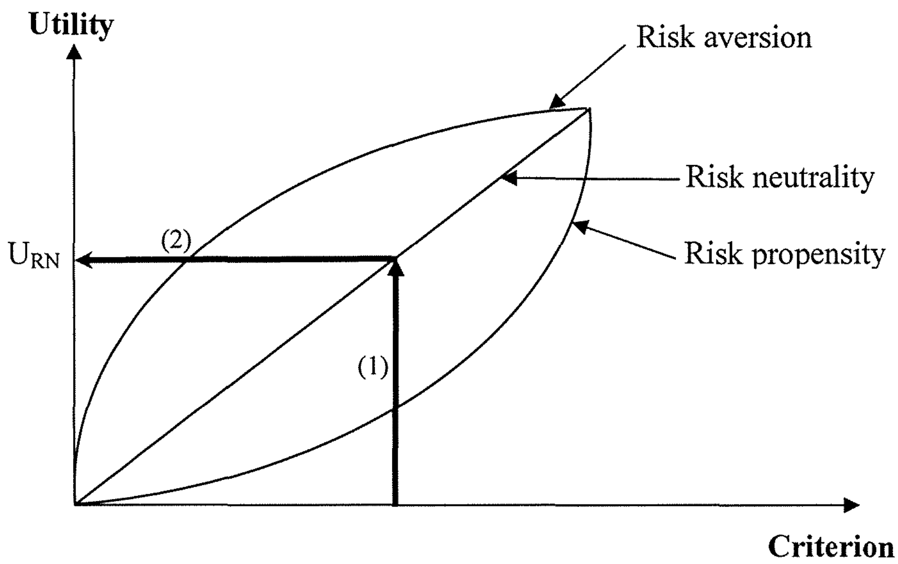

Figure 24 Utility measuring process for risk neutrality type

The deviation above U_{RN} results from a risk-propensity attitude (denoted U_{RP}); whereas that below U_{RN} from risk-aversion attitude (denoted U_{RA}). How large a deviation depends on the decision-maker's degree of attitude towards risk arising from uncertainty. Clearly, if a decision-maker has:

- Risk aversion, the decision-maker will express a lower utility than U_{RN}, denoted U_{RA}
- Risk propensity, the utility will be higher than U_{RN}, called U_{RP}.

The steps, (1) – (4), in finding a utility for a criterion for risk aversion type are shown in Figure 25.

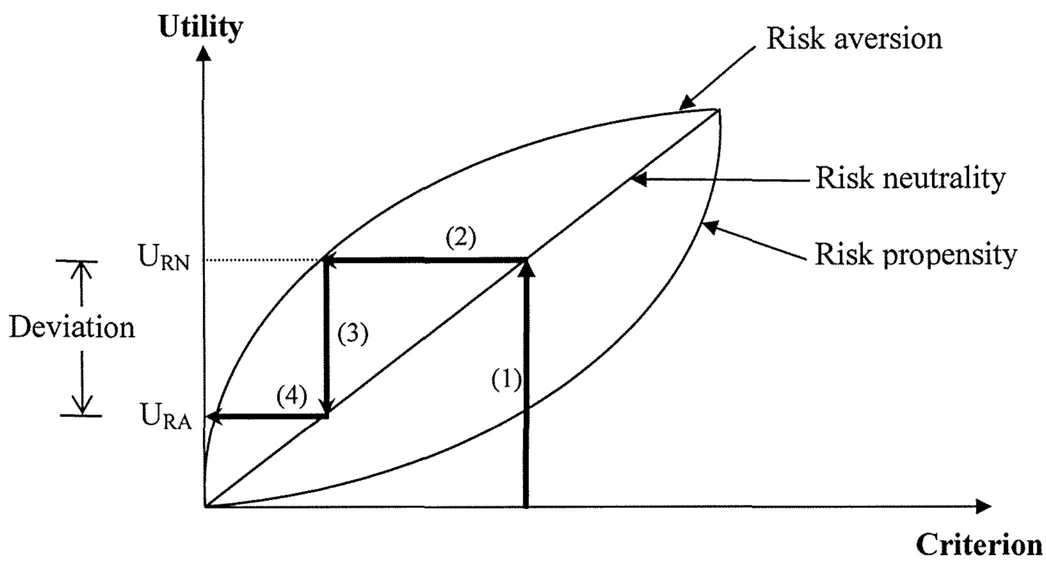

Figure 25 Utility measuring process for risk aversion type

On the other hand, the steps, (1') – (4'), in finding a utility for a criterion for risk propensity type are shown in Figure 26.

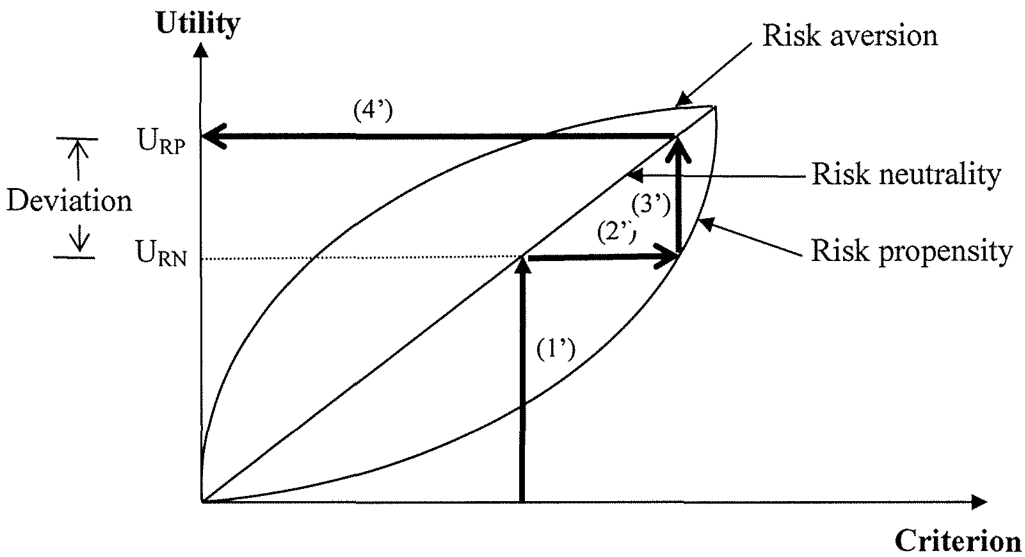

Figure 26 Utility measuring process for risk propensity type

To simply determine a utility, each decision-maker is asked to follow three steps:

- Think of the utility (value) for the criterion without risk involved (U_{RN})
- Consider risk and uncertainty (resulting from, eg, market situation, political pressure, competition and crises) in selecting the contractor: whether they will perform within time, cost, quality and safety requirements
- Express your utility for the criterion (U_{RA} or U_{RP} or even U_{RN}), depending on what type of risk attitude the decision-maker has.

Here, the utility is an analytical value expressed by a decision-maker after risk in selecting the contractor is considered.

6.2.2 A weighted additive model

As a basis for modelling the tender evaluation, a special form of the utility function, a *weighted additive* model is selected because of its simplicity. It can be written in a linear form as follows:

$$U^{CA} = \sum_{j=1}^{n} w_j^{nor} U_j \quad \text{for all contractors} \qquad (2)$$

with constraints

where w_j^{nor} is a normalised weight of a tender evaluation criterion obtained by solving the equation:

$$w_j^{nor} = \frac{w_j}{\sum_{j=1}^{n} w_j} \times 100\,\% \qquad (2.1)$$

where w_j is a weight of a tender evaluation criterion

U_j is a utility of a tender evaluation criterion

UC^A is an overall utility indicating contractor ability for a single decision-maker

n is the number of tender evaluation criteria

constraints are ranges of any criteria that must not be exceeded.

6.3 A social welfare function

In most organisations, more than one decision-maker participates in tender evaluation. However, a utility function does not unite their individual participation. Therefore, a social welfare function is subsequently combined with the utility function to incorporate the participation, and can be written as:

$$\mathbf{U^{CA}} = \sum_{k=1}^{q} W_k\, U_k^{CA} \quad \text{for all contractors} \qquad (3)$$

where W_k is a positive weight of each decision-maker (the model treats all decision-makers equally)

U_k^{CA} is a utility indicating contractor ability of the k^{th} decision-maker

$\mathbf{U^{CA}}$ is a social welfare utility indicating an overall contractor ability

q is the number of decision-makers.

By solving equation (3), the overall contractor ability, $\mathbf{U^{CA}}$, is obtained. The contractor ability (U_k^{CA}) of each decision-maker will then be balanced with the bid price to select the best contractor by solving the equation:

$$\mathbf{U^{CA\&Bp}} \quad = \quad \sum_{k=1}^{q}(W_k^{CA}\ U_k^{CA} + W_k^{Bp}\ U_k^{Bp}) \quad \text{for all contractors} \qquad (4)$$

where W_k^{Bp} is a normalised weight of bid price of the k^{th} decision-maker obtained by solving the equation:

$$W_k^{Bp} \quad = \quad \frac{w_k^{Bp}}{w_k^{Bp} + w_k^{CA}} \times 100\ \% \qquad (4.1)$$

where w_k^{Bp} is an articulated weight for bid price given by the k^{th} decision-maker

w_k^{CA} is an articulated weight for contractor ability given by the k^{th} decision-maker

W_k^{CA} is a normalised weight of contractor ability of the k^{th} decision-maker obtained by solving the equation:

$$W_k^{CA} \quad = \quad \frac{w_k^{CA}}{w_k^{Bp} + w_k^{CA}} \times 100\ \% \qquad (4.2)$$

U_k^{Bp} is a utility of bid price given by the k^{th} decision-maker

$\mathbf{U^{CA\&Bp}}$ is an overall social welfare utility.

Each contractor can be ranked according to their social welfare utility, $\mathbf{U^{CA\&Bp}}$; or maximisation of $\mathbf{U^{CA\&Bp}}$ provides the best contractor winning the contract.

6.4 An example

With expansion in the growth of a company, an owner wants to build a new industrial workshop. This workshop project is comprised of 2 basements and 5 floors, which will produce 1,500 square metres of working area. Two decision-makers are involved in selecting the *best* contractor to complete the project. After tenders are called, three contractors respond. Their bid price details are given:

Tenders	Bid price (bath)
A	5,400,000
B	5,550,000
C	6,000,000

On the basis of the results in Chapter 5, to evaluate contractor the owner selects nine criteria, namely, "engineering/construction," "procurement/contract," "project managers," "human resources," "quality management systems," "health and safety," "plant/equipment," "financial strength" and "public relations." To gather the information of all the contractors, the details of these criteria are as follows:

- **Engineering/construction** considers:
  - project planning looking at master plans, detailed plans, resource plans, budgeting and contingency plans
  - project execution looking at communication of the plans to people involved and technical ability
  - project monitoring looking at continuous reporting and analysed reporting
  - ability to adjust a project looking at weekly actions and monthly actions

- **Procurement/contract** considers:
  - procurement plans looking at material schedule and subcontract schedule
  - delivery control looking at warehouse procedures, distribution procedures and receipt of goods
  - subcontractor control looking at general conditions of subcontracts, special conditions of subcontracts, interaction between the contractor and subcontractors, methods of reviewing drawings and change orders, communication lines, and *power leverages*

- **Project managers** considers:
  - project management experience looking at problem solving skills, management of conflict, and previous and current position
  - communication skills looking at observation, analysis, and persuasive skills
  - adaptability looking at tolerance for ambiguity and changes, and balance ability between conserving and challenging traditional operations or behaviours

- **Human resources** considers:
  - personnel planning looking at a personnel chart
  - personnel development looking at in-house training, and supervisor coaching

- **Quality management systems** considers:
  - quality system implementation looking at progressive steps of implementing a quality system
  - quality system audits looking at documented processes in place ready to address standard elements, documented processes being followed by the contractor, and documented processes being effective and suitable

- **Health and safety** considers:
  - health and safety plan and health and safety control

- **Plant/equipment** considers:
  - plant/equipment acquisition looking at a list of plant/equipment, and a plan of renting or leasing plant/equipment
  - plant/equipment maintenance looking at programmed maintenance, and spare parts stocking

- **Financial strength** considers:
  - financial ratios looking at financial leverage ratio
  - banking arrangements looking at length of time with that bank, backing preparation and a line of credit to the contractor from the bank

- credit ratings looking at average length of time that the contractor pays subs/suppliers, and conditions in bank guarantee

- **Public relations** considers:
  - past performance and current performance.

After the information on the above criteria was received, the flow diagram of tender evaluation as shown in Figure 27 was drawn up.

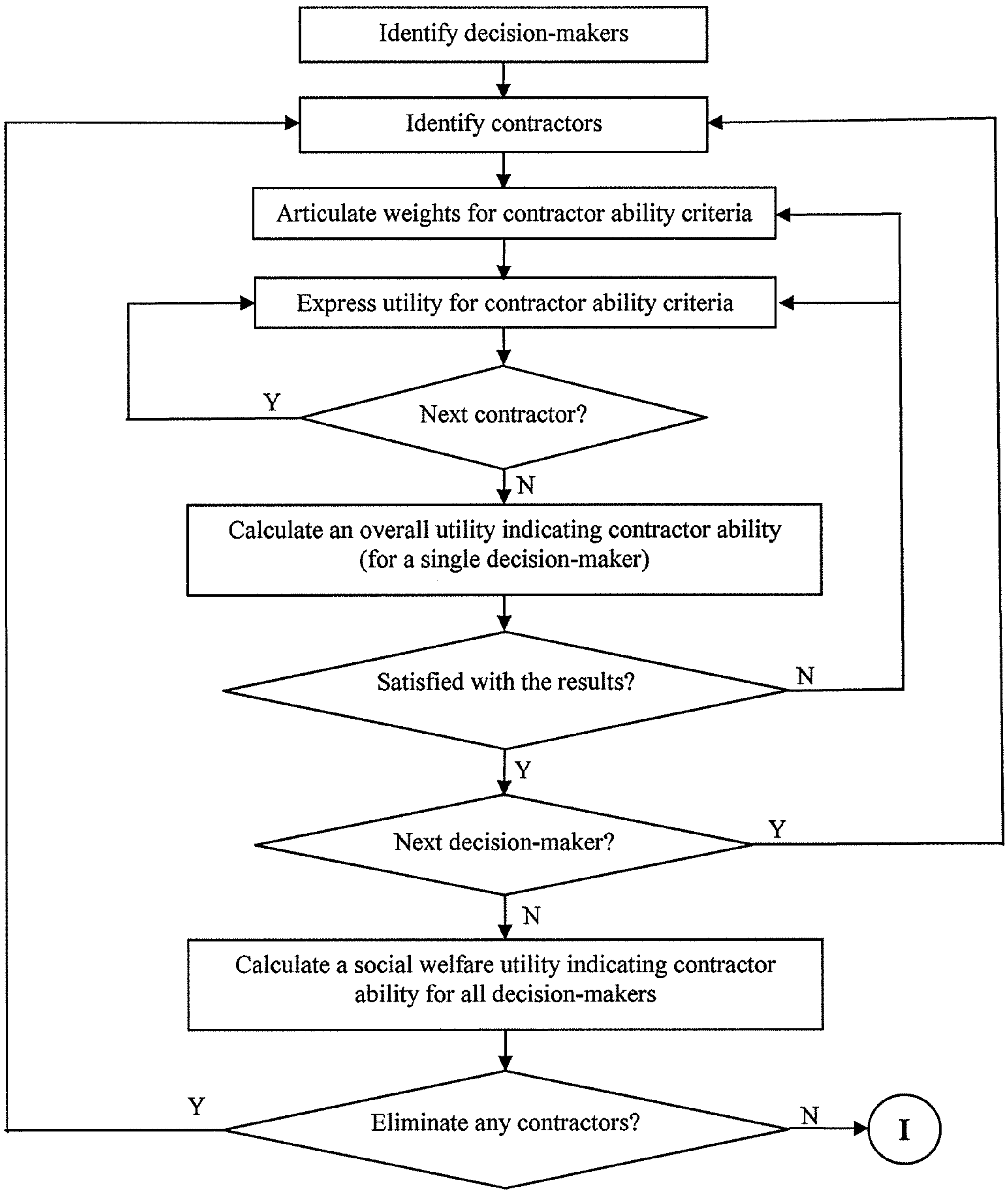

Figure 27 A flow diagram of tender evaluation (Step 1: evaluating contractor ability)

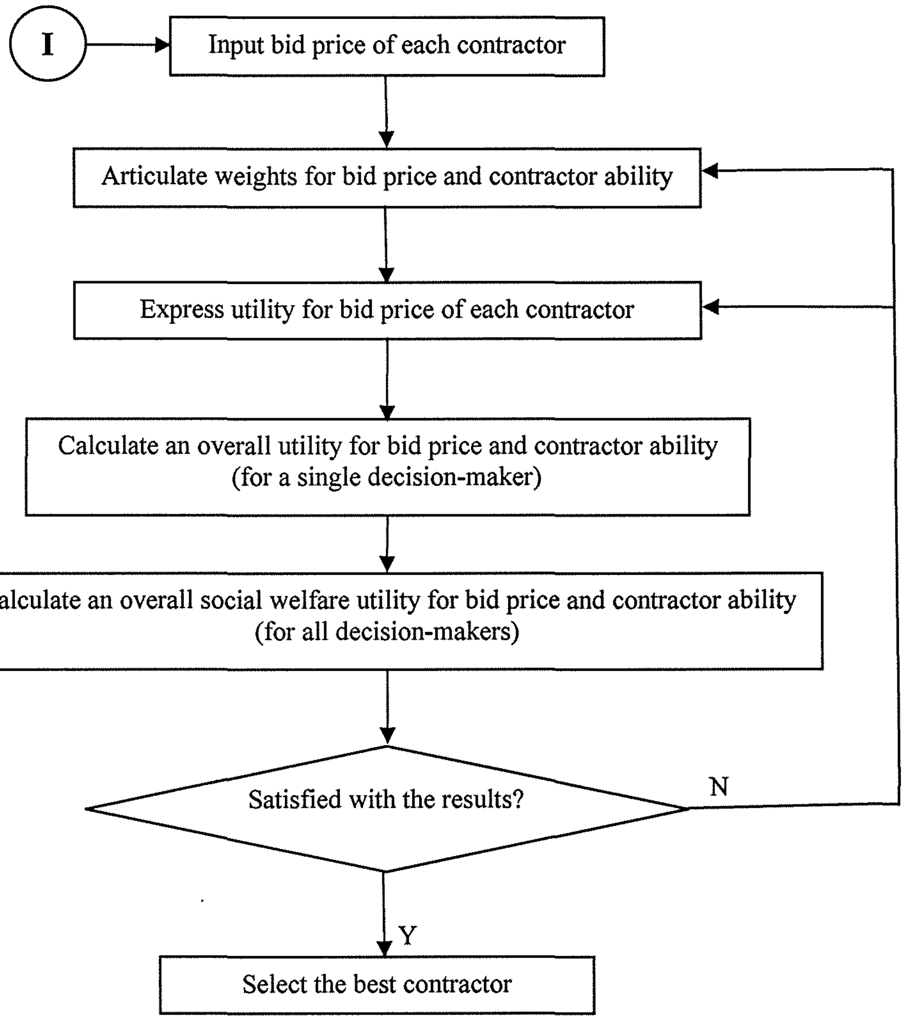

Figure 27 (Continued, Step 2: evaluating tenders)

The stepwise procedure to find the best contractor is the following:

a) Articulate weights to contractor ability criteria. The two decision-makers give their weights as shown in Table 16.

Table 16 Weights given by two decision-makers

No.	Criteria	Weight given by DM1, %	Normalised weight for DM1, %	Weight given by DM2, %	Normalised weight for DM2, %
1	Engineering/construction	54	55	57	57
2	Procurement/contract	10	10	10	10
3	Project managers	6	6	6	6
4	Human resources	6	6	6	6
5	Quality mangt systems	6	6	6	6
6	Health and safety	4	4	4	4
7	Plant/equipment	4	4	4	4
8	Financial strength	5	5	4	4
9	Public relations	4	4	3	3

In Table 16, the given weights are then normalised using equation (1.1) as shown in the shaded area.

b) Express utility between 1 and 10 (1 indicates extremely low whilst 10 indicates extremely high) as shown in Table 17.

Table 17 Utilities given by two decision-makers

No.	Criteria	Utility given by DM1 for			Utility given by DM2 for		
		Contr A	Contr B	Contr C	Contr A	Contr B	Contr C
1	Engineering/construction	9	8	9	9	9	9
2	Procurement/contract	9	8	9	9	8	9
3	Project managers	8	8	7	9	9	9
4	Human resources	8	8	7	8	9	8
5	Quality mangt systems	8	8	8	9	9	9
6	Health and safety	8	8	8	8	8	8
7	Plant/equipment	8	8	8	8	8	8
8	Financial strength	10	8	9	9	8	9
9	Public relations	9	9	9	8	8	8

c) Calculate an overall utility indicating contractor ability for a single decision-maker using equation (2). Table 18 summarises the calculation.

Table 18 The overall utility for two decision-makers

Criteria	Decision-maker 1				Decision-maker 2			
	Weight, w^{nor} %	Overall utility, $w_j^{nor}Uj$			Weight, w^{nor} %	Overall utility, $w_j^{nor}Uj$		
		$w_1^{nor}U_1$ for A	$w_2^{nor}U_2$ for B	$w_3^{nor}U_3$ for C		$w_1^{nor}U_1$ for A	$w_2^{nor}U_2$ for B	$w_3^{nor}U_3$ for C
Engineering/construction	55	5.0	4.4	5.0	57	5.1	5.1	5.1
Procurement/contract	10	0.9	0.8	0.9	10	0.9	0.8	0.9
Project managers	6	0.5	0.5	0.4	6	0.5	0.5	0.5
Human resources	6	0.5	0.5	0.4	6	0.5	0.5	0.5
Quality mangt systems	6	0.5	0.5	0.5	6	0.5	0.5	0.5
Health and safety	4	0.3	0.3	0.3	4	0.3	0.3	0.3
Plant/equipment	4	0.3	0.3	0.3	4	0.3	0.3	0.3
Financial strength	5	0.5	0.4	0.5	4	0.4	0.3	0.4
Public relations	4	0.4	0.4	0.4	3	0.2	0.2	0.2
$\sum_{j=1}^{n} w_j^{nor}Uj$		8.9	8.1	8.7		8.7	8.5	8.7

d) Calculate a social welfare utility indicating overall *contractor ability* for all decision-makers using equation (3) as the following:

A social welfare utility for contractor A = 8.9 + 8.7 = 17.6

A social welfare utility for contractor B = 8.1 + 8.5 = 16.6

A social welfare utility for contractor C = 8.7 + 8.7 = 17.4

The result shows that contractor A has the highest ability followed by contractors C and B, respectively.

e) Articulate weight for bid price and contractor ability as shown in Table 19.

Table 19 Weights between bid price and *contractor ability* given by two decision-makers

No.	Criteria	Weight given by DM1 %	Normalised weight for DM1, %	Weight given by DM2 %	Normalised weight for DM2, %
1	Bid price	55	58	60	55
2	*contractor ability*	40	42	50	45

f) Express utility between 1 and 10 (1 indicates extremely high bid price; whereas 10 indicates extremely low bid price) for bid price for all contractors. To facilitate decision-makers in the expression, *percentile* as a measure of distribution, is used. Table 20 shows the suggested utility deriving from percentile of bid price distribution.

Table 20 Utility suggestion based on percentile of bid price distribution

Condition for utility suggestion	Suggested utility
If bid price $\leq P^{10}$	10
If $P^{10} <$ bid price $\leq P^{20}$	9
If $P^{20} <$ bid price $\leq P^{30}$	8
If $P^{30} <$ bid price $\leq P^{40}$	7
If $P^{40} <$ bid price $\leq P^{50}$	6
If $P^{50} <$ bid price $\leq P^{60}$	5
If $P^{60} <$ bid price $\leq P^{70}$	4
If $P^{70} <$ bid price $\leq P^{80}$	3
If $P^{80} <$ bid price $\leq P^{90}$	2
If $P^{90} <$ bid price $\leq P^{100}$	1

However, depending on subjective judgment, decision-makers express their utility in Table 21.

Table 21 Utility on bid price given by two decision-makers

Contractor	Bid price (Baht)	Suggested utility	Utility by DM1	Utility by DM2
A	5,400,000	10	8	9
B	5,550,000	6	7	5
C	6,000,000	1	5	5

g) Calculate an overall social welfare utility for bid price and contractor ability using equation (4) for all decision-makers. The result is summarised as follows (the number of decision-makers, 2, and the coefficient of 100/10 divide equation (4) to level the overall social welfare utility to 100):

An overall social welfare utility for contractor A = $[(58 \times 8) + (42 \times 8.9) + (55 \times 9) + (45 \times 8.7)]/(2\times100/10)$

= 86

An overall social welfare utility for contractor B = $[(58 \times 7) + (42\times 8.1) + (55 \times 5) + (45 \times 8.5)]/ (2\times100/10)$

= 70

An overall social welfare utility for contractor C = $[(58 \times 5) + (42 \times 8.7) + (55 \times 5) + (45 \times 8.7)]/ (2\times100/10)$

= 66

h) Select the *best* contractor or rank the contractors

In step g), maximisation of the social welfare utility suggests that the contract should be awarded to contractor A, having the highest social welfare utility of 86.

6.5 Conclusions

Due to the abundance of uncertainty in tender evaluation decisions, various techniques have evolved to cope with uncertain consequences of risky choices. Amongst these, the utility technique has been found to be the most superior. However, this technique is restricted to one decision-maker's involvement. As such, a social welfare technique, summing the individual utilities, appears to be the most attractive to democratic organisations.

The main aim of this chapter was to develop a realistic working method using a combination of the utility and social welfare functions. This method seems more realistic than existing tender evaluation models because it considers risk stemming from uncertainty and preferences of multiple decision-makers. No existing model in tender evaluation has these capabilities. In the combination process, the utility function was simplified for practical application. This simplification proposed in this research helps to reduce the difficulty in expressing utility for contractor ability criteria. Percentile of bid price distribution proposed also helps to alleviate the onus on decision-makers in the utility expression for bid price.

Lastly, an example was used to demonstrate how to combine these two functions. This demonstration provides a preliminary step for modelling the tender evaluation. To be adaptable to changes in circumstances, the method should have an interactive nature through a computer program. The computer program of the method is detailed in the next chapter.

Chapter 7

A multicriteria and multidecision-makers' model

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7.1 Introduction

In conjunction with chapter 6, the multicriteria and multidecision-makers' model proposed in this chapter is developed on the method using a combination of a utility function and social welfare function. The model uses a two-step evaluation to select the best contractor: step 1 evaluating contractor ability and step 2 evaluating tenders. These two steps consist of three main processes: (1) contractor ability criteria selection process, (2) contractor ability criteria balancing/measuring process and (3) bid price and contractor ability balancing/measuring process. Subjectivity arises within all these processes. In addition, a flow diagram is created to further analyse the logical order in all stages of the model process. This analysis then leads to refine the model process. After that, the three processes are coded using Excel with Visual Basic for Application (VBA). Excel is selected because it is a good calculating and reporting tool and also because of its familiarity for most users. To automatically handle repetitive tasks and offer friendly interaction with users, VBA is used. Combined, these Excel, *UserForms* and codes (procedures) created the model.

The chapter aims at developing a realistic working model capable of simultaneously putting together preferences of multiple decision-makers, covering elements of risk and uncertainty, and offering computer interaction that makes the model flexible to any changes in situation.

7.2 Tender evaluation model process

The tender evaluation model process is divided into two main steps:

- Step 1 is evaluating contractor ability which consists of two processes: (1) contractor ability criteria selection process and (2) contractor ability criteria balancing/measuring process.
- Step 2 is evaluating tenders, which comprises one process: (3) bid price and contractor ability balancing/measuring process.

The two-step evaluation including the three processes is shown in Figure 28.

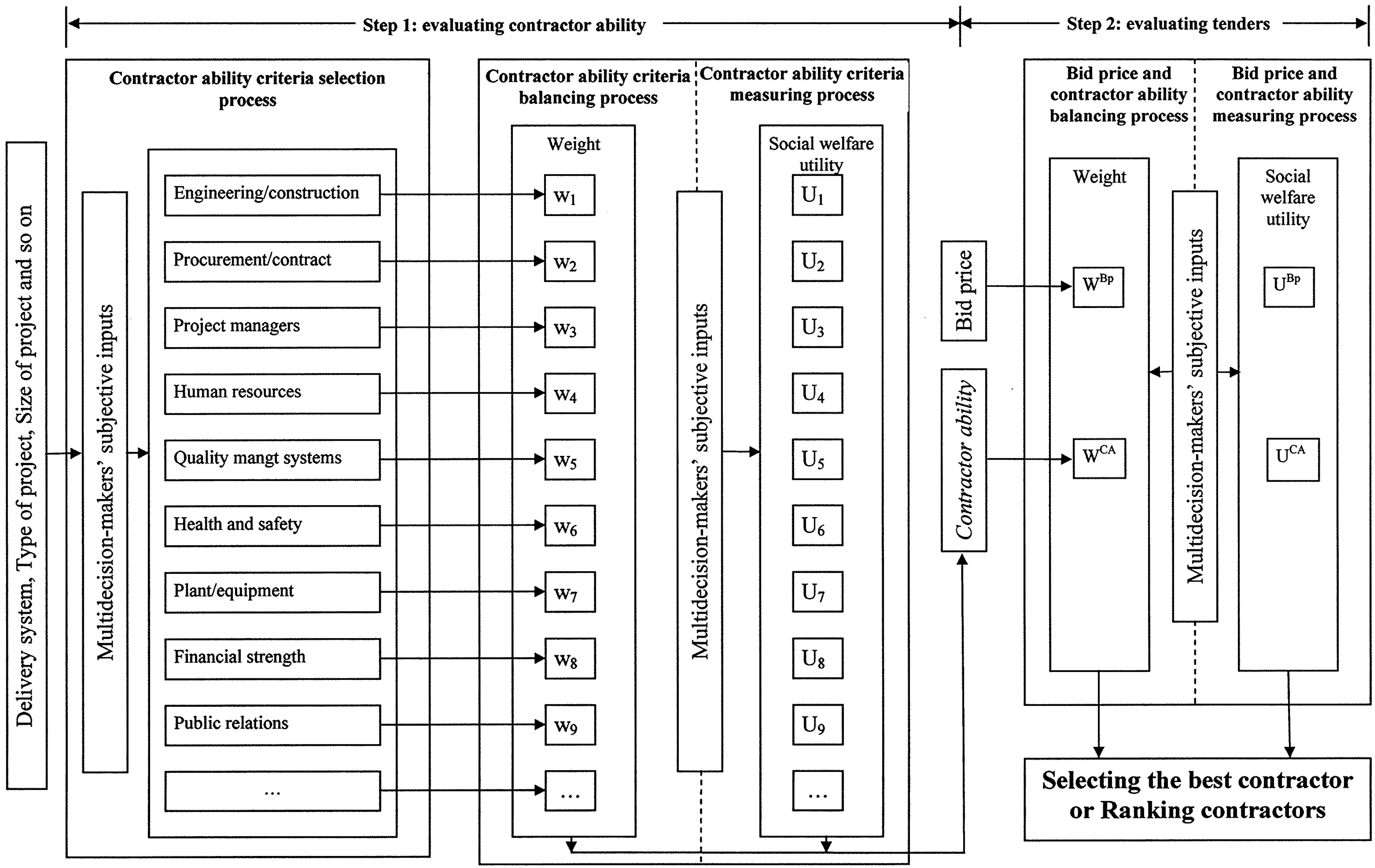


Figure 28 The tender evaluation model process (showing a two-step evaluation)

According to Figure 28, whilst the model is searching for the best contractor, decision-makers are required to provide or exchange subjective inputs in the forms of weights of relative importance or utilities (analytical values including risk arising from uncertainty). This presents interactive nature of the model. The following explain all the processes.

7.2.1 Contractor ability criteria selection process

In this process, each decision-maker is provided with nine criteria (for evaluating *contractor ability*), namely:

- engineering/construction (57%)
- procurement/contract (10%)
- project managers (6%)
- human resources (6%)
- quality management systems (6%)
- health and safety (4%)
- plant/equipment (4%)
- financial strength (4%)
- public relations (4%).

With these criteria, their weights of relative importance derived from the questionnaire analyses in Chapter 5 are suggested in the brackets. However, these criteria can be changed as required by each individual decision-maker or added to, if necessary. This ability causes the model to be flexible to change in situations.

7.2.2 Contractor ability criteria balancing/measuring process

For each decision-maker, the main steps of this process are:

- articulate weight (w_j) for all contractor ability criteria (normally nine)
- normalise weight using equation (2.1) in Section 6.2.2

- express utility (U_j) between 1 to 10 (1 indicates extremely low whilst 10 indicates extremely high) for all the criteria for all the contractors
- calculate an overall utility (U^{CA}) indicating *contractor ability* for a single decision-maker using equation (2) in Section 6.2.2
- calculate a social welfare utility ($\mathbf{U}^{\mathbf{CA}}$) indicating overall contractor ability for all decision-makers using equation (3) in Section 6.3.

7.2.3 Bid price and contractor ability balancing/measuring process

In this section of the model, decision-makers include bid price to select the *best* contractor. The stepwise procedure for each decision-maker is as follows:

- input bid price of all contractors
- articulate weight (w^{Bp}) for bid price
- articulate weight (w^{CA}) for the *contractor ability*
- normalise weight using equations (4.1 and 4.2) in Section 6.3
- express utility (U_k^{Bp}) between 1 to 10 (1 indicates extremely high bid price whilst 10 indicates extremely low bid price) for all the contractors
- calculate an overall social welfare utility ($\mathbf{U}^{\mathbf{CA\&Bp}}$) for all decision-makers using equation (4) in Section 6.3
- select the *best* contractor or rank the contractors.

As an outline process, the model process helps to determine the main activities of tender evaluation.

7.3 Model development

To expand the outline process in the previous section for the purpose of further analysing the logical sequence in all stages of the model process, a flow diagram was developed. The flow diagram helps to plan the event-oriented computer program of the model as shown in Figure 29.

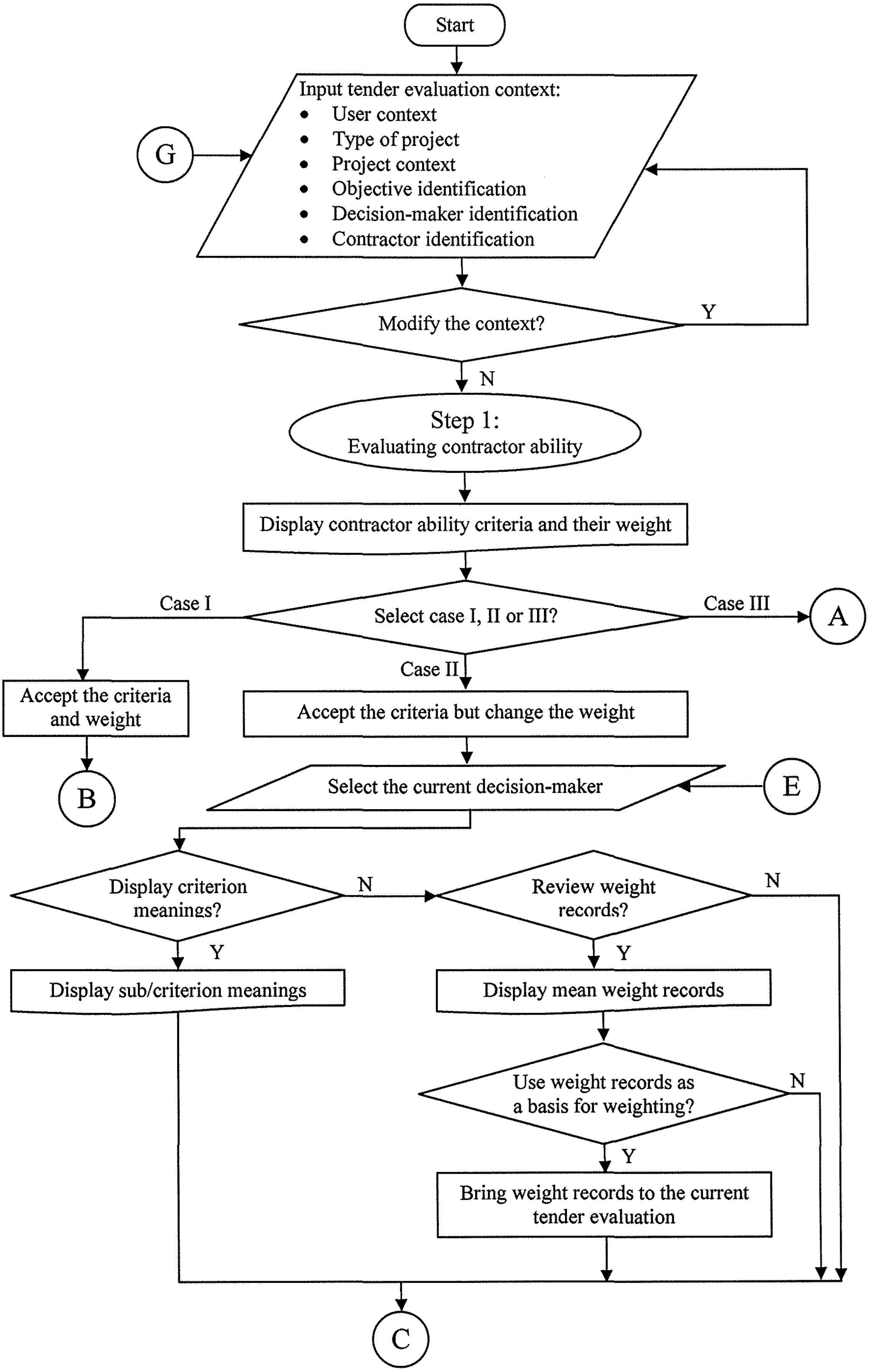


Figure 29 The flow diagram of the model

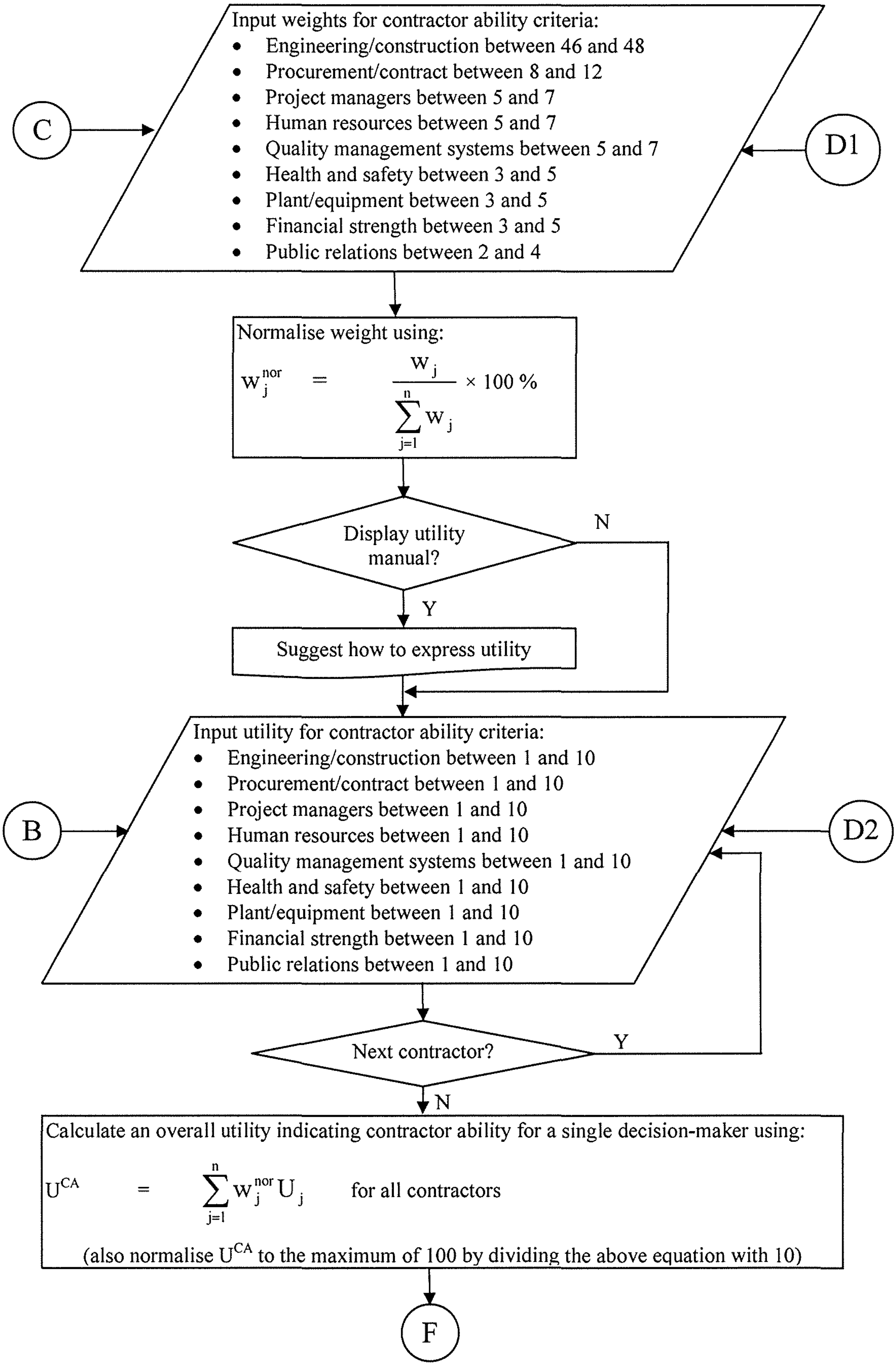


Figure 29 (Continued)

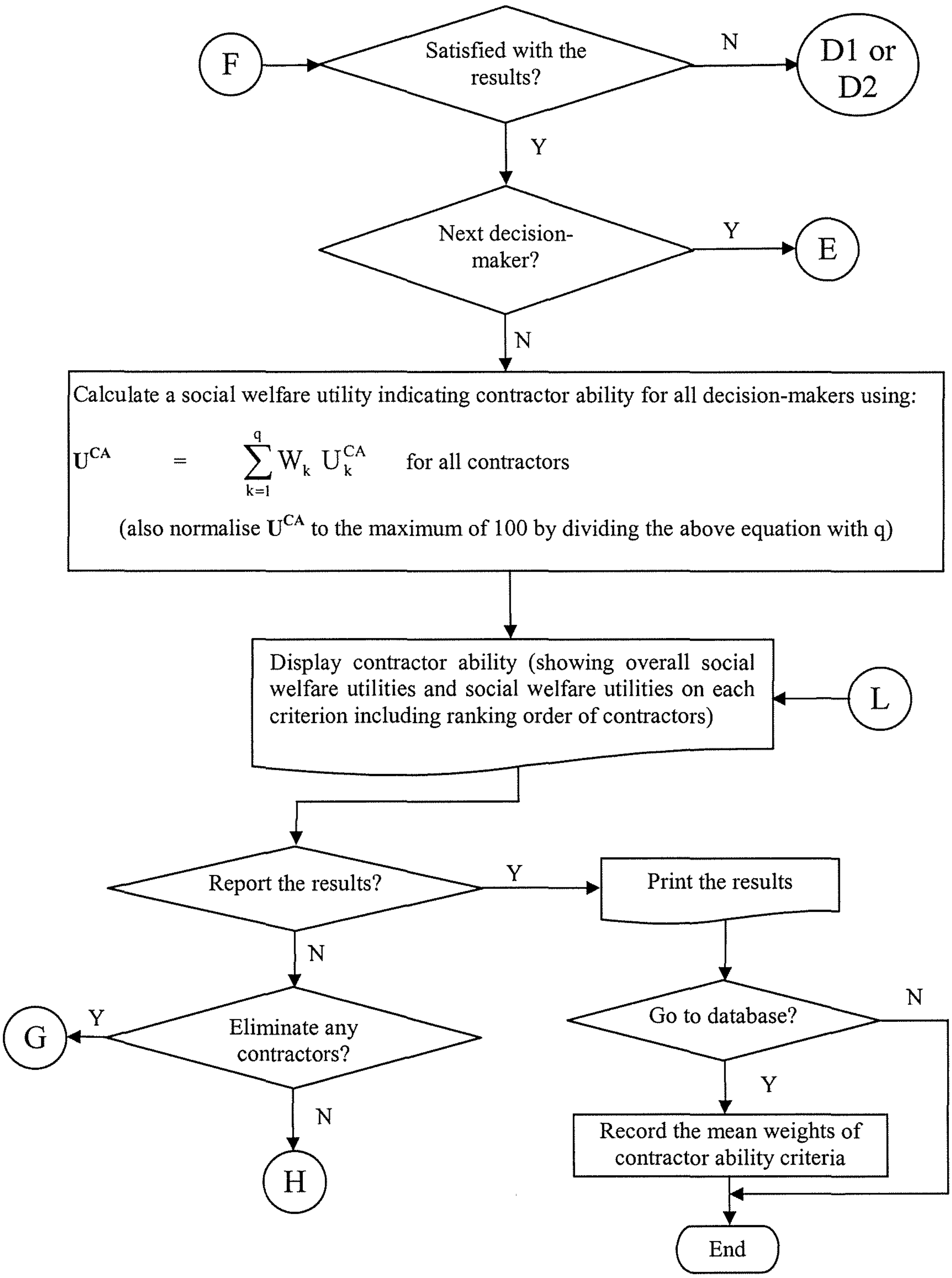


Figure 29 (Continued)

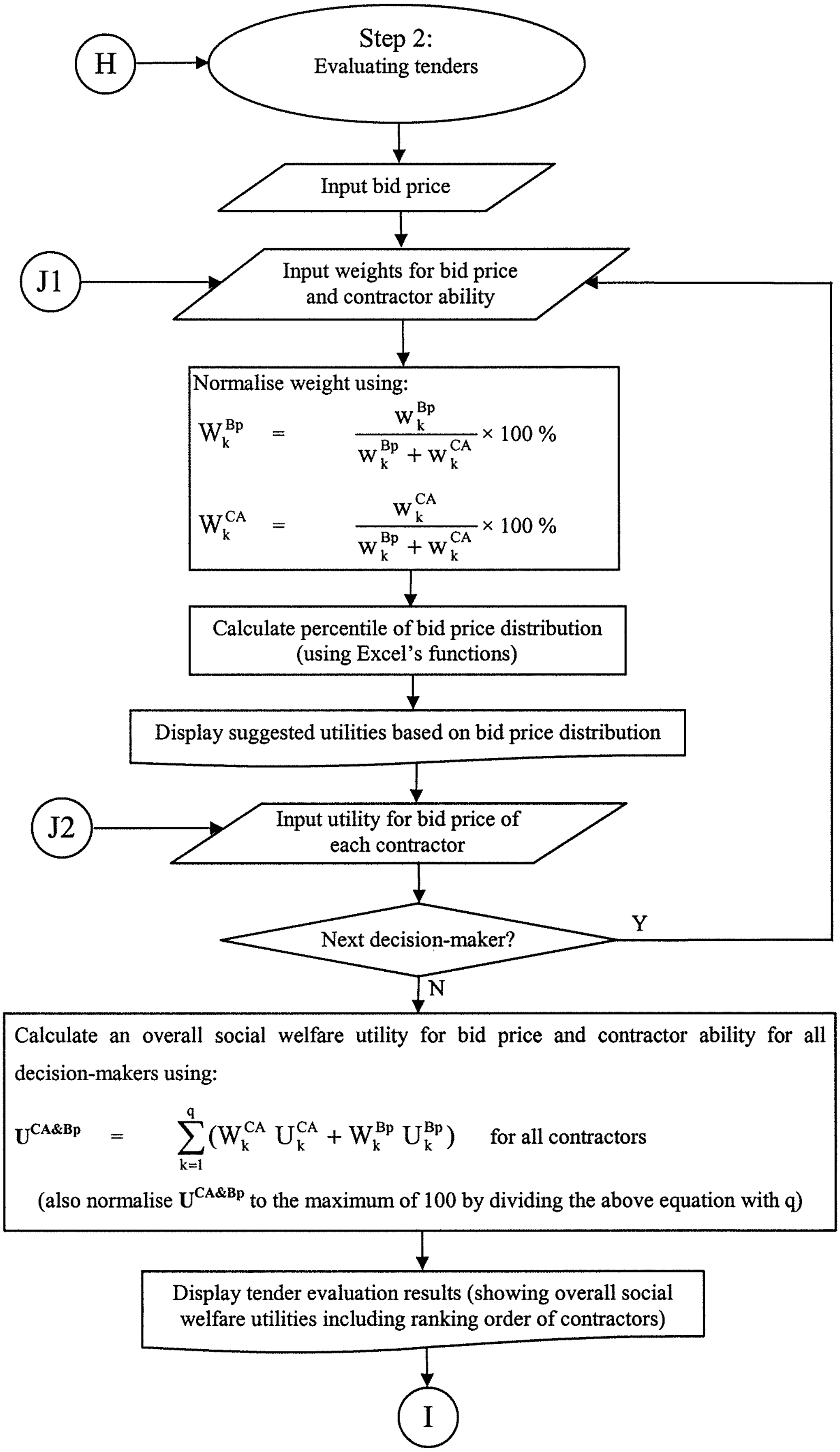
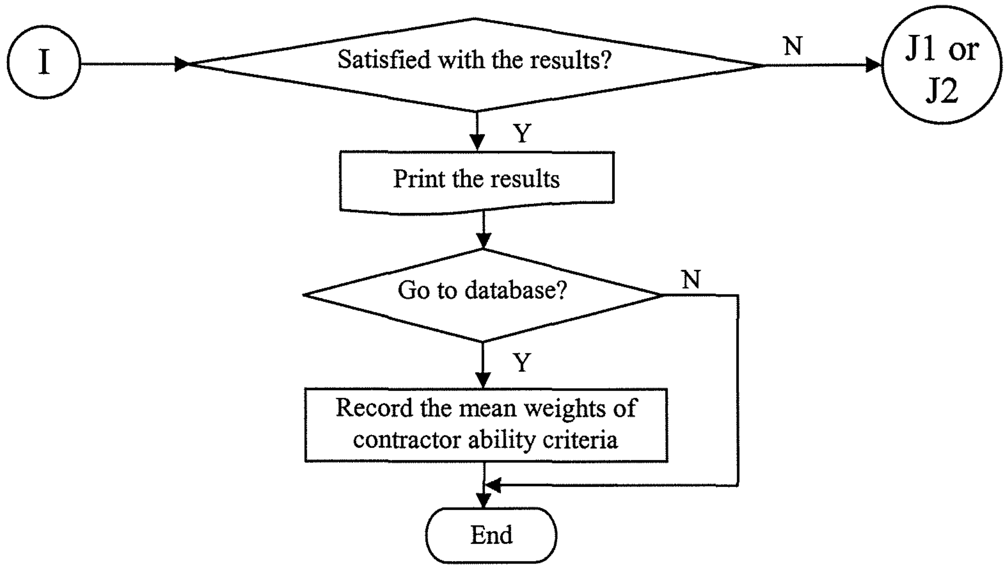


Figure 29 (Continued)



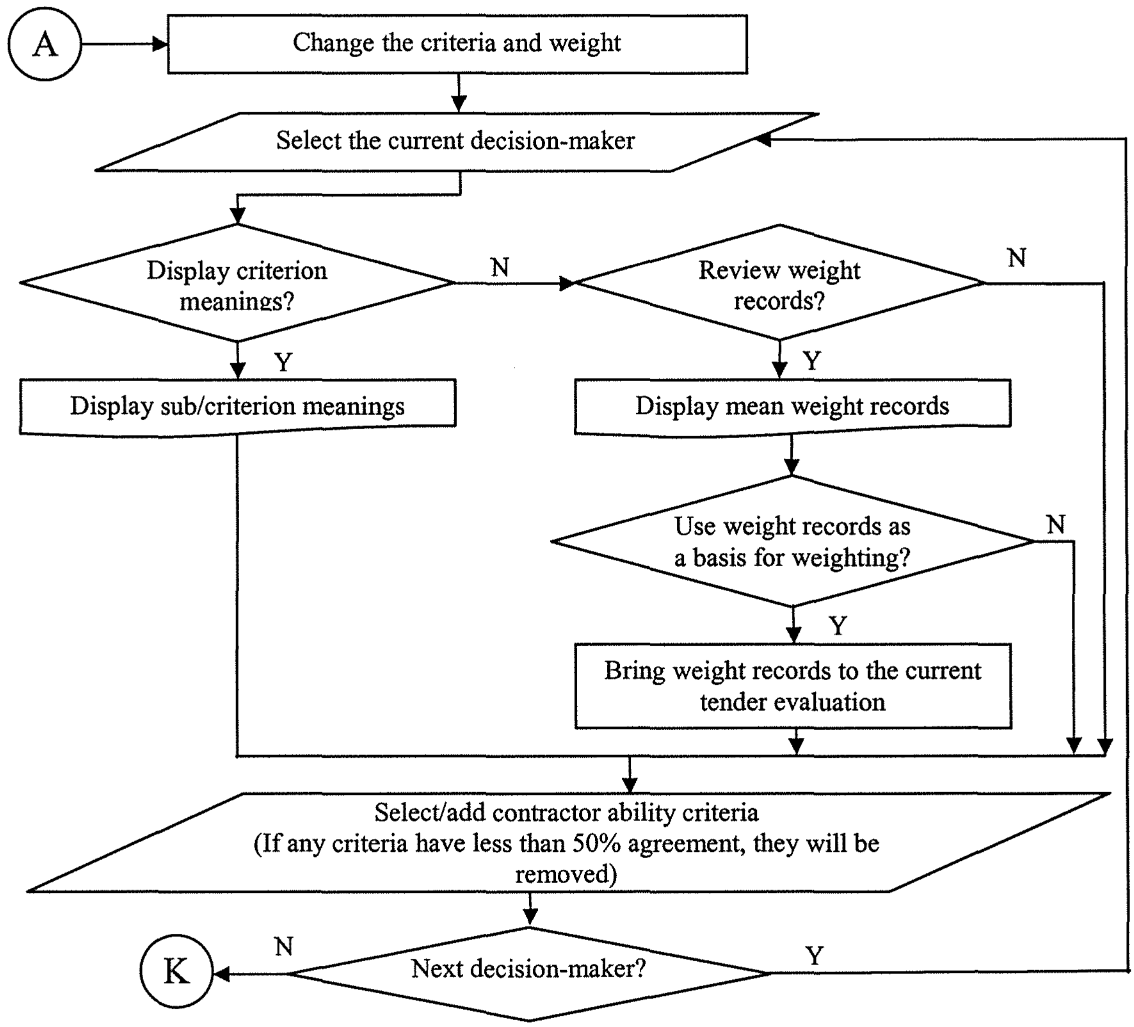


Figure 29 (Continued)

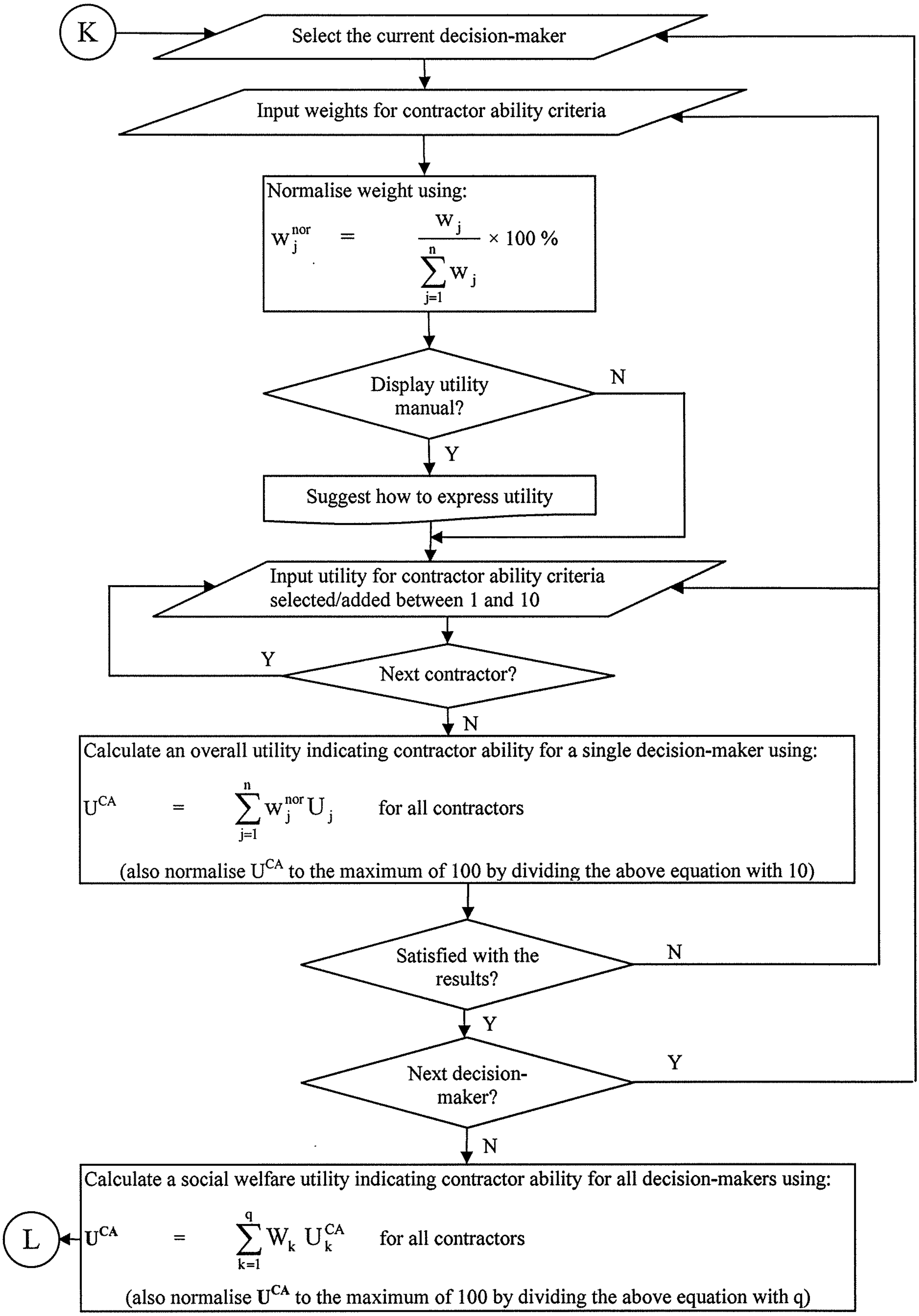


Figure 29 (Continued)

According to Figure 29, the user first identifies the project environment, namely, user context, type of project, project context, objective identification, decision-maker identification and contractor identification. The last two items will be automatically used to support decision-makers along the tender evaluation process.

The user then moves to step 1 (evaluating contractor ability). The nine contractor ability criteria with their weights (derived from the questionnaire analyses in Chapter 5) are provided to decision-makers. Then decision-makers have three selecting cases:

- Case I: Accept the criteria and weight.

- Case II: Accept the criteria but change the weight. This case means decision-makers accept the suggested criteria but they want to change the weight for each criterion. The model offers weights varying from -20% to +20% of the original suggested weight. The choice of the variation is under the writer's subjectivity. However, the range of variation available controls decision-makers so that major changes to the weights cannot be made to allow a decision-maker to pre-determine the final choice. The model will normalise the weights automatically.

- Case III: Change the criteria and weight. Here, the model allows decision-makers to select their own criteria and weight. Only the criteria that are selected by a minimum of half of the number of decision-makers are accepted. Then, decision-makers have to give weights for the selected criteria. After that, the given weights will be normalised automatically.

Thirdly, decision-makers have to express utilities (analytical values including risk consideration) for the selected criteria for all contractors. The utility manual informs decision-makers on: (1) meanings of utility and (2) how to express utility (details in Section 6.2.1). This manual facilitates the utility expression for contractor ability criteria.

Fourthly, after the model has completely received/exchanged subjective inputs from/with all decision-makers, the contractor ability is evaluated. The results of this evaluation are shown to decision-makers. If any decision-makers are not satisfied with the results, they can go back to change their weights and/or utilities. In order to provide a paper trail a program is available. Some contractors may be eliminated from bidding. The elimination depends on a decision-maker's judgment. For example, if any contractors have social welfare utilities less than 50, they should be eliminated from bidding; or, if any contractors have social welfare utilities less than 50 on any criteria, they should be eliminated from bidding; or, the number of contractors should be less than 6 for submitting tenders so as to limit the number of unsuccessful contractors. The model leaves the decision to decision-makers.

Fifthly, step 2 (evaluating tenders) begins. To evaluate tenders, the bid price of each contractor, the weight (to balance between bid price and contractor ability) and the utilities for bid prices are put into the model. Percentile of bid price distribution is calculated to facilitate decision-makers in expressing utilities for bid prices. After that, the results of the tender evaluation are displayed to decision-makers, if they are not satisfied with the results, they can again go back to change the weights and/or utilities. A report of the results can be made.

Lastly, the mean weights of contractor ability criteria are recorded according to a specific type of the project for future use.

It should be noted that the flow diagram is used only for analysing logical order at all stages of the model, which supports model programming in the next section.

7.4 Model programming

The tender evaluation process in the previous section was programmed using Excel with Visual Basic for Application (VBA). Due to advantages in calculation and reporting and the wide acceptance by users, Excel was selected. On the other hand, VBA was used for the sake of user friendliness and task-repetition management. VBA provides *UserForms* which allow the adding of controls (eg, *CommandButton* and *ListBox*) onto them. These controls can store a number of procedures (VBA code), which will activate when setting events occur. The details of VBA can be seen in Walkenbach (1995, 1999) and Leclerc (2001). The tender evaluation model process (consisting of (1) contractor ability criteria selection process, (2) contractor ability criteria balancing/measuring process, and (3) bid price and contractor ability balancing/measuring process) was divided into seven main steps as shown in the front page of the model. Figure 30 shows this front page (showing connections between the steps).

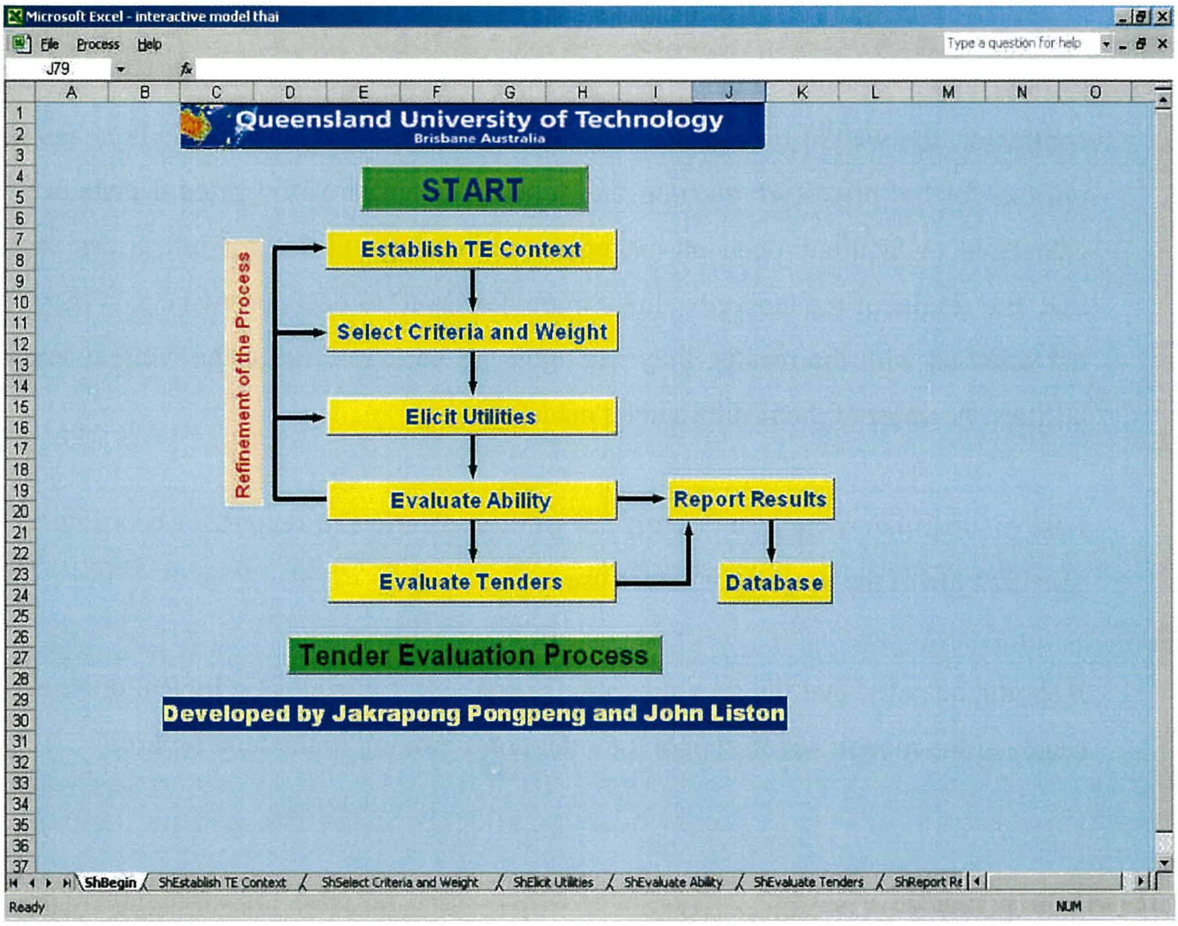


Figure 30 The front page of the tender evaluation model

This page will give users the overall picture of the tender evaluation model process. The following describes the process step by step.

7.4.1 Establish tender evaluation context

This step lets users identify a project context, namely:

- User context: user name and evaluation date
- Type of project
- Project context: owner name, project ID no., project name, and project start date
- Objective identification
- Decision-maker identification as shown in Figure 31. (up to 9 decision-makers)
- Contractor identification as shown in Figure 32. (up to nine contractors)

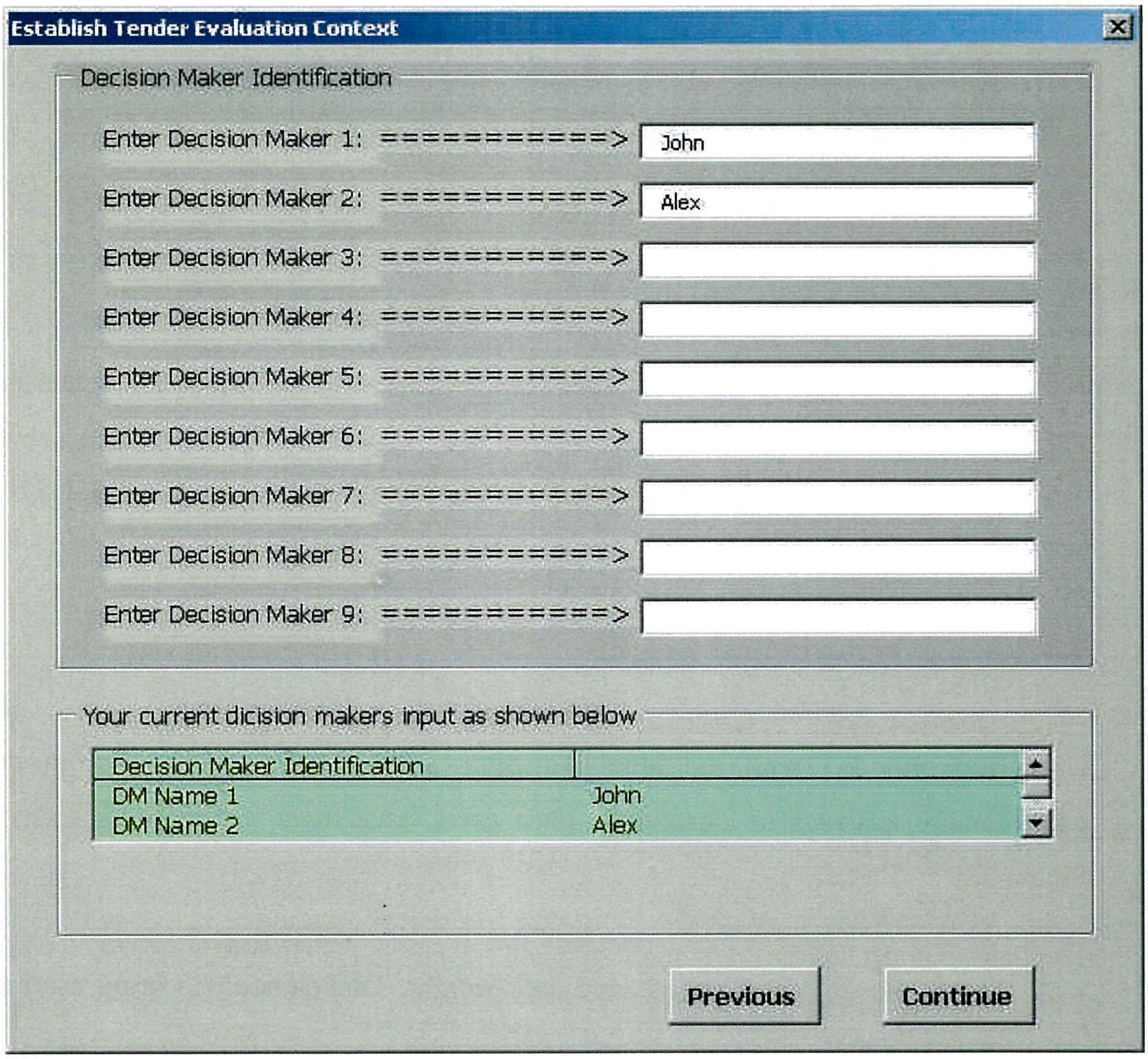


Figure 31 Decision-maker identification menu

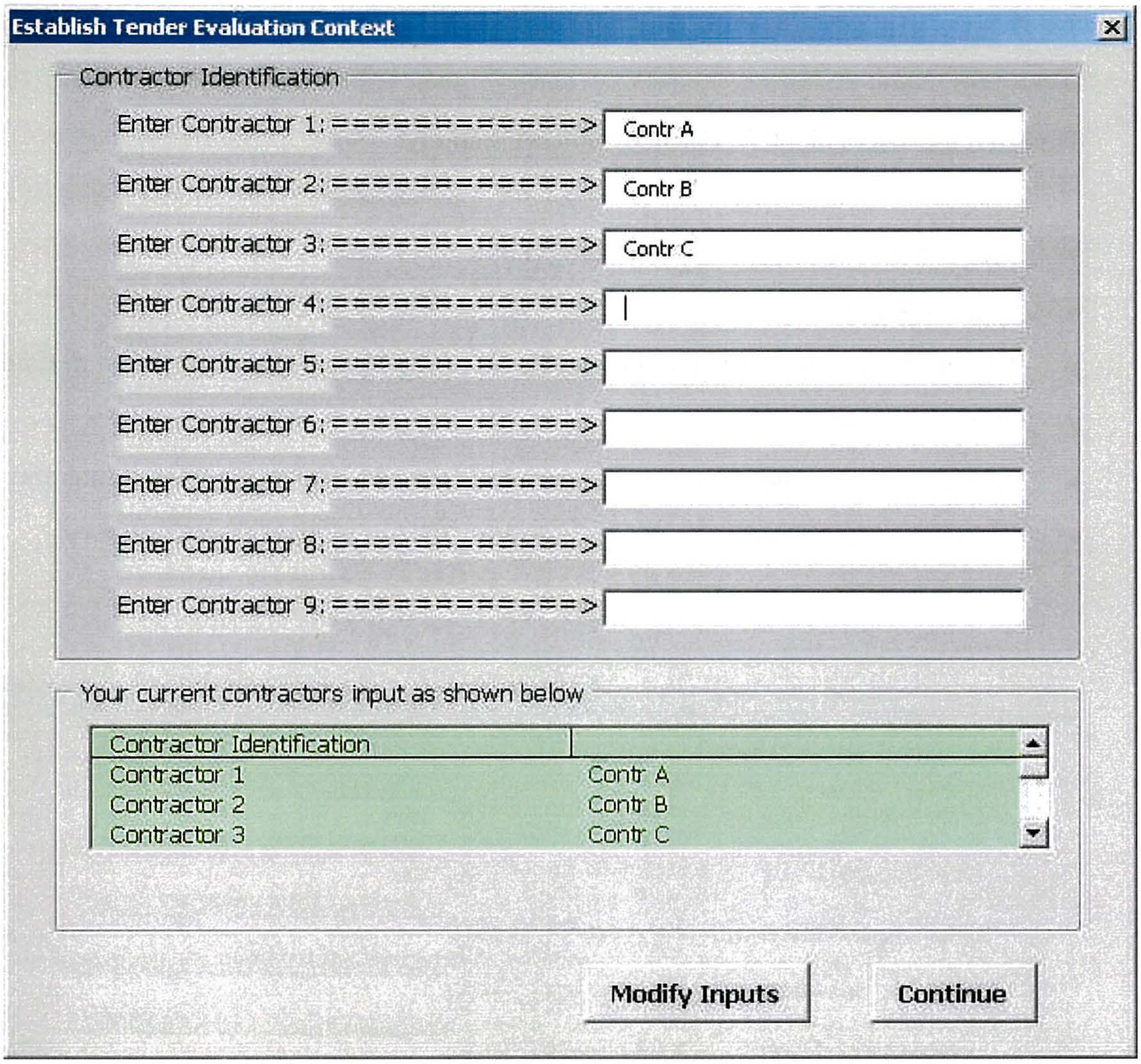


Figure 32 Contractor identification menu

7.4.2 Select criteria and weight

Users are provided with the nine contractor ability criteria derived from the questionnaire analyses in Chapter 5. Then users have three options as shown in Figure 33:

- Accept the suggested criteria and their weight. This choice will bring users to the next step.
- Change the weight. Users agree with the suggested criteria but want to change the weight for each criterion. If users select this option, they accept the

suggested criteria but want to assign their own weight for each criterion. The model provides users the menu to change the weight as required as shown in Figure 34.

- Change both the criteria and weight. Users can select their own criteria and assign weight through the menus as shown in Figures 35 and 36.

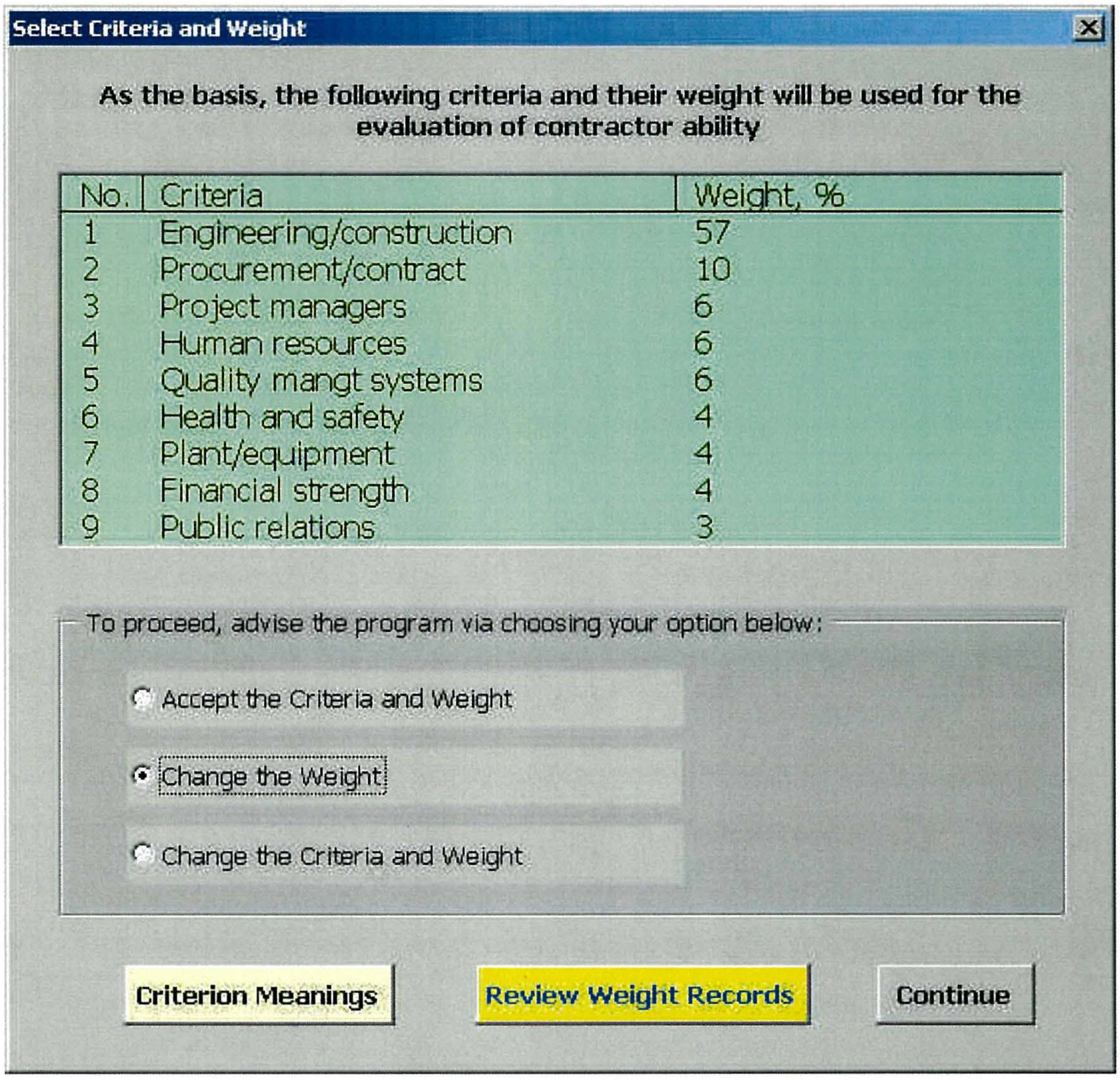


Figure 33 A tender evaluation criteria selection menu

The "Review Weight Records" button permits users to use their weight database as the basis for weighting. The "Criterion Meanings" button explains the meanings of each criterion using sub-criteria and subsub-criteria as shown in Figure 37.

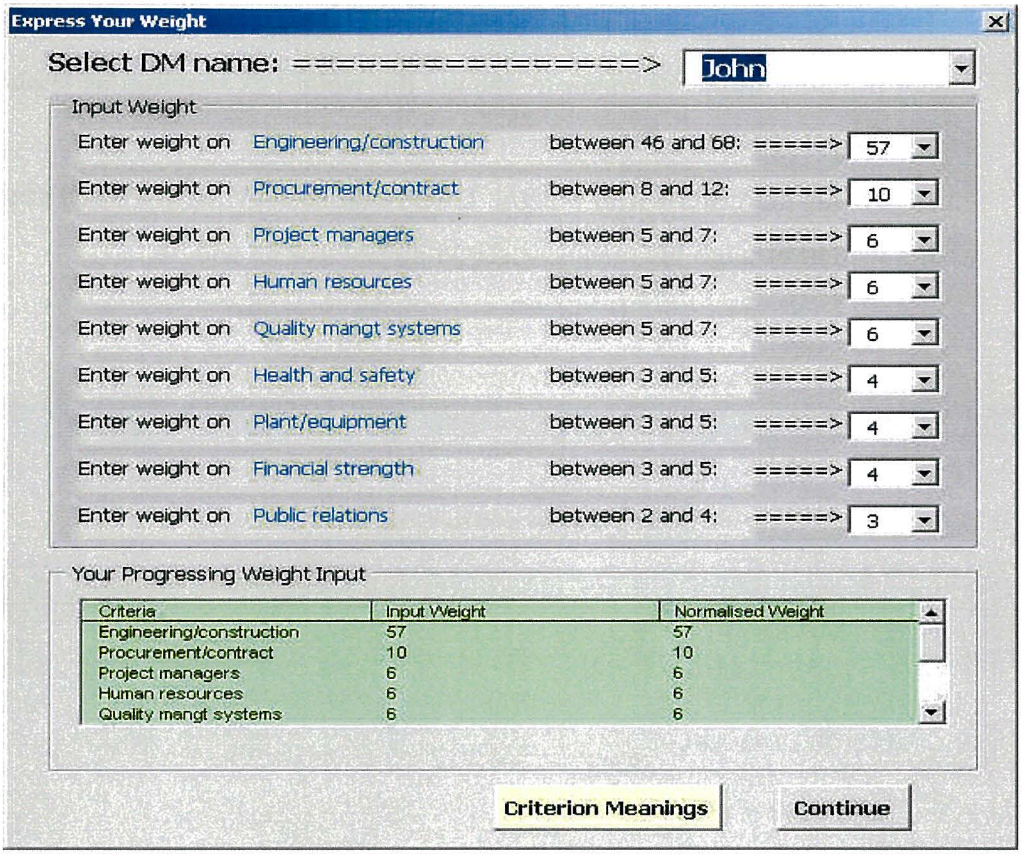


Figure 34 Expressing weight menu

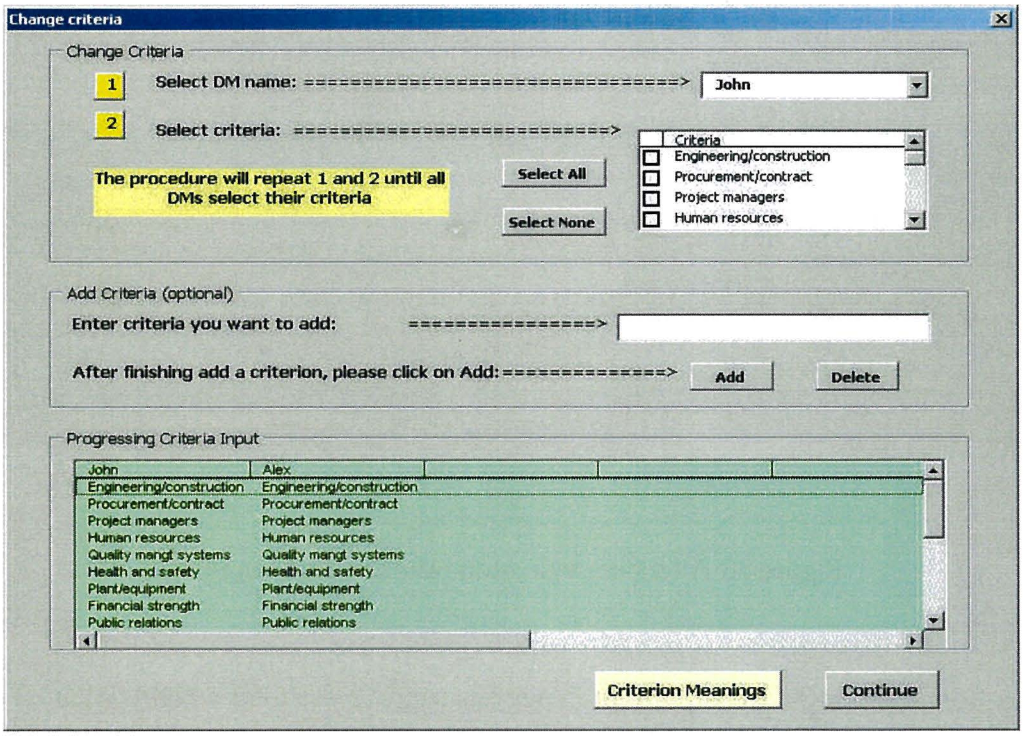


Figure 35 Changing criteria menu

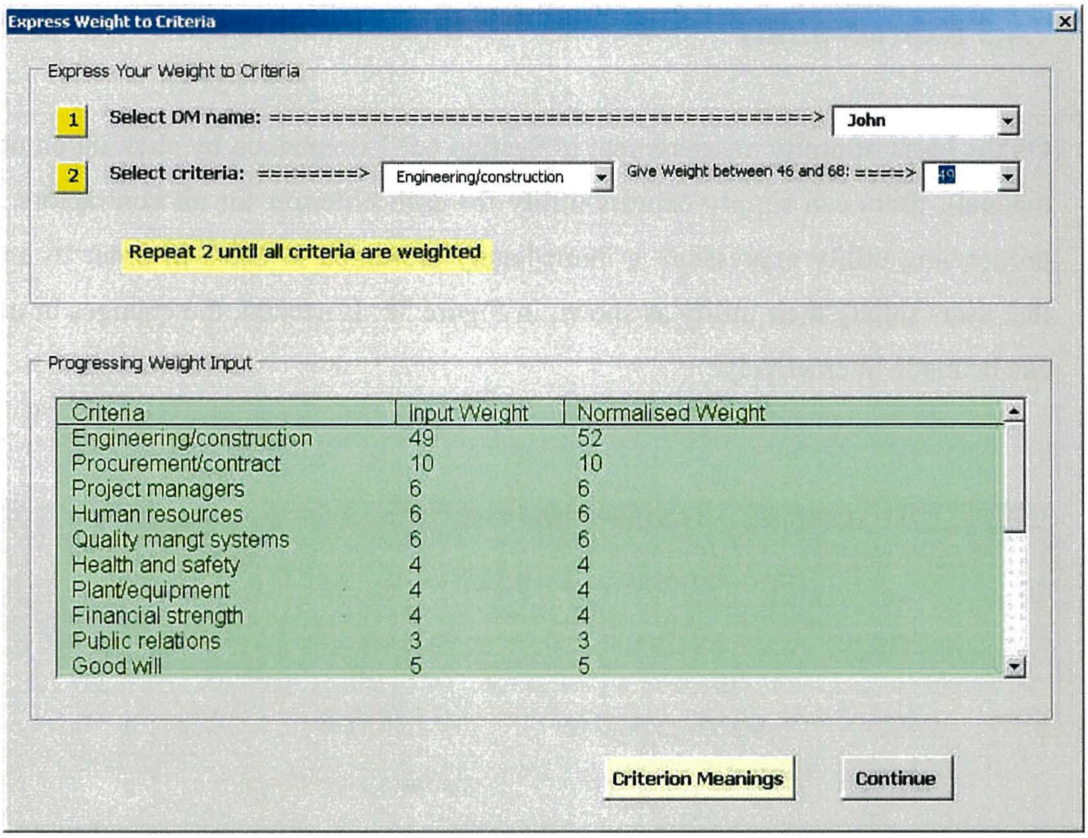


Figure 36 Expressing weight to the changed criteria menu

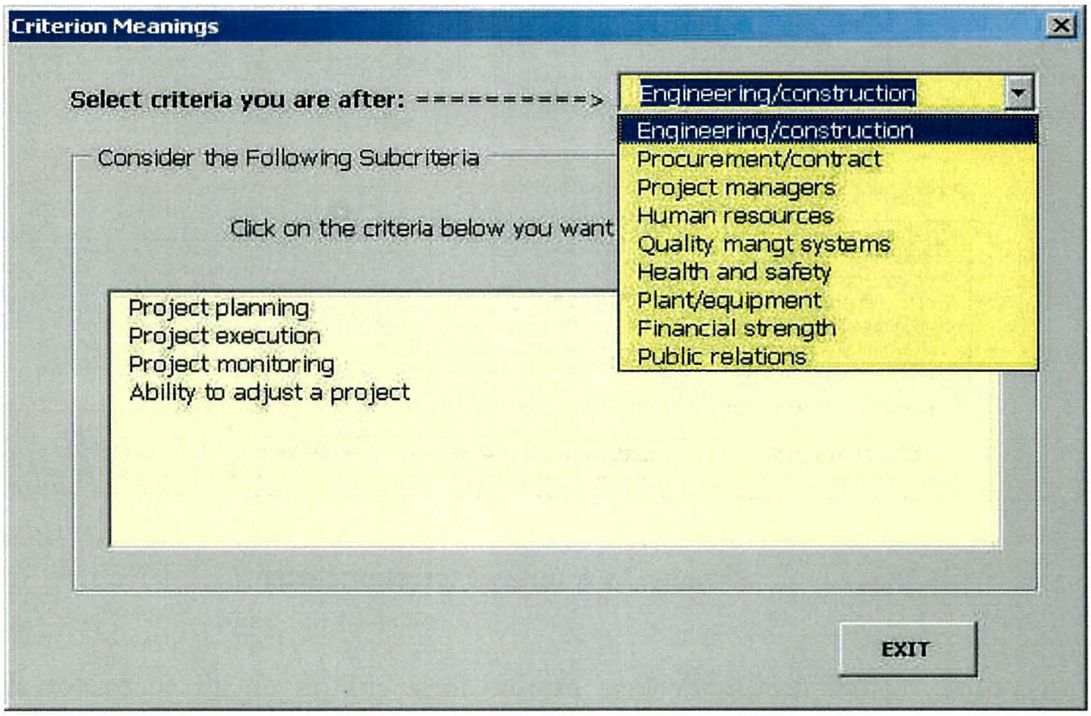
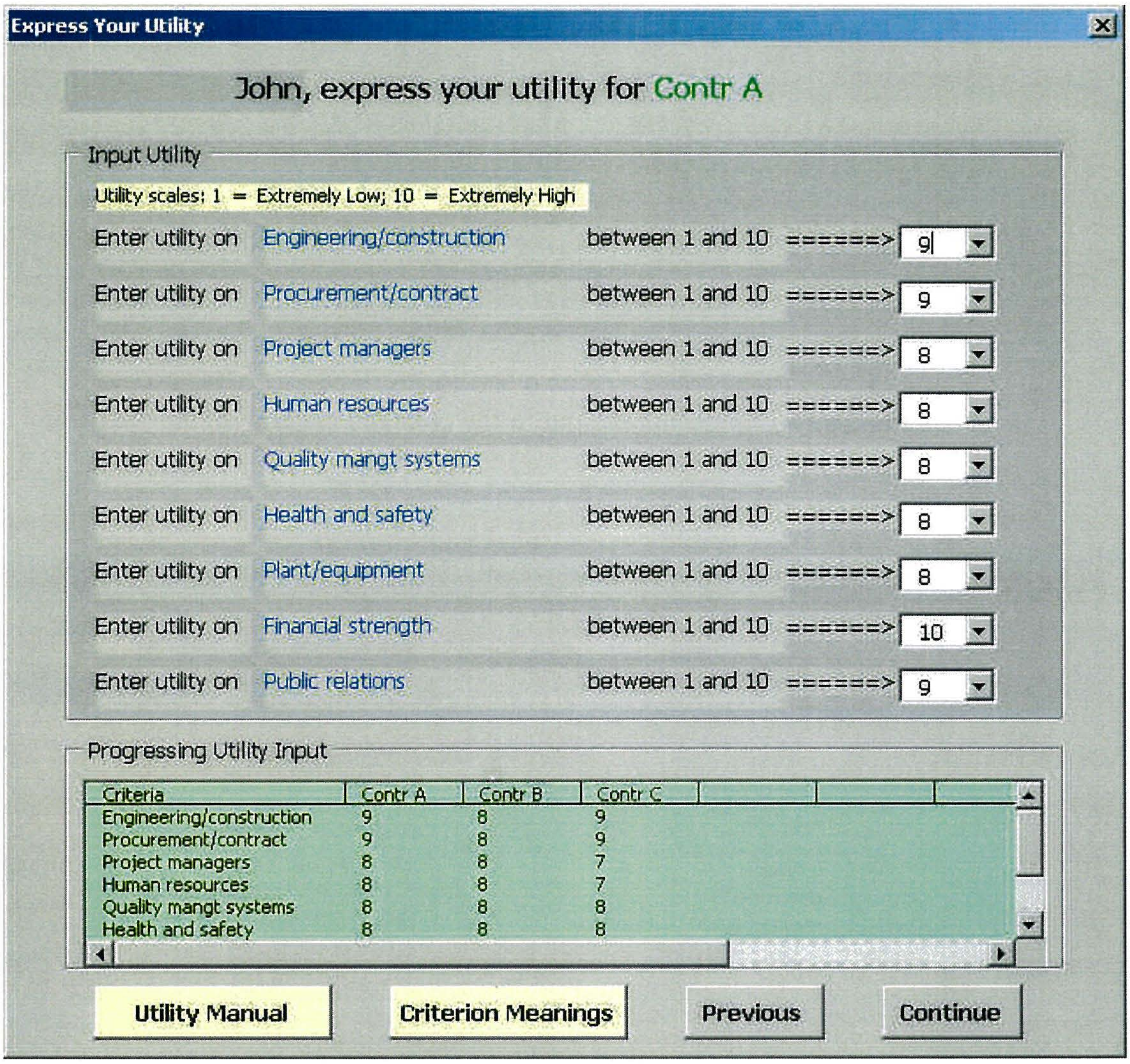


Figure 37 A criterion meanings menu

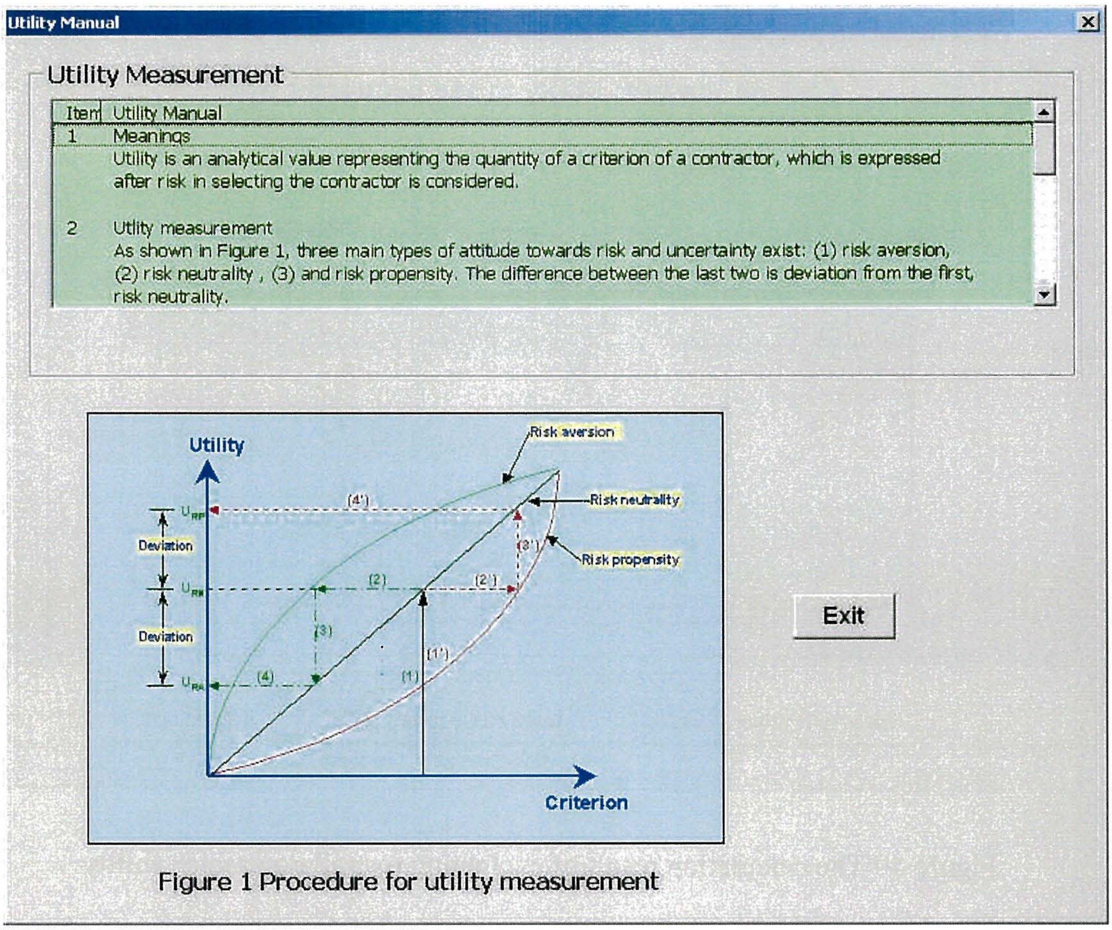
7.4.3 Express utility

On the basis of utility measurement in Section 6.2.1 (explained by clicking on utility manual), users can simply express utility for each criterion for all contractors. The progressing utility expression is immediately presented to users in order to ensure that users satisfy their utility as shown in Figure 38. If needed, the changes in utility can be made interactively.



Figurer 38 A utility expression menu

However, before decision-makers express their utilities on all contractor ability criteria, they are encouraged to click on "Utility Manual" button. Then the utility manual menu will pop up as shown in Figure 39.



Figurer 39 A utility manual menu

The manual tells decision-makers the procedure for utility measurement as discussed in Section 6.2.1.

7.4.4 Evaluate ability

This step evaluates contractor ability and reports the results for decision-makers as shown in Figures 40 and 41. If decision-makers are not satisfied with the results, they can go back to change their subjective inputs (ie, weight and utility) by clicking on the "Back to change weights" or "back to change utility" buttons until they are satisfied. The calculation for a single decision-maker uses equation (2) in Section 6.2.2 whereas equation (3) in Section 6.3 is for integrating all decision-makers' utilities.

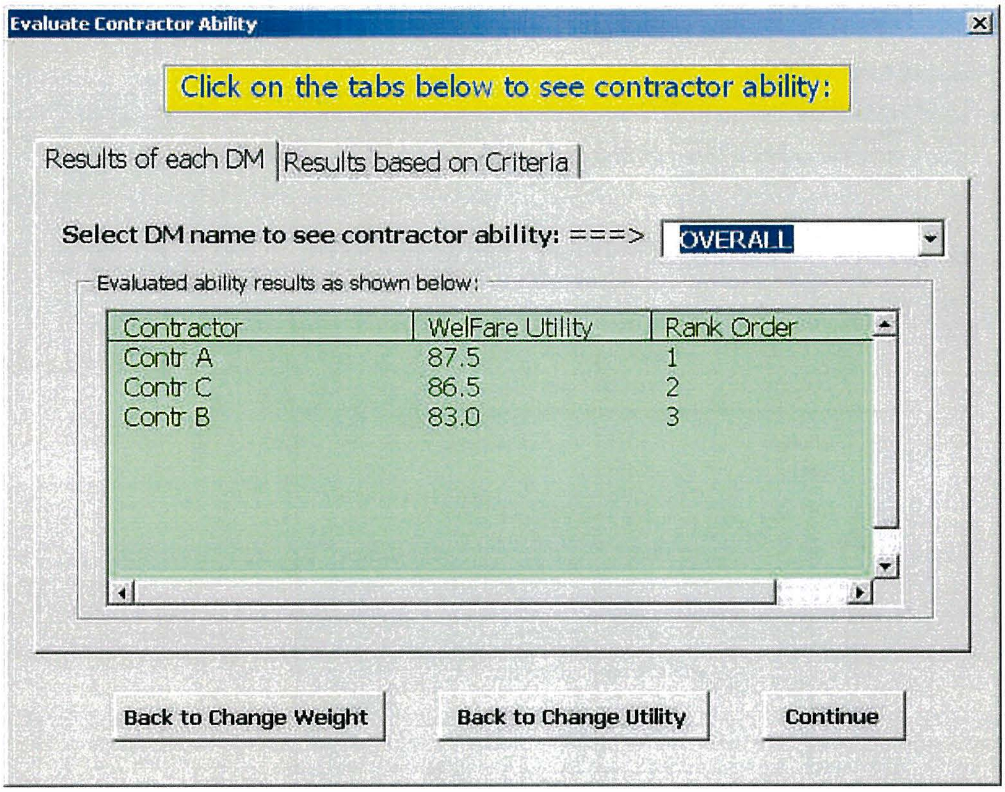


Figure 40 The calculation result of evaluating overall contractor ability

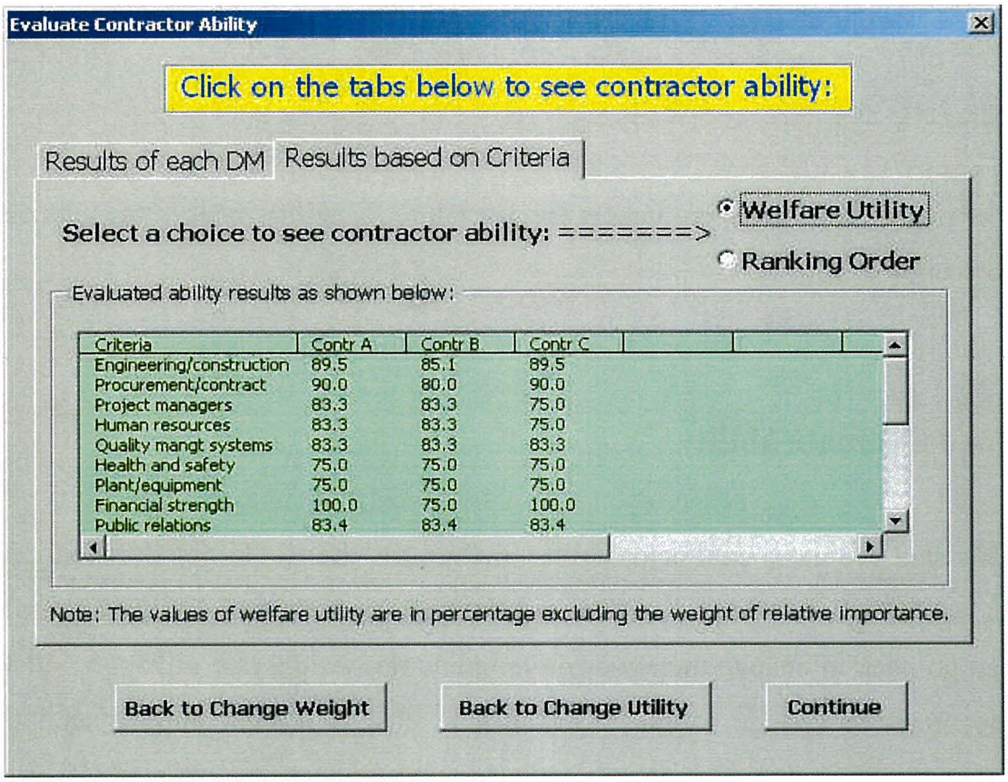


Figure 41 The calculation result of evaluating contractor ability on each criterion

7.4.5 Evaluate tenders

Bid price of each contractor is included in this step to finalise tender evaluation. The weights (to balance between bid price and contractor ability) are required as shown in Figure 42.

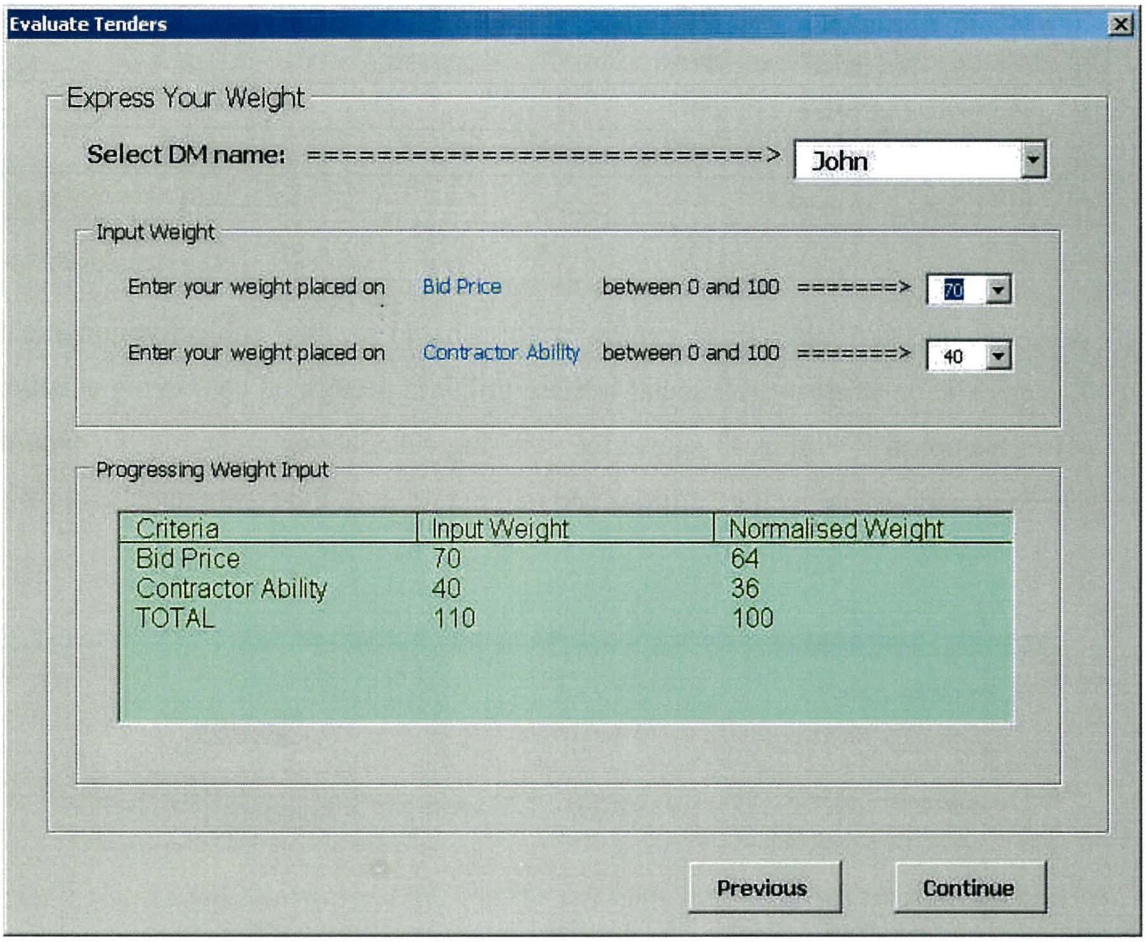


Figure 42 A bid price and contractor ability balancing menu

To facilitate decision-makers in the expression, *percentile*, as a measure of distribution, is used. Table 22 shows the suggested utility based on percentile of bid price distribution.

Table 22 Utility suggestion based on percentile of bid price distribution

Condition for utility suggestion	Suggested utility
If bid price $<$ P^{10}	10
If P^{10} $\leq$ bid price $<$ P^{20}	9
If P^{20} $\leq$ bid price $<$ P^{30}	8
If P^{30} $\leq$ bid price $<$ P^{40}	7
If P^{40} $\leq$ bid price $<$ P^{50}	6
If P^{50} $\leq$ bid price $<$ P^{60}	5
If P^{60} $\leq$ bid price $<$ P^{70}	4
If P^{70} $\leq$ bid price $<$ P^{80}	3
If P^{80} $\leq$ bid price $<$ P^{90}	2
If bid price $\geq$ P^{90}	1

However, decision-makers can express utilities based on their subjective judgment. The calculation of an overall social welfare utility is performed by solving equation (4) in Section 6.3. Figure 43 shows the resulting calculations including the *should-win* contractor, social welfare utilities and ranking order of the contractors.

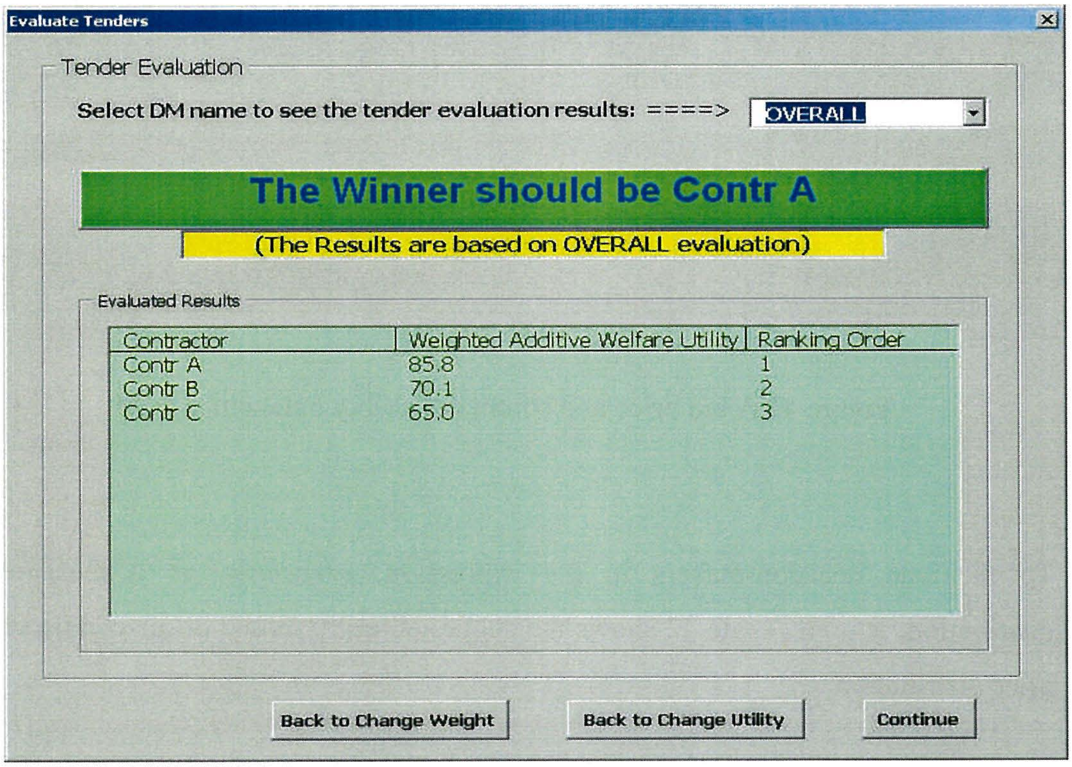


Figure 43 An overall social welfare utility menu

7.4.6 Report results

The results are presented in a tableau for clarity of comparison of contractors. Three main results to be printed were:

- Overall tender evaluation. This result presents the ranking order and social welfare utility. Also, it suggests the *should-win* contractor.

- *Contractor ability* comparison, which shows the contractor ability in terms of the social welfare utility and ranking order.

- *Contractor ability* comparison on each selected criterion. Where the social welfare utilities of contractors are close in value, this result helps to determine strong and weak areas of contractors in order to facilitate the selection of the best contractor.

7.4.7 Database

In this step, the average weights, as measures of central tendency, are automatically calculated. Then, the average weights placed on criteria are recorded, corresponding to a specific type of project, for future uses.

7.5 Conclusions

Based on the literature findings that all existing tender evaluation models have a lack of integration in the joint area of simultaneously putting together preferences of multiple decision-makers, covering elements of risk and uncertainty and offering computer interaction, this research developed a more realistic working model incorporating the necessary capabilities mentioned. The developed model was divided into two steps: step 1 evaluating contractor ability and step 2 evaluating tenders, which consisted of three main processes: (1) the contractor ability criteria selection process, (2) the contractor ability balancing/measuring process and (3) the bid price and contractor ability balancing/measuring process (refer to Figure 28). In all these processes, subjective inputs (a statement of preference) arise (exchanged between the model and the decision-makers or provided by the decision-makers):

- In the contractor ability criteria selection process, the nine criteria with their weights of relative importance (derived from the questionnaire analyses in Chapter 5) were suggested to decision-makers. However, the decision-makers were allowed to change the weights and/or the criteria, if required, making the model flexible to changes in relation to a particular situation and perhaps flexible for use anywhere in the world. This suggestion of criteria and the facility for change show the exchange of subjective inputs between the model and the decision-makers.

- In the contractor ability criteria balancing/measuring process, the decision-makers provided subjective inputs through expressing utilities for contractor ability criteria. In this process, a new utility measurement was also introduced and employed by the writer so as to reduce the difficulty in finding utility functions for all contractor ability criteria.

- In the bid price and contractor ability balancing/measuring process, subjective inputs were provided via the articulation of weights for bid price and contractor ability. Then, subjective inputs were exchanged again through the suggestion of utility for the bid price (by the model) and the expression of utility for the bid price (by the decision-makers). *Percentile* was used to guide the decision-makers in expressing utility for the bid price. This suggestion helps to reduce utility-expression onus on the decision-makers.

After the model has provided the results of the evaluation (both in steps 1 and 2), if the decision-makers are not satisfied, they can go back to change their weights and utilities until they are satisfied with the results. This again presents the exchange of subjective inputs between the model and decision-makers through the resulting solutions.

Clearly, as the model is searching for the best contractor, subjective inputs are evolved. This evaluation leads to the reduction of the difficulty in finding fixed and well-defined subjective inputs upfront and offers an opportunity for changes to subjective inputs in relation to a particular situation.

In addition, using Excel with VBA to create the model renders a good calculating and reporting tool and offers a friendly interaction. The next chapter shows the tests of the realistic workability of the model.

Chapter 8

Model test

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8.1 Introduction

A main aim of the research was to develop a more realistic working model that is simultaneously capable of (1) compiling multiple decision-makers' preferences, (2) including elements of risk arising from uncertainty, and (3) providing sufficient flexibility to absorb changes of preference in relation to a particular situation via computer interaction.

The confirmation of achieving this research aim was performed by testing the model for user friendliness, verification, sensitivity analysis and validation. These tests then show that the suggested model is more realistic than those including only one decision-maker preference and those having no computer interaction and not covering elements of risk and uncertainty currently, which are used in tender evaluation.

8.2 User-friendliness

In developing the model, the applied operations research techniques (utility and social welfare functions) were simplified to suit tender evaluation practitioners. Excel with VBA was selected because it renders a good calculating tool and a high interface between users and the model. To meet user satisfaction, the planning structure of the model was as follows:

- Calculation. In Excel, one workbook with nine sheets was used to perform calculations. Within these sheets, Excel functions were used to reduce computing time — Excel calculates faster than VBA (Walkenbach, 1999).

- Interaction between users and the model. In realising that some users may not be experienced sufficiently in using Excel, VBA's *UserForms* were used as the menus driving the whole tender evaluation process (refer to Figure 36). Furthermore, the *UserForms* visually assist user inputs, receive users' options and preferences, and then link to the Excel sheets for calculation.

Finally, the model was tested with one Australian tender evaluation practitioner, four Thai tender evaluation practitioners and one computer-program developer to improve its practical application. As a result, the model was modified until it satisfied current practitioners' requirements. In addition, during the test it was found that the utility measurement (Section 6.2.1) and the suggested utility for bid price (based on percentile of bid price distribution) was helpful in reducing the utility expression on the part of decision-makers.

8.3 Verification

As a process of showing that there are no bugs and errors, verification tests the accuracy of programs. It is a controversial but necessary part of any program proof in terms of techniques used (Millo *et al.*, 1979). Some programmers prefer to use a *pro forma* verification process, which is a step by step method using deductive science of reasoning. However, this method does not guarantee the absence of errors (Kiangi, 1988). Others adopt a *relaxed* process, which is an informal or *ad hoc* method. This method may be more attractive to many programmers. Selecting such a process by comparison of needs, importance and beneficial results requires subjective judgment (Millo, Lipton and Perlis, 1979). Based on the writer's subjectivity, the *relaxed* process was chosen. Within the process, two broad proving methods were considered (cf, Kiangi, 1988):

- Proof with existing knowledge. This can be performed by comparison of the model results with those of other models solving similar problems. However, because the existing tender evaluation models have different-element structures (eg, criteria, basic adopted procedures and assumptions), it is most likely that different results are obtained and, therefore, difficult to make the comparison. Thus, this method was not chosen for this research.

- Proof with experimentation. A program normally comprises more than one module. The connections (eg, value delivery/exchange and display) between these modules should be investigated for accuracy. An easily and popularly used method is comparing the model results with those solved manually. Based on ease and popularity, this research adopted this method. Table 23 summarises the results.

Table 23 Comparison of the model results and the results solved manually

Contractor	Social welfare utility derived from the model (out of 100)	Social welfare utility derived from solving manually (out of 100)
A	87	87
B	72	72
C	70	70

Clearly, in the Table the model results are the same as those solved manually. In addition, the model itself was broken down into a number of procedures in order to monitor the calculating process. Value displays (eg, weight and utility inputs and social welfare utility of each decision-maker) provide calculating tracks, helping to find bugs and errors. Furthermore, the diagram of the tender evaluation model process (refer to Figures 36 and 37) clarifies the logic of the model. Collectively, these methods declare the correct workability of the model.

8.4 Sensitivity analysis

No model can exactly copy reality (de Neufville, 1990), which means a solution by a model is an estimated solution to reality. When a model is developed, assumptions (eg, certainty, *parametric* measurement and *hypothetical* process) are always made due to constraints on resources (eg, time and money). Therefore, obtaining only one solution from a model may not provide confidence in selecting the final solution. It is interesting to understand what changes in data inputs (ie, weight and utility) result in what changes in the model results. This understanding helps to identify sensitive (or even weak) points of the model and to make effective plans in response to those noticeable changes.

The changes in data inputs, resulting from uncertainty and inconsistency, lead to variation in the model results. If a small change in the data inputs alters the model results, these model results are sensitive. To investigate this sensitivity, each criterion in terms of weight and utility inputs was varied from -20% to +20%. Table 24 shows percentage change in social welfare utility of varying by ±20% weight; Table 25 shows that of varying by ±20% utility.

Table 24 Percentage change in social welfare utility by varying ±20% weight

Criteria	**% change in social welfare utility after the weight input of the criteria varied ±20%**	
	Minimum	Maximum
Engineering/construction	-0.4	+1.1
Procurement/contract	-0.3	+0.4
Project managers	-0.1	+0.4
Human resources	-0.3	+0.4
Quality mangt systems	-0.1	+0.4
Health and safety	-0.4	0.0
Plant/equipment	-0.4	0.0
Financial strength	-0.4	+0.4
Public relations	-0.1	+0.4
Bid price	-2.7	+2.9

In Table 24, amongst the tender evaluation criteria, 'bid price' is the most sensitive (–2.7% to +2.9% change in social welfare utility) followed by 'engineering/ construction' accounting for –0.4% to +1.1% change in social welfare utility. This means that the bid price is the most important criterion and requires the highest attention from participants. However, variation of the social welfare utility does not change the ranking order of the contractors.

Table 25 Percentage change in social welfare utility by varying ±20% utility

Criteria	% change in social welfare utility after the utility input of the criteria varied ±20%	
	Minimum	Maximum
Engineering/construction	-6.7	+8.6
Procurement/contract	-1.6	+3.8
Project managers	-0.7	+3.8
Human resources	-0.7	+3.8
Quality mangt systems	-0.7	+3.8
Health and safety	-0.9	+3.5
Plant/equipment	-0.9	+3.5
Financial strength	-0.9	+0.7
Public relations	-0.4	+0.4
Bid price	-10.9	+8.1

Again in Table 25, the first and second most sensitive criteria are bid price (a range of -10.9% to +8.1% change in social welfare utility) and 'engineering/construction' (a range of -6.7% to +8.6% change in social welfare utility), respectively. This also does not alter the final ranking of the contractors. The results in both the Tables show the small changes in social welfare utility when weight and utility were varied from -20% to +20%. Also, the variation does not change the conclusion (the ranking order) provided by the model. This presents a robustness of the model in absorbing changes resulting from uncertainty.

8.5 Validation

As an ultimate process convincing people that a model can do as it claims to do, validation makes the model acceptable or proves the following truth: the model does not assume that there is one decision-maker involved, considers risk arising from uncertainty and provides computer interaction. This model then produces a more realistic result than those of existing models.

Socrates says "agree with me if I seem to speak the truth" (after Millo, Lipton and Perlis, 1979). In this research, to reach agreement in Socrates' sense, the model results were compared with real-case results. Seven real-case projects in Thailand were selected: in cases 1-6 two decision-makers were involved and in case 7 three decision-makers participated. The Spearman rank correlation method was used to calculate correlation coefficients between real-case ranking order and model ranking order. Tables 26-32 summarise the comparison.

Table 26 Comparison of case 1 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
A	1	1	1.0
B	2	2	
C	3	3	

Table 27 Comparison of case 2 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
D	1	1	0.7
E	4	2	
F	2	3	
G	3	4	
H	5	5	

Table 28 Comparison of case 3 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
I	1	1	1.0
J	2	2	
K	3	3	

Table 29 Comparison of case 4 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
L	1	1	
M	2	2	1.0

Table 30 Comparison of case 5 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
N	1	1	
O	2	2	1.0

Table 31 Comparison of case 6 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
P	1	1	
Q	2	2	
R	3	3	1.0
S	4	4	

Table 32 Comparison of case 7 and the model results

Contractor	Ranking order by owner (real-case)	Ranking order by the model	Correlation coefficient between real-case and model results
T	1	1	
U	2	2	1.0

From the Tables, all the cases except case 2 have correlation coefficients of 1, which indicates the strongest relationship between real-case results and model results. In case 2, although the model suggests the successful contractor A as the same as that selected by the owner, the correlation coefficient is at 0.7. This is possibly because one of the two decision-makers lost his data on the last three contractors (F, G and H). For this reason, during the test, the data input (ie, utility) for the three contractors was assumed as the same as that of the other decision-maker. This assumption causes a deviation between the real-case result and model result. If, however, the last three contractors are removed from the test, the model will yield the same result as that of the real-case. Thus this model is still valid in showing that it can perform as it claims.

8.6 Conclusions

To obtain a realistic working product, the model was tested for user-friendliness, verification, sensitivity analysis, and validation. The tests for user-friendliness relied upon the planning structure of the model and upon Thai tender evaluation practitioners' requirements. On the other hand, verification used experimental proof by comparing the model results and those solved manually. The logical diagrams (the model process and the flow diagram in Sections 7.2 and 7.3) also showed verification of the model. The sensitivity of the model was tested by the variation of data inputs (ie, weight and utility). As the ultimate test, the model results were validated with the seven real-case results. The tests showed that the model incorporating multidecision-makers' preferences, elements of risk and uncertainty and computer interaction was a more realistic working product in solving tender evaluation problems. Consequently, selecting the *best* contractor using this model results in (1) a saving in time and (2) the selection of a contractor that will perform within time, budget, quality and safety requirements.

Chapter 9

Conclusions and recommendations

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9.1 Conclusions

Although many sets of tender evaluation criteria (contractor ability criteria and bid price) and many tender evaluation models have been suggested to select a competent contractor, construction problems such as budget overruns, extended time in planned schedules, low quality work and poor safety standards still occur. This presents drawbacks in current tender evaluation resulting from not selecting the best contractor to complete a project. Accordingly, the owners need a more realistic working model to evaluate contractors/tenders.

However, a review of literature revealed that there is a lack of commonality in selecting tender evaluation criteria that meet a project's requirements and that existing tender evaluation models are not capable of simultaneously including preferences of multiple decision-makers, covering elements of risk and uncertainty and offering computer interaction, showing two gaps of knowledge that need to be filled. Therefore, the main research aims were to originally contribute to fill these two knowledge gaps by developing (1) a common set of tender evaluation criteria and (2) a more realistic working model incorporating the essential capabilities mentioned.

The following sections conclude the research on the basis of its aims, starting from the tender evaluation survey, utility and social welfare functions, to the multicriteria and multidecision-makers' model.

9.1.1 The tender evaluation survey

A review of the literature on tender evaluation showed that there is no consensus on a common set of tender evaluation criteria, showing a gap of knowledge that needs to be filled. To fill this gap and to investigate tender evaluation procedures, tender evaluation criteria and tender evaluation models, the Thai construction industry was surveyed. A total of 210 questionnaires (translated into Thai) were sent to both government and private sectors. 142 questionnaires were returned at a return rate of

68 %, which was considered good. The data on (1) tender evaluation procedures, (2) tender evaluation criteria and (3) tender evaluation models were gathered and analysed (Chapters 4 and 5).

9.1.1.1 Tender evaluation procedures

The results confirm the findings from the literature review that three broad procedures exist (excluding negotiated tendering): the selective tendering process with prequalification, the selective tendering process without prequalification and the open tendering process. The first two processes employ a two-step evaluation: step 1 evaluating contractor ability and then step 2 evaluating tenders based on the lowest bid or a trading off between bid price and contractor ability. On the other hand, the last process uses a one-step evaluation. That is, contractor ability and bid price are evaluated at the same time. Because the two-step evaluation allows the application of one-step evaluation, it was chosen for modelling tender evaluation in this research. In addition, all the procedures involved multiple criteria and multiple decision-makers.

Furthermore, a comment from some respondents was that bid price was not the sole criterion in selecting the best contractor because the lowest bid did not mean the lowest cost at completion. They included contractor ability into the decision. This presents a move for trading off between bid price and contractor ability to select the best contractor. This move was included into the developed model in this research (in step 2: evaluating tenders).

9.1.1.2 Tender evaluation criteria

Three main analyses focusing on the degree of importance of criteria and their measures were performed:

- Determining similarities and differences in the selection of criteria between government and private sectors using the comparison of importance index (mean/STD) and using hypothesis tests on mean differences of criteria and measures. The results revealed that both the government and private sectors consider similar criteria in performing tender evaluation (in step 1: evaluating contractor ability). This then suggests a common set of criteria.

- Examining relationships between all criteria and measures using Spearman rank correlation coefficients. Overall, the result showed that criteria and measures were correlated.

- Applying factor analysis to group all highly correlated measures together. This resulted in all measures being grouped into nine criteria, namely, "engineering/construction," "procurement/contract," "project managers," "human resources," "quality management systems," "health and safety," "plant/equipment," "financial strength" and "public relations," which were compatible with hierarchical organisational units of contractors.

This section of the research attempted to develop a common hierarchy/set of criteria (for evaluating contractor ability, step 1) using data from the Thai construction industry. The theory of *hierarchy, multilevel, systems* led the writer to infer that the criteria should be developed to correspond to existing hierarchical organisational units of contractors. The results of the factor analysis confirmed this inference. One possible reason is that a characteristic common to all contractors in the world is the existence of their hierarchical organisational units, which in general structure an organisation as shown in Figure 44. The commonality then leads to the development of a common set of criteria. This common set, which is the result of the initial initiative in this research, improves on those of other researchers/organisations because here physical characteristics (ie, hierarchical organisational units) are included. This inclusion possibly increases the potential success of designing a hierarchical system which is likely to be used by the construction industry anywhere. Although differences in organisational units between contractors may exist, similar necessary functions are performed in order to operate their businesses. Thus, this reason is still valid.

Another result from the Mann Whitney U test was that the government and private sectors considered similar criteria as they undertook tender evaluation (during the evaluation of contractor ability, step 1). This result again infers that if criteria are developed consistent with organisational units of contractors, types of owners do not affect the selection of criteria, showing a generality of the set criteria proposed in this research. This generality helps to reduce the waste of world owners' repetitive resources in developing tender evaluation criteria (contractor ability criteria and bid price) and results in the development of a generic model (the multicriteria and multidecision-makers' model) for both government and private sectors. The development of the common set of tender evaluation criteria incorporated physical characteristics of contractors makes an *original* contribution to fill a knowledge gap in tender evaluation.

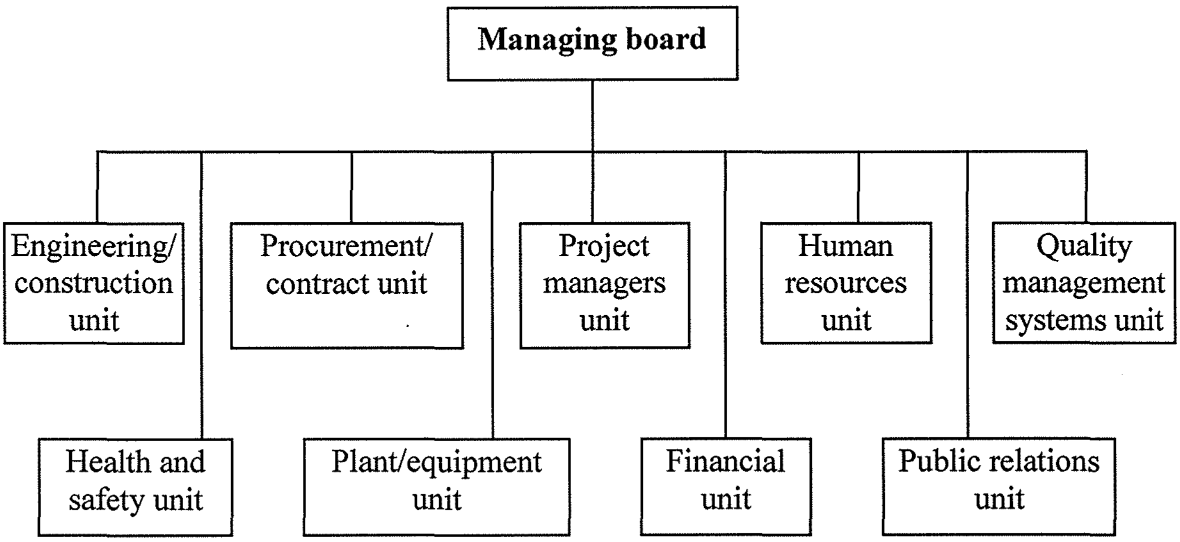


Figure 44 Hierarchical organisational units of a contractor

9.1.1.3 Tender evaluation models

The result showed that weighting models were the most popular in the Thai construction industry. This was followed by utility models, personal judgment and computer programs. However, these models are not similar to what happens in reality (ie, there is no consideration of multiple decision-makers). Thus, the multicriteria and multidecision-makers' model proposed considered the involvement of multiple decision-makers.

9.1.2 The method: utility and social welfare functions

To cope with risk stemming from uncertainty, a utility function was regarded as the best technique in analysing risky solutions. The utility function can incorporate (1) preference of a decision-maker about uncertain consequences in selecting a contractor within any criterion, which affects the value (utility) of the criterion and (2) preference of a decision-maker about the criteria selected, which reflects the weights of relative importance. However, finding a utility function is a difficult task. Thus, an assumption on a *know* utility was made. To be useful, a simple *know* utility function, termed a multiattribute utility function in a *weighted additive* form, was selected. Nevertheless, finding the utility function (a *weighted additive* form) is still difficult. To reduce this difficulty, the research introduced some modification by replacing theoretically determined utility function with a new utility measurement (Section 6.2.1) to suit tender evaluation practitioners. This utility measurement was found to be attractive to decision-makers during the model test.

In addition, percentile of bid price distribution was introduced and used to provide a suggested utility for bid price to decision-makers so as to facilitate the expression of utility (Section 6.4). This suggestion was found to be helpful in reducing the difficulty of expressing utility for bid price during the model test.

Although the utility function has the advantage of including risk in the contractor/tender analyses, it has a limitation in handling multiple decision-makers. To conquer this limitation, a social welfare function was found to be the most attractive in a democratic organisation. A social welfare function aggregates utilities of multiple decision-makers participating in tender evaluation. The main aim of the social welfare function is to search for the best contractor for the whole owner's organisation by aggregating utilities of all decision-makers.

Having examined the utility and social welfare functions, it was found that combining both the functions provided a realistic working method. The method using a combination of both the functions was identified as state-of-the-art (Section 2.4.2.2). This method (Chapter 6), with the new utility measurement developed, provides the capability of simultaneously incorporating risk and multidecision-makers' involvement. However, no existing tender evaluation model has these capabilities. Some include elements of risk and uncertainty but assume only one decision-maker involved. Others consider the involvement of multiple decision-makers but have no consideration of risk and uncertainty. Therefore, this method shows a superiority over all existing tender evaluation models.

9.1.3 The multicriteria and multidecision-makers' model

The multicriteria and multidecision-makers' model proposed (Chapter 7) was broken down into two main steps (step 1: evaluating contractor ability and step 2 evaluating tenders) consisting of three main processes: (1) contractor ability criteria selection process, (2) contractor ability criteria balancing/measuring process, and (3) bid price and contractor ability balancing/measuring process. The model used the method that combines a utility function and a social welfare function as the theoretical framework for its development. As such, the advantages of this method (proposed in Chapter 6) over all existing tender evaluation models are still inherent in the model.

In this model, the theoretical technique of finding a utility function was adjusted for uncomplicated measurement of utility in order to suit tender evaluation practitioners. The process of the measurement is explained by the model to help practitioners articulate utility regarding risk, which leads to a reduction of utility-elicitation effort. A suggested utility for bid price based on percentile of bid price distribution is also provided. This helps decision-makers express utility for bid price. By using the social welfare function, the model can integrate preferences of multiple decision-makers. This integration reflects a reality of this model.

To reduce strain on decision-makers and to adapt to changes, the model incorporated computer interaction in which Microsoft Excel performed data analysis tasks whilst Visual Basic for Application (VBA) was coded for user interaction. VBA's *UserForms*, functioning as the menus driving the tender evaluation process, lead decision-makers (users) to the end of the tender evaluation. As the model is operating, subjective inputs (a statement of preference) are exchanged between the model and decision-makers or provided by decision-makers. For example, in the contractor ability criteria selection process, nine criteria with their weights for evaluating contractor ability are suggested to decision-makers. Then, each decision-maker has three options: (1) accept the criteria and weight, (2) change the weight and (3) change the criteria and weight. Here, subjective inputs are exchanged through selecting one of these options. The last two options provide a flexibility permitting decision-makers to change the weight and/or criteria as required. This flexibility possibly makes the model adaptable for use in any country.

Therefore, this multicriteria and multidecision-makers' model offers users a more realistic working solution that takes into account (1) preferences of multiple decision-makers, (2) elements of risk and uncertainty and (3) a flexibility to absorb changes in preference in relation to a particular situation via computer interaction, which could be used anywhere in the world. The capabilities of the model developed by the writer help to fill another knowledge gap mentioned, which make an *original* contribution to the body of knowledge in tender evaluation.

9.1.4 Model test

To obtain a realistic working product, the model was tested (Chapter 8) for user friendliness, verification, sensitivity analysis, and validation with historical cases in construction practice. It was found that the incorporation of multidecision-makers' preferences, elements of risk and uncertainty and computer interaction is a more rational and realistic approach in solving a tender evaluation problem. Consequently, selecting the best contractor using this model results both in a saving in time and in the selection of a contractor that will perform within time, budget, quality and safety constraints. This in turn reduces the problems such as schedule delays, budget overuse, low quality of work and suffering of the public, which leads to the future growth of owners' organisations.

9.2 Recommendations

9.2.1 Recommendations for further research

The research was performed to contribute to (1) the establishment of a common set of tender evaluation criteria and to (2) the development of a more realistic working model for use in evaluating tenders. Recommendations are developed based on these two contributions as a base.

9.2.1.1 The common set of criteria

The common set of criteria developed based on existing hierarchical organisational units of contractors has been investigated only in the Thai construction industry. Although the result of the investigation does suggest that a commonality of criteria between the government and private sectors exists on this basis (which means types of organisations do not affect the selection of criteria), wider investigations in various countries is still necessary to support this inference, as a *generalisation* process. This wider investigation opens the way for further research. Also, in this investigation, some criteria such as "insurance" and "related entities" may be suggested to respondents for a specific interest.

Then, other factors such as delivery systems and type and size of project may not affect the selection of tender evaluation criteria if the criteria are developed on this basis. The effects of these factors on the selection of criteria also need more investigation.

Moreover, although the common set of criteria is suggested to the construction industry, the quantification of these criteria (including quality of data) has not been developed in this research. This development could be another direction for further research.

9.2.1.2 The multicriteria and multidecision-makers' model

The direction for further research could be as follows:

(i) In this model, the theoretical framework for dealing with multiple decision-makers used a social welfare function as the aggregation tool. The aggregation tool is open to the criticism that persons are interested only in themselves and try to gain the most benefit for their own interests. A solution to deal with such criticism is to combine political prediction tools such as *game theory* into the model.

(ii) For acceptance by tender evaluation practitioners, the model should be formatted in HTML (the World Wide Web language). This format accelerates a social process via the use of the World Wide Web.

(iii) In reality, a decision is unlikely to be made based on the results of a computer program. Similarly, the results of the developed computer model will be fed into the pre-award round of meeting. Although the developed model produces (1) a ranking order of contractors and (2) strengths and weaknesses on each criterion (refer to Figure 41), some additional statistics could be included and then used to identify criteria in which the top three (say) contractors are *significantly different* to each other. Identification of these criteria could serve as a useful focus in the pre-award to confirm differentiation between contractors. This could be particularly important on those criteria with relatively low weighting such as "health and safety" and "financial strength".

(iv) There is a tendency to want to exclude bias; however, it is better to catalogue it and deal rationally with it because it cannot be avoided. If a contractor has a reputation of "bid low then go for extra" resulting in bias to evaluators, this bias should not be excluded from the evaluation. The further developed model could be included *bias inputs* as additional remarks that will be revealed to the other evaluators at the end of the model process. This could be useful feed for the pre-award.

(v) The tender evaluation process potentially has an audit trail, particularly where evaluators change their minds about weighting. Not only can this audit trail serve to demonstrate that due process has been followed, it could be used to investigate and understand (also potentially improve) the tender evaluation process itself where organisations adopt the approach as standard procedure. It may also be possible to develop a subsequent rating for project staff to complete after work. It is quite common in practice for the tender evaluators to have quite a different view of certain contractors compared with the project teams that have to work with them. It would be useful to be able to quantify such differences.

9.2.2 Recommendations for the construction industry

Based on the questionnaire tested with real practitioners and the literature review, different organisations always have different tender evaluation criteria. This leads to repetitive effort in developing the criteria. Hence, a tender evaluation criterion standard is necessary for the world (or at least regional) construction industry to reduce this effort and in turn to improve contractor ability. The tender evaluation criteria developed by this research (corresponding to physical characteristics of contractor organisations) is promising. It is suggested that these criteria should be used and then *standardised.* Once the standard tender evaluation criteria are released, periodical review and then improvement will be performed to maintain their applicability to current society in terms of, eg, technology, environment, politics and economics.

Developed in conjunction with the tender evaluation criteria, the multicriteria and multidecision-makers' model blends multiple decision-makers' preference (representing whole organisation preference), risk stemming from uncertainty and computer interaction into the tender evaluation process. Thus, practitioners should use this model to select the *best* contractor to complete a project within time, cost, quality and safety requirements in order to save time and effort in tender-data analysis.

Appendix A

Some conversion tables

(mapping quantities of criteria into scores)

The Royal Irrigation Department

(after Tharavijitkul, 1990)

Table A1 Conversion table for financial status

Criteria	Score													
	1	2	3	4	5	6	8	9	10	11	12	13	14	15
Nominal capital (MB)	1.25	2.95	4.64	6.34	8.03	9.73	13.12	14.82	16.51	18.21	19.91	21.60	23.29	25.00
Bank credit (MB)	1.00	5.33	9.66	14.00	22.65	26.98	35.64	40.00						
Net worth (MB)	1.00	2.36	3.72	5.07	6.43	7.79	10.50	11.86	13.22	14.57	15.93	17.28	18.64	20.00

Table A2 Conversion table for experience

Criteria	Score													
	1	2	3	4	6	7	8	9	10	11	12	13	14	15
Experience in construction work for 5 years continuously, yrs	2.0	2.5	3.0	3.5	4.5	5.0								
Approximate value of all contracts completed within last 5 yrs, MB	2.5	50	75	100	150	175	200							
Maximum value of contracts completed within last 5 yrs, MB	10	20	30	40	60	70	80	90	100	110	120	130	140	150

Table A3 Conversion table for equipment

Criteria	Score													
	1	2	3	4	5	7	8	9	10	11	12	13	14	15
Cost of equipment (MB)	2.5	3.75	5.00	6.25	7.50	8.75	11.25	12.50	13.75	15.00	16.25	17.50	18.75	20.00

Table A4 Conversion table for personnel

Criteria	Score										
	0.25	0.50	1.00	2.00	3.00	5.00	6.00	7.00	8.00	9.00	10.00
Engineers											
• Number of senior civil engineers					1		2			3	
• Number of associated civil engineers			1	2	3	5	6	7	8	9	10
• Number of junior civil engineers				1			3		4		5
• Number of other engineers		1	2	4							
Technicians											
• Number of technicians having experience less than 5 yrs	1	2	4	8	12	20					
• Number of technicians having experience between 5-10 yrs		1	2	4	6	10					
• Number of technicians having experience greater than 10 yrs			1	2	3	5					

Appendix B1

Questionnaire (English)

Multicriteria and multidecision makers in tender evaluation

Physical Infrastructure Centre
School of Civil Engineering
Queensland University of Technology

This questionnaire survey is conducted in partial fulfillment of PhD research at QUT, and aimed at gathering data on (1) the criteria influencing the selection of a contractor, (2) tender evaluation procedures, and (3) tender evaluation models.

The responses are used only for the study and will be completely confidential. As soon as the study has been finished, the responses will be destroyed. The questionnaire is separated into four parts, and will take around 20-30 minutes to finish.

Please return the completed questionnaire in the <u>pre-paid envelope supplied</u>, before 19 March 2001.

Thank you very much for your time and kind cooperation

A. Some characteristics of you and your organisation

Instruction: Fill your responses in the blank and tick the box of your choice (more than one where appropriate)

1. Please give some personal details, namely:

   1.1 Current position ....

   1.2 Working duration in the position (yrs) ....

   1.3 Current function

   - ☐ Contract preparation
   - ☐ Contractor selection
   - ☐ Tender evaluation
   - ☐ Other..

   1.4 Your educational background

   - ☐ Architect
   - ☐ Quantity surveyor
   - ☐ Civil engineer
   - ☐ Other..

2. Please give some details of your organisation, namely:

   2.1 Sector

   - ☐ Public
   - ☐ State enterprise
   - ☐ Private
   - ☐ Other...................

   2.2 Business

   - ☐ Owner
   - ☐ Consultant
   - ☐ Architect
   - ☐ Project manager
   - ☐ Engineering
   - ☐ Contractor
   - ☐ Other..

   2.3 Type of work and average number of annual contracts

   - ☐ Building works and number..............
   - ☐ Civil works and number.................
   - ☐ Services and number.........................
   - ☐ Maintenance and number...............
   - ☐ Other..

   2.4 Approximate annual contract value (only your sole company) $M..........................

   2.5 Minimum and maximum contract values $M......................to $M.............

B. The criteria influencing the selection of a contractor

Instruction: The following questions seek your attitude or opinion **derived from your experience** to determine the degree of importance of each of the following criteria toward tender evaluation. Please circle only one number on each criterion where:

1 *means* Very low importance or not at all
2 *means* Low importance
3 *means* Medium importance
4 *means* High importance
5 *means* Very high importance.

3. There are criteria important to the success of project requirements. What are the degrees of the importance? And what are other criteria together with their degrees of the importance not written down?

Criteria and measures	**Degree of importance** Very high..............Very low
3.1 Financial strength	
• Are financial ratios important?	5 4 3 2 1
Below are the measures, please indicate the importance that you place on **each** measure by circling **one** number and identify an acceptable range in ☐.	
• Gross profit [= (Sales revenues – Cost of sales)/Sales revenues] What would be an acceptable range? Min ☐ Max ☐	5 4 3 2 1
• Asset turnover ratio [= Sales revenues/(Total liability + Owner's equity)] What would be an acceptable range? Min ☐ Max ☐	5 4 3 2 1
• Financial leverage ratio [= Return on owner's equity/Return on total funds employed] What would be an acceptable range? Min ☐ Max ☐	5 4 3 2 1
• Working capital ratio [= Current assets/Current liabilities] What would be an acceptable range? Min ☐ Max ☐	5 4 3 2 1
• Quick asset ratio [= (Current assets - inventory - prepayments)/(Current liabilities - bank overdraft)] What would be an acceptable range? Min ☐ Max ☐	5 4 3 2 1
• Others, please specify...	5 4 3 2 1

2

Criteria and measures	Degree of importance Very high.............Very low				
• Are banking arrangements important?	5	4	3	2	1
Below are the measures, please indicate the importance that you place on **each** measure by circling **one** number.					
• Current banking organisation	5	4	3	2	1
• Length of time with that bank	5	4	3	2	1
• Backing preparation from the bank	5	4	3	2	1
• A line of credit to the contractor from the bank	5	4	3	2	1
• Interest rate charged by the bank	5	4	3	2	1
• Collateral for security to the bank	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are credit ratings important?	5	4	3	2	1
Below are the measures, please indicate the importance that you place on **each measure** by circling **one** number.					
• Average length of time that the contractor pays subs/suppliers	5	4	3	2	1
• Conditions in bank guarantee	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1
3.2 Quality management systems					
• Is quality system selection important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• AS 3900 series	5	4	3	2	1
• ISO 9000 series	5	4	3	2	1
• Others, please specify..	5	4	3	2	1

3

Criteria and measures	Degree of importance Very high............Very low				
• Is quality system implementation important?	5	4	3	2	1
Below are suggested measures, for each measure please circle **one** number that is closest to your selection.					
• Progressive steps of implementing a quality system (eg, basis, substantial or fully implementation)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are quality system audits important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Documented processes in place ready to address standard elements	5	4	3	2	1
• Documented processes being followed by the contractor	5	4	3	2	1
• Documented processes being effective and suitable	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1
3.3 Human resources					
• Is personnel planning important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• A personnel chart (showing personnel demands and supplies of a contractor along with time horizon)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1

4

Criteria and measures	Degree of importance Very high				Very low
• Is personnel development important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• In-house training	5	4	3	2	1
• Supervisor coaching	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Is personnel maintenance (keeping high-talent personnel) important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Competitive incomes/welfare	5	4	3	2	1
• Social reputation of contractor	5	4	3	2	1
• Promotion	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify...	5	4	3	2	1
3.4 Public relations					
• Is performance important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Past performance (including meeting time, budget and quality requirements, having intention of chasing claims; having payments to suppliers and subcontractors; and having fraud scandals)	5	4	3	2	1
• Current performance (including conflicts with union and within the contractor company; and any current litigating cases)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1

Criteria and measures	Degree of importance Very high............Very low				
• Is health and safety important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Health and safety plan (including health and safety policy statement, safety training, workplace rules, accident recording and reporting and emergency preparations)	5	4	3	2	1
• Health and safety control (including frequency of safety training, site safety meetings and inspections)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1
3.5 Procurement/contract					
• Are procurement plans important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Material schedule	5	4	3	2	1
• Subcontract schedule	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Is delivery control important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Warehouse procedures (to prevent materials from being damaged and lost)	5	4	3	2	1
• Distribution procedures (to keep records of the quantities used)	5	4	3	2	1
• Receipt of goods (to verify the quality and quantity delivered)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1

Criteria and measures	Degree of importance Very high.............Very low				
• Is subcontractor control important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• General conditions of subcontracts (including subcontractors' rights and responsibilities, variations to subcontract work, method and time for payments, retention money, and dispute procedures)	5	4	3	2	1
• Special conditions of subcontracts (including the time allowed for execution of subcontracts, damages payable for the late completion and special restrictions on subcontractors)	5	4	3	2	1
• Interaction between the contractor and subcontractors (including work, services and facilities provided and charged by the contractor)	5	4	3	2	1
• Methods of reviewing drawings and change orders (including participants and time of notifications to participants)	5	4	3	2	1
• Communication lines (including the way that subcontractors knows when needed on the project and site meetings for subcontractors)	5	4	3	2	1
• *Power leverages* look at the way that the contractor deals with extra work done by subcontractors and the way that the contractor deals with his/her or others' mistakes affecting subcontractors' cost	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1
3.6 Plant/equipment					
• Is plant/equipment acquisition important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• a list of plant/equipment (showing numbers and condition)	5	4	3	2	1
• a plan of renting or leasing plant/equipment	5	4	3	2	1
• Others, please specify..	5	4	3	2	1

Criteria and measures	Degree of importance Very high............Very low				
• Is plant/equipment maintenance important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Programmed maintenance (including regular schedule of inspection/repair or replacement of plant/equipment)	5	4	3	2	1
• Spare parts stocking (involving inventory to prevent the shortage and non-timing delivery of the spare parts)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1
3.7 Engineering/construction					
• Is project planning important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Master plans (including main activities, milestones, and main required resources for the whole period of a project)	5	4	3	2	1
• Detailed plans (including operating tasks in details for monthly, weekly, and daily tasks)	5	4	3	2	1
• Resource plans (including manpower plans, material plans and plant/equipment plans)	5	4	3	2	1
• Budgeting (including cash inflow and outflow of a project such as *S curves*)	5	4	3	2	1
• Contingency plans (including "what-if" plans)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1

Criteria and measures	Degree of importance Very high.............Very low				
• Is project execution important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Communication of the plans to involved people (including tables, pictures and diagrams)	5	4	3	2	1
• Technical ability (by considering length of experience, complexity and scale of projects done, type of projects done and in-house knowledge/technology currently used)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Is project monitoring important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Continuously reporting (including daily, weekly and monthly reports)	5	4	3	2	1
• Analysed reporting (including comparison between planned and executed S curves)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Is the ability to adjust a project important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Weekly actions (eg. to solve current problem)	5	4	3	2	1
• Monthly actions (eg. to accelerate project execution by using overtime)	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1

Criteria and measures	Degree of importance Very high.............Very low				
3.8 Project managers					
• Is project management experience important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Problem solving skills (including allocating project resource requirements, surviving company constraints, and managing risk associated with projects)	5	4	3	2	1
• Management of conflict (including the balance between the jurisdiction of functional departments and that of projects and developing contingency plans with and without consultation of functional department managers)	5	4	3	2	1
• Previous and current position (including acceptance by functional departments including creditability, social status and authority)	5	4	3	2	1
• Others, please specify...	5	4	3	2	1
• Are communication skills important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Observation skills (including actively listening, reading and organising messages)	5	4	3	2	1
• Analysis skills (including separating between the relevant and related information to solve a particular problem)	5	4	3	2	1
• Persuasive skills (including selecting an effective presentation method and the right time to suitable personnel)	5	4	3	2	1
• Others, please specify...	5	4	3	2	1

Criteria and measures	Degree of importance Very high.............Very low				
• Is adaptability important?	5	4	3	2	1
Below are the measures, for each measure please circle **one** number that is closest to your selection.					
• Tolerance for ambiguity and changes	5	4	3	2	1
• Balance ability between conserving and challenging traditional operations or behaviours	5	4	3	2	1
• Others, please specify..	5	4	3	2	1
• Are there any others? Please specify..	5	4	3	2	1

C. Tender evaluation procedures

Instruction: Tick the box of your choice (more than one where appropriate)

4. Which of the following procedures do you use for tender evaluation?

Procedures	**How to make a short list?**
☐ Selective tendering	☐ With prequalification (if you tick this box, answer question 6.1) ☐ Without prequalification (if you tick this box, answer question 6.2)
☐ Open tendering	(if you tick this box, answer question 6.3)
☐ Negotiated tendering	

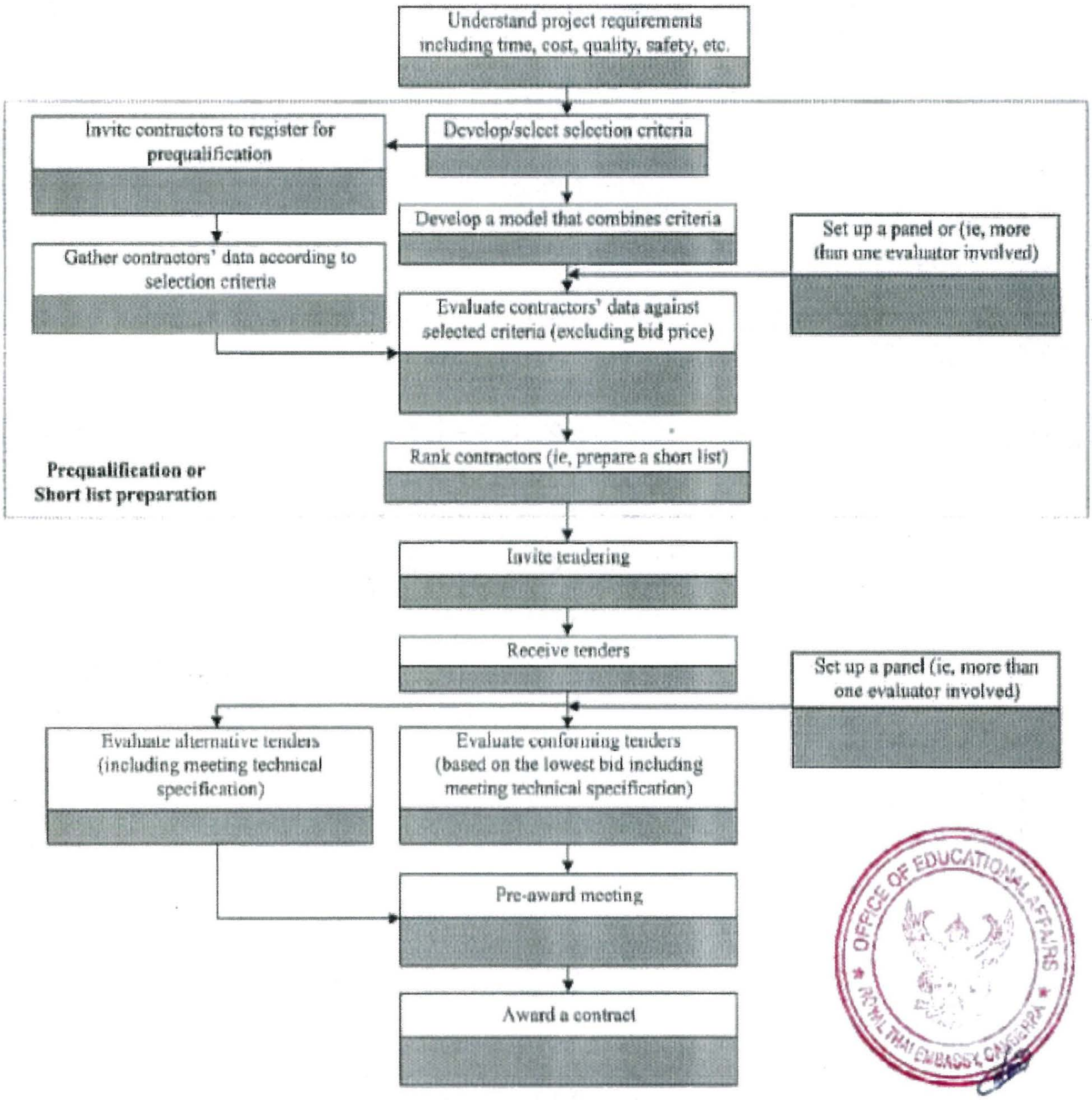
5. How many people are involved in evaluating contractors in your company?

☐ One ☐ More than one ☐ Don' t know

6. The following procedures are shown as flow diagrams:

Within the diagrams, each block represents a step of the tendering process. If you do not agree with any step of the process, please change it, override it or show by a freehand sketch the modification you believe applicable.

6.1 If you agree with each step, leave the shaded area empty. If not, then please modify as required.



A proposed selective tendering process with prequalification

Please comment, if needed: ....

....

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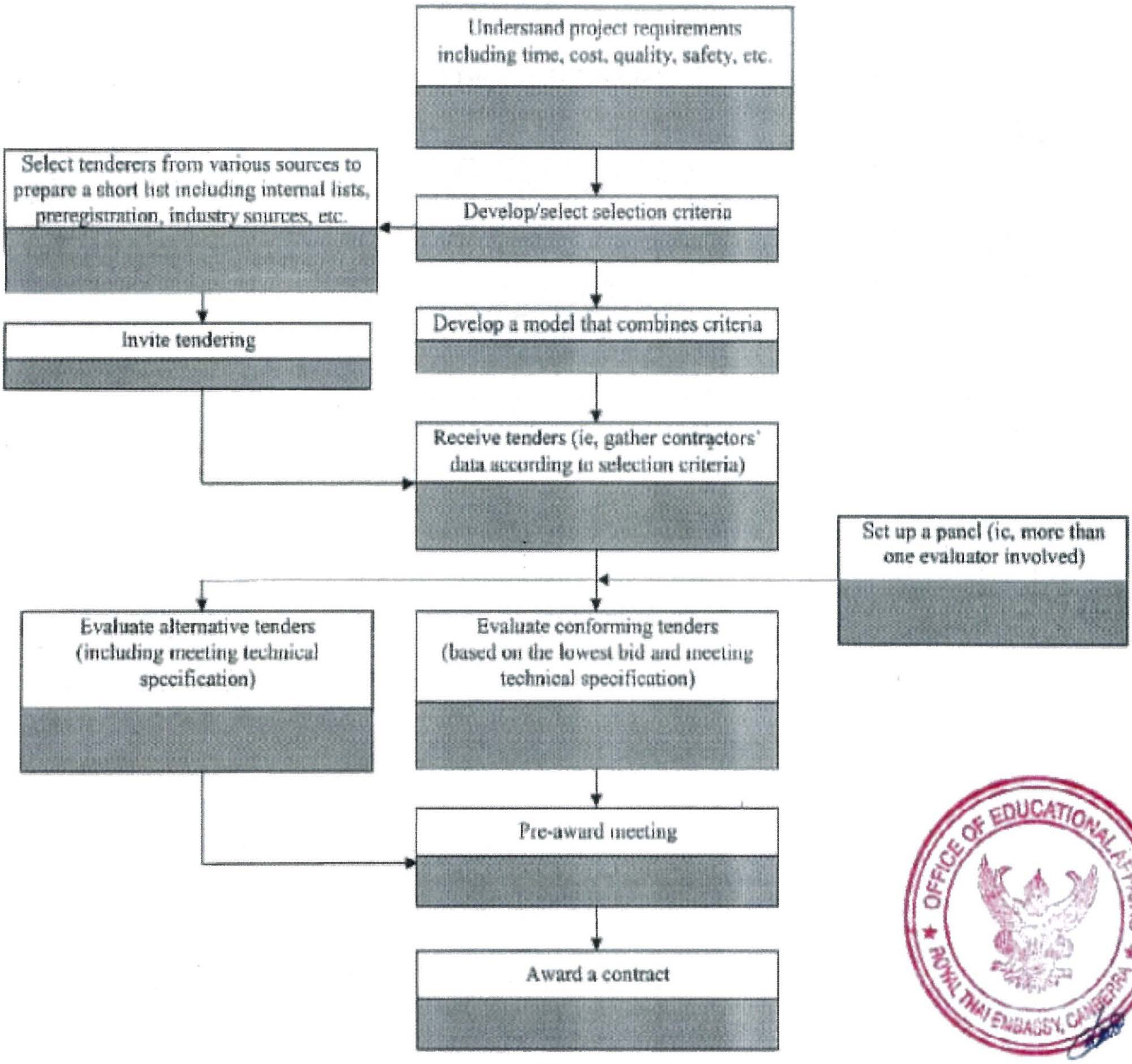
6.2 If you agree with each step, leave the shaded area empty. If not, then please modify as required.



A proposed selective tendering process without prequalification

Please comment, if needed: ....

....

....

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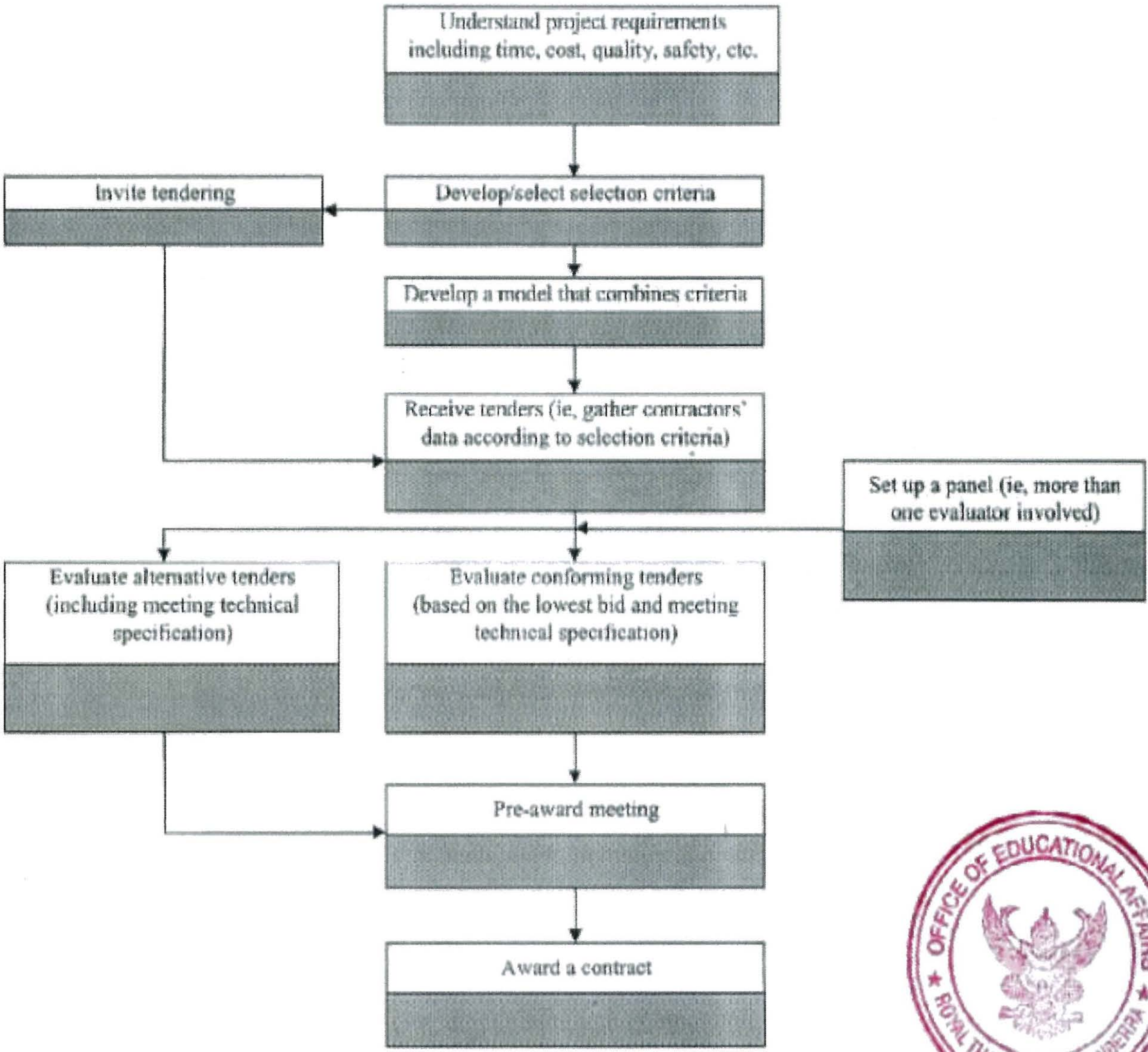
6.3 If you agree with each step, leave the shaded area empty. If not, then please modify as required.



A proposed open tendering process

Please comment, if needed: ....

....

....

15

D. Tender evaluation models

Instruction: Please tick the box of your choice (more than one where appropriate)

7. Which of the following models/equations do you use for evaluating contractors?

☐ Personal judgment

☐ Weighting models, like

Overall score = A summation of all of (weight × score of each criterion)

Score is the quantity of a criterion of a contractor, which has no element of risk and uncertainty.

☐ Utility models, like

Overall utility = A summation of all of (weight × utility of each criterion)

Utility is the preference (representing a quantity) of the decision maker for a criterion of a contractor, which includes his/her attitude toward risk and uncertainty.

☐ Computer programs, like

Expert systems or Artificial Neural Networks

☐ Others, please specify...
....
....
....

16

Appendix B2

Questionnaire (Thai)

Multicriteria and multidecision makers in tender evaluation

Physical Infrastructure Centre

School of Civil Engineering

Queensland University of Technology

แบบสอบถามเป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาเอก ณ QUT ซึ่งมีจุดประสงค์เพื่อเก็บข้อมูลเกี่ยวกับ (1) ปัจจัยที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา, (2) กระบวนการคัดเลือกผู้รับเหมา และ (3) แบบจำลองที่ใช้คัดเลือกผู้รับเหมา

ข้อมูลที่ได้จากแบบสอบถามจะถูกใช้เพื่อการศึกษาเท่านั้น และจะถูกเก็บไว้เป็นความลับ ไม่มีทางเป็นไปได้ที่จะระบุหรืออ้างถึงท่าน ผู้ตอบแบบสอบถามได้เลย หลังจากที่การศึกษาครั้งนี้เสร็จสิ้นลง ข้อมูลที่ได้จากท่านจะถูกทำลายทิ้งทันที การตอบแบบสอบถามนี้แบ่งเป็น 4 ส่วนใช้เวลาประมาณ 20-30 นาที

กรุณา ใส่แบบสอบถามในซองที่แนบมาด้วย ซึ่งได้ติดแสตมป์ไว้แล้ว และส่งคืนภายในวันที่ 19 มีนาคม 2544

ขอบพระคุณอย่างสูงในการตอบแบบสอบถามของท่าน

ก. คุณสมบัติของท่านและองค์กร

คำแนะนำการตอบ: กรุณาเติมคำในช่องว่างและเขียน ✓ ใน ☐ ตามความเป็นจริง **(อาจเขียน✓ มากกว่า 1 แห่ง ถ้าเหมาะสม)**

1. ขอทราบคุณสมบัติของท่านดังนี้

   1.1 ตำแหน่งปัจจุบัน ....

   1.2 ระยะเวลาที่ดำรงตำแหน่งปัจจุบัน ....

   1.3 หน้าที่ปัจจุบันของท่านเกี่ยวข้องกับ

   ☐ เตรียมเอกสารสัญญา ☐ จัดการเรื่องการประมูลงาน
   ☐ คัดเลือกผู้รับเหมา ☐ อื่นๆ..

   1.4 คุณวุฒิหรือสาขาการศึกษา

   ☐ สถาปนิก ☐ วิศวกรโยธา
   ☐ ผู้สำรวจปริมาณ ☐ อื่นๆ..

2. ขอทราบคุณสมบัติขององค์กรของท่านดังนี้

   2.1 ประเภทขององค์กร

   ☐ ราชการ ☐ รัฐวิสาหกิจ ☐ เอกชน ☐ อื่นๆ..

   2.2 ประเภทของธุรกิจขององค์การ

   ☐ เจ้าของ ☐ ที่ปรึกษา ☐ สถาปัตย์
   ☐ ผู้บริหารโครงการ ☐ วิศวกรรม ☐ ผู้รับเหมา
   ☐ อื่นๆ..

   2.3 ลักษณะของงานและจำนวนโดยเฉลี่ยของงานนั้นๆต่อปี

   ☐ อาคาร จำนวน.............................. ☐ งานโยธา จำนวน..............................
   ☐ งานบริการ จำนวน.............................. ☐ งานซ่อมบำรุง จำนวน..............................
   ☐ อื่นๆ..

   2.4 มูลค่าโดยประมาณของงานที่องค์กรท่านทำต่อปี (เฉพาะของบริษัทท่าน) ....ล้านบาท

   2.5 มูลค่าต่ำสุดและสูงสุดที่องค์กรท่านทำ .... ล้านบาท ถึง............................ ล้านบาท

1

ข. ปัจจัยต่างๆ ที่มีอิทธิพลต่อการคัดเลือกผู้รับเหมา

คำแนะนำการตอบ: เพื่อแสดงถึงทัศนคติหรือความคิดเห็นที่ เกิดจากประสบการณ์ของท่านที่มีต่อปัจจัยต่างๆที่มีผลกระทบต่อการคัดเลือกผู้รับเหมา กรุณาเขียนวงกลมรอบตัวเลข 1-5 ที่กำหนดให้เพียงหนึ่งตัวต่อหนึ่งปัจจัยและตัววัด โดยตัวเลขนี้หมายถึง

1 หมายถึง ระดับผลกระทบของปัจจัยนั้นต่ำมาก หรือไม่มีผลกระทบเลย
2 หมายถึง ระดับผลกระทบของปัจจัยนั้นต่ำ ต่อการคัดเลือกผู้รับเหมา
3 หมายถึง ระดับผลกระทบของปัจจัยนั้นปานกลาง ต่อการคัดเลือกผู้รับเหมา
4 หมายถึง ระดับผลกระทบของปัจจัยนั้นสูง ต่อการคัดเลือกผู้รับเหมา
5 หมายถึง ระดับผลกระทบของปัจจัยนั้นสูงมาก ต่อการคัดเลือกผู้รับเหมา

3. มีปัจจัยต่างๆ และตัววัด ดังแสดงข้างล่าง ขอทราบระดับของความสำคัญของปัจจัยและตัววัดเหล่านี้ที่มีต่อการคัดเลือกผู้รับเหมาของหน่วยงานของท่าน? และขอทราบปัจจัยและตัววัดอื่นๆที่ไม่ได้แสดงไว้ แต่ท่านคิดว่ามีความสำคัญต่อการคัดเลือกผู้รับเหมาของหน่วยงานของท่าน?

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	**ระดับของความสำคัญ** สูงมาก.......................ต่ำมาก
3.1 ความเข้มแข็งทางการเงิน	
• อัตราส่วนทางการเงิน	5 4 3 2 1
สิ่งที่แสดงข้างล่างคือ ตัววัด โปรดระบุระดับความสำคัญที่ท่านให้ต่อแต่ละตัววัดนี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด และถ้าเป็นไปได้ช่วยระบุช่วงของตัววัดเหล่านี้ใน ☐	
• อัตราส่วนกำไรทั้งหมด [= (รายได้จากการขาย – รายจ่ายจากการขาย)/รายได้จากการขาย] ช่วงที่ท่านสามารถยอมรับได้? ค่าน้อย ☐ ค่ามาก ☐	5 4 3 2 1
• อัตราการหมุนเวียนของทรัพย์สินรวม [= รายได้จากการขาย/(หนี้สินทั้งหมด + ส่วนของผู้ถือหุ้น)] ช่วงที่ท่านสามารถยอมรับได้? ค่าน้อย ☐ ค่ามาก ☐	5 4 3 2 1

2

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก......................ต่ำมาก
• อัตราส่วนความสามารถในการก่อหนี้ [= ผลตอบแทนต่อผู้ถือหุ้น / ผลตอบแทนต่อเงินลงทุนทั้งหมด] ช่วงที่ท่านสามารถยอมรับได้? ค่าน้อย [ ] ค่ามาก [ ]	5 4 3 2 1
• อัตราส่วนเงินทุนหมุนเวียน [= สินทรัพย์หมุนเวียน/หนี้สินหมุนเวียน] ช่วงที่ท่านสามารถยอมรับได้? ค่าน้อย [ ] ค่ามาก [ ]	5 4 3 2 1
• อัตราส่วนเงินทุนหมุนเวียนเร็ว [= (สินทรัพย์หมุนเวียน - สินค้าคงเหลือ - เงินจ่ายล่วงหน้า)/ (หนี้สินหมุนเวียน หนี้สินต่อธนาคาร)] ช่วงที่ท่านสามารถยอมรับได้? ค่าน้อย [ ] ค่ามาก [ ]	5 4 3 2 1
• อื่นๆ โปรดระบุ	5 4 3 2 1
• การเตรียมการเกี่ยวกับธนาคาร	5 4 3 2 1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด	
• ธนาคารที่ใช้บริการปัจจุบัน	5 4 3 2 1
• ระยะเวลาที่ใช้บริการกับธนาคารนั้นๆ	5 4 3 2 1
• การเตรียมการสนับสนุนจากธนาคารนั้น	5 4 3 2 1
• เครดิตที่ธนาคารนั้นให้กับผู้รับเหมา	5 4 3 2 1
• อัตราดอกเบี้ยที่ธนาคารนั้นคิดต่อผู้รับเหมา	5 4 3 2 1
• ทรัพย์สินที่ใช้ค้ำประกันกับธนาคารนั้น	5 4 3 2 1
• อื่นๆ โปรดระบุ..	5 4 3 2 1

3

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก......................ต่ำมาก				
• ระดับความน่าเชื่อถือ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• ระยะเวลาโดยเฉลี่ยที่ผู้รับเหมาจ่ายเงินต่อผู้รับเหมารายย่อย หรือผู้ขายวัสดุอุปกรณ์ก่อสร้าง	5	4	3	2	1
• เงื่อนไขต่างๆในใบค้ำประกันจากธนาคาร	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5	4	3	2	1
3.2 ระบบการบริหารคุณภาพ					
• การเลือกระบบคุณภาพ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• AS 3900 series	5	4	3	2	1
• ISO 9000 series	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก........................ต่ำมาก				
• การนำระบบคุณภาพไปปฏิบัติงานจริง	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• ระดับขั้นของการปฏิบัติระบบคุณภาพ (ตัวอย่างเช่น เบื้องต้น, ปานกลาง และปฏิบัติเต็มระบบคุณภาพ)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• ระบบการตรวจสอบคุณภาพ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• กระบวนการด้านเอกสารพร้อมที่จะปฏิบัติตามขั้นตอนมาตรฐานของระบบคุณภาพ	5	4	3	2	1
• กระบวนการด้านเอกสารต้องถูกปฏิบัติโดยผู้รับเหมา	5	4	3	2	1
• ความมีประสิทธิภาพและความเหมาะสมของกระบวนการด้านเอกสาร	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5	4	3	2	1

ปัจจัยและตัวชี้วัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.....................ต่ำมาก				
3.3 ทรัพยากรบุคคล					
• การวางแผนบุคคล	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• แผนผังบุคลากร (แสดงความต้องการด้านบุคคลและการวางแผนในการสรรหาบุคลากรของผู้รับเหมา)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• การพัฒนาบุคลากร	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การอบรมบุคลากรภายในองค์กรของผู้รับเหมา	5	4	3	2	1
• การสอนงานจากผู้มีประสบการณ์	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• การสงวนรักษาบุคลากร	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• รายได้และสวัสดิการที่เหมาะสม	5	4	3	2	1

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ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.........................ต่ำมาก
• ชื่อเสียงทางสังคมที่ถูกยอมรับของผู้รับเหมา • การส่งเสริมเลื่อนขั้นหรือค่าตอบแทน • อื่นๆ โปรดระบุ..	5 4 3 2 1 5 4 3 2 1 5 4 3 2 1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5 4 3 2 1
3.4 ความสัมพันธ์ต่อสาธารณะชน	
• ผลของการดำเนินงาน สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด • ผลของการดำเนินงานในอดีต (ตัวอย่างเช่น การทำงานเสร็จตามเวลา, งบประมาณ และคุณภาพที่ต้องการ, มีความตั้งใจที่หาเงินจากการเรียกร้องสิทธิ์ (Claims), หนี้สินต่อผู้รับเหมารายย่อยหรือผู้ขายวัสดุอุปกรณ์, มีเรื่องราวเกี่ยวกับการคดโกง) • ผลของการดำเนินงานในปัจจุบัน (ตัวอย่างเช่น มีกรณีฟ้องร้องที่ยังไม่จบอยู่ และผลการปฏิบัติงานปัจจุบันที่กระทบกับสิ่งแวดล้อม) • อื่นๆ โปรดระบุ..	5 4 3 2 1 5 4 3 2 1 5 4 3 2 1 5 4 3 2 1

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.......................ต่ำมาก				
• สุขภาพและความปลอดภัย	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด ไปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การวางแผนด้านสุขภาพและความปลอดภัย (ตัวอย่างเช่น นโยบายเกี่ยวกับสุขภาพและความปลอดภัย, การอบรมเรื่องความปลอดภัย, กฎในการปฏิบัติงาน, การบันทึกและรายงานเกี่ยวกับอุบัติเหตุ, และการเตรียมการเพื่อเหตุฉุกเฉิน)	5	4	3	2	1
• การควบคุมสุขภาพและความปลอดภัย (ตัวอย่างเช่น ความถี่ของการการอบรมเรื่องความปลอดภัย, การประชุมและการตรวจสอบความปลอดภัยในบริเวณก่อสร้าง)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5	4	3	2	1
3.5 การจัดซื้อวัสดุอุปกรณ์และการทำสัญญา					
• การวางแผนการจัดซื้อ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การวางแผนวัสดุ	5	4	3	2	1
• การวางแผนผู้รับเหมารายย่อย	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก	....	....	....	ต่ำมาก
• การควบคุมและการตรวจรับวัสดุอุปกรณ์	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• โรงจัดเก็บวัสดุและอุปกรณ์ก่อสร้าง (เพื่อป้องกันการแตกหักและสูญหายของวัสดุและอุปกรณ์)	5	4	3	2	1
• กระบวนการใช้วัสดุและอุปกรณ์ (เพื่อจัดเก็บและบันทึกปริมาณที่ถูกใช้)	5	4	3	2	1
• การตรวจรับวัสดุอุปกรณ์ (เพื่อตรวจสอบคุณภาพและปริมาณของวัสดุและอุปกรณ์สำหรับงานก่อสร้าง)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• การควบคุมผู้รับเหมารายย่อย	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• เงื่อนไขทั่วไปของสัญญาก่อสร้างรายย่อย (ตัวอย่างเช่น สิทธิและความรับผิดชอบของผู้รับเหมารายย่อย, งานเพิ่ม/ลด สำหรับผู้รับเหมารายย่อย, วิธีการและช่วงเวลาการจ่ายเงิน, เงินประกันผลงาน, กระบวนการแก้ไขข้อขัดแย้ง)	5	4	3	2	1
• เงื่อนไขพิเศษของสัญญาก่อสร้างรายย่อย (ตัวอย่างเช่น เวลาที่ยอมให้ผู้รับเหมารายย่อยทำงาน, ความเสียหายที่ต้องจ่ายโดยผู้รับเหมารายย่อย, และข้อจำกัดพิเศษต่อผู้รับเหมารายย่อย)	5	4	3	2	1
• ความสัมพันธ์ระหว่างผู้รับเหมากับผู้รับเหมารายย่อย (ตัวอย่างเช่น งานบริการและอุปกรณ์ที่จะหาให้และคิดเงินโดยผู้รับเหมา)	5	4	3	2	1

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.......................ต่ำมาก
• วิธีการปรับแก้แบบรูปและความต้องการของเจ้าของ (ตัวอย่างเช่น เวลาที่แจ้งให้ผู้มีส่วนเกี่ยวข้องทราบ และผู้เกี่ยวข้องควรจะเป็นใครบ้าง)	5 4 3 2 1
• สายการสื่อสาร (ตัวอย่างเช่น วิธีการที่ใช้แจ้งให้ผู้รับเหมาทราบเมื่อเขาถูกต้องการในงานก่อสร้าง และการประชุมสำหรับผู้รับเหมารายย่อย)	5 4 3 2 1
• การใช้อำนาจที่เหนือกว่า (ตัวอย่างเช่น การให้ผู้รับเหมารายย่อยทำงานเพิ่มพิเศษ และวิธีการแก้ไขปัญหาที่เกิดจากความผิดพลาดของผู้รับเหมาหลักที่มีผลกระทบต่อค่าใช้จ่ายของผู้รับเหมารายย่อย)	5 4 3 2 1
• อื่นๆ โปรดระบุ..	5 4 3 2 1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ...	5 4 3 2 1
3.6 เครื่องจักรและเครื่องมือก่อสร้าง	
• กระบวนการได้มาของเครื่องจักรและเครื่องมือก่อสร้าง	5 4 3 2 1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด	
• รายการเครื่องจักรและเครื่องมือก่อสร้าง	5 4 3 2 1
• แผนของการเช่า เช่าซื้อ เครื่องจักรและเครื่องมือก่อสร้าง	5 4 3 2 1
• อื่นๆ โปรดระบุ..	5 4 3 2 1

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ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก......................ต่ำมาก				
• การบำรุงรักษาเครื่องจักรและเครื่องมือก่อสร้าง	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การวางแผนการซ่อมบำรุง (ตัวอย่างเช่น ตารางเช็คซ่อมแซม หรือเปลี่ยนเครื่องจักรและเครื่องมือก่อสร้าง)	5	4	3	2	1
• การสำรองอะไหล่ (เพื่อป้องกันการขาดแคลนและการส่งอะไหล่ที่สำคัญไม่ตรงเวลา)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5	4	3	2	1
3.7 วิศวกรรมและการก่อสร้าง					
• การวางแผนโครงการ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• แผนงานหลัก/แม่บท (ตัวอย่างเช่น กิจกรรมหลัก, จุดวิกฤตของโครงการ, และทรัพยากรหลักที่สำคัญสำหรับตลอดช่วงอายุของโครงการ)	5	4	3	2	1
• แผนรายละเอียด (ตัวอย่างเช่น แผนปฏิบัติงานรายเดือน, รายสัปดาห์, รายวัน)	5	4	3	2	1
• แผนทรัพยากร (ตัวอย่างเช่น แผนกำลังคน, แผนวัสดุ และแผนเครื่องจักรและอุปกรณ์ก่อสร้าง)	5	4	3	2	1

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ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.......................ต่ำมาก				
• แผนงบประมาณ (ตัวอย่างเช่น แผนการหมุนเวียนของการเงินเข้าและออกของโครงการ เช่น S-Curve)	5	4	3	2	1
• แผนเผื่อความไม่แน่นอน (ตัวอย่างเช่น "จะทำอะไร - ถ้าเกิด")	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• การดำเนินโครงการ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การถ่ายทอดแผนต่างๆ ไปสู่ผู้ปฏิบัติเกี่ยวข้อง (ตัวอย่างเช่น การใช้ตาราง, ภาพ และแผนภาพ)	5	4	3	2	1
• ความสามารถทางเทคนิค (โดยพิจารณาประสบการณ์, ความซับซ้อน และขนาดของโครงการที่เคยทำมา, ประเภทของโครงการที่ทำ, และความรู้และเทคโนโลยีที่ใช้ในปัจจุบัน)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• การติดตามและควบคุมโครงการ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การทำรายงานอย่างต่อเนื่อง (ตัวอย่างเช่น รายงานประจำวัน ประจำสัปดาห์, และประจำเดือน)	5	4	3	2	1

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ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.......................ต่ำมาก				
• การทำรายงานเปรียบเทียบ (ตัวอย่างเช่น การเปรียบเทียบแผนและการปฏิบัติจริงบน S-Curve)	5	4	3	2	1
• อื่นๆ โปรดระบุ	5	4	3	2	1
• การปรับแก้การปฏิบัติงานโครงการ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• การปรับปรุงการปฏิบัติรายสัปดาห์ (ตัวอย่างเช่น เพื่อแก้ปัญหาต่างๆ)	5	4	3	2	1
• การปรับปรุงการปฏิบัติรายเดือน (ตัวอย่างเช่น เพื่อเร่งการปฏิบัติงานโดยทำงานนอกเวลา)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5	4	3	2	1
3.8 ผู้จัดการโครงการ					
• ประสบการณ์ของผู้จัดการโครงการ	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• ทักษะในการแก้ปัญหา (ตัวอย่างเช่น การกระจายทรัพยากรในโครงการ, การจัดการภายใต้ข้อจำกัดขององค์กร, และการบริหารความเสี่ยงของโครงการ)	5	4	3	2	1

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รับเหมา	ระดับของความสำคัญ สูงมาก.......................ต่ำมาก				
• การจัดการความขัดแย้ง (ตัวอย่างเช่น ความสมดุลของขอบเขตอำนาจระหว่างแผนกตามหน้าที่และโครงการ และการพัฒนาแผนความไม่แน่นอนโดยการปรึกษาหรือไม่ปรึกษากับหัวหน้าแผนกตามหน้าที่)	5	4	3	2	1
• ตำแหน่งปัจจุบันและตำแหน่งก่อนปัจจุบัน (เพื่อประโยชน์ของการยอมรับจากหัวหน้าแผนกตามหน้าที่ เช่น สถานภาพทางสังคม และความน่าเชื่อถือ)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• ทักษะการสื่อสาร	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อแต่ละตัววัดเหล่านี้ โดยการวงกลมรอบตัวเลขเพียง 1 ตัว สำหรับแต่ละตัววัด					
• ทักษะการสังเกต (ตัวอย่างเช่น ความกระตือรือร้นในการฟัง, อ่าน และการจัดระบบข้อมูล)	5	4	3	2	1
• ทักษะการวิเคราะห์ (ตัวอย่างเช่น ความสามารถในการแยกแยะข้อมูลที่เกี่ยวข้องและไม่เกี่ยวข้องในการแก้ปัญหาขั้นหนึ่ง)	5	4	3	2	1
• ทักษะในการชักนำหรือโน้มน้าว (ตัวอย่างเช่น การเลือกวิธีการและจังหวะเวลาของการนำเสนอที่เหมาะสมต่อกลุ่มบุคคล)	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1

ปัจจัยและตัววัด ที่มีความสำคัญต่อการคัดเลือกผู้รำแหนา	**ระดับของความสำคัญ** สูงมาก.......................ต่ำมาก				
• ความสามารถในการปรับตัว	5	4	3	2	1
สิ่งที่แสดงข้างล่างคือตัววัด โปรดระบุความสำคัญที่ท่านให้ต่อ**แต่ละตัววัดเหล่านี้** โดยการวงกลมรอบตัวเลขเพียง 1 **ตัว** สำหรับแต่ละตัววัด					
• ความอดทนต่อความคลุมเครือและการเปลี่ยนแปลงของโครงการ	5	4	3	2	1
• ความสามารถในการทำให้สมดุลระหว่างการปฏิบัติงานแบบเก่าดั้งเดิมกับการปฏิบัติงานแบบสมัยใหม่ซึ่งท้าทาย	5	4	3	2	1
• อื่นๆ โปรดระบุ..	5	4	3	2	1
• มีปัจจัยอื่นอีกไหม? โปรดระบุ..	5	4	3	2	1

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ค. กระบวนการคัดเลือกผู้รับเหมา

คำแนะนำการตอบ: กรุณาเขียน √ ใน ☐ ตามความเป็นจริง **(อาจเขียน√ มากกว่า 1 แห่งถ้าเหมาะสม)**

4 วิธีการใดตามข้างล่างที่ท่านใช้ในการคัดเลือกผู้รับเหมา

วิธีการ	วิธีการใดที่ใช้ในการคัดเลือกเบื้องต้น ?
☐ มีการคัดเลือกผู้รับเหมาเบื้องต้น เพื่อลดจำนวนผู้เข้าประมูลงาน	☐ ทำการตรวจสอบคุณสมบัติเบื้องต้นของผู้รับเหมา (prequalification) (ถ้าท่านเลือกข้อนี้กรุณาตอบคำถามข้อ 6.1) ☐ คัดเลือกผู้รับเหมาที่ลงทะเบียน (ตามลำดับชั้น) ไว้กับองค์กร (ถ้าท่านเลือกข้อนี้กรุณาตอบคำถามข้อ 6.2)
☐ การเปิดประมูลทั่วไปโดยไม่มีการคัดเลือกผู้รับเหมาเบื้องต้น (ถ้าท่านเลือกข้อนี้กรุณาตอบคำถามข้อ 6.3)	
☐ เจรจาต่อรอง	

5. ในองค์กรของท่านมีผู้เกี่ยวข้องกี่คนในการคัดเลือกผู้รับเหมา?

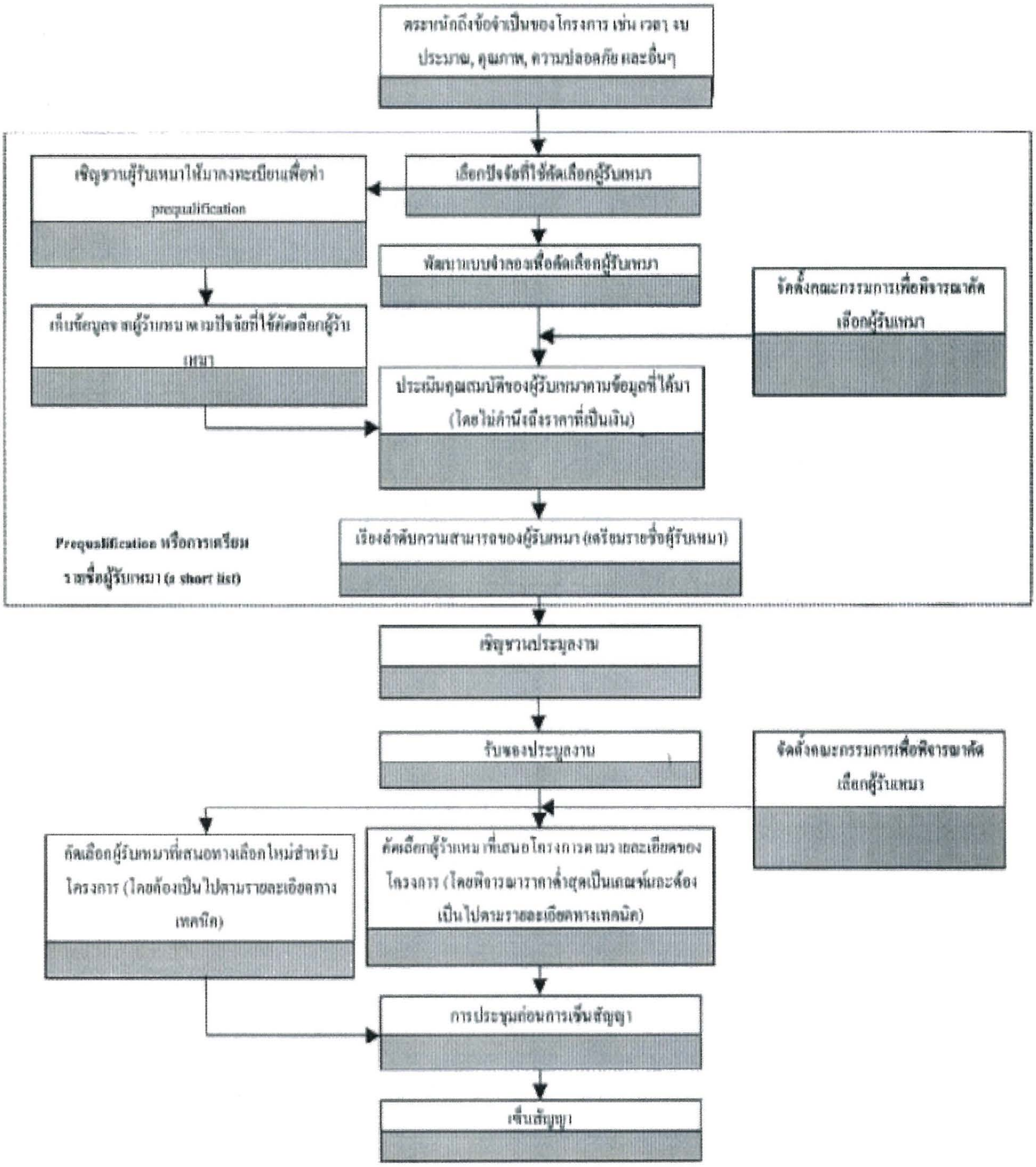
☐ คนเดียว ☐ มากกว่า 1 คน (เช่นคณะกรรมการ) ☐ ไม่ทราบ

6. กระบวนการคัดเลือกผู้รับเหมาแต่ละวิธีแสดงเป็นแผนภาพต่อไปนี้

ในแต่ละแผนภาพ แต่ละสี่เหลี่ยมแสดงขั้นตอนของการคัดเลือกผู้รับเหมา ถ้าท่านไม่เห็นด้วยในขั้นตอนใด กรุณา

- แก้ไข
- เขียนทับใหม่ หรือ
- เขียนสเกตช์แผนภาพใหม่ตามความเป็นจริง

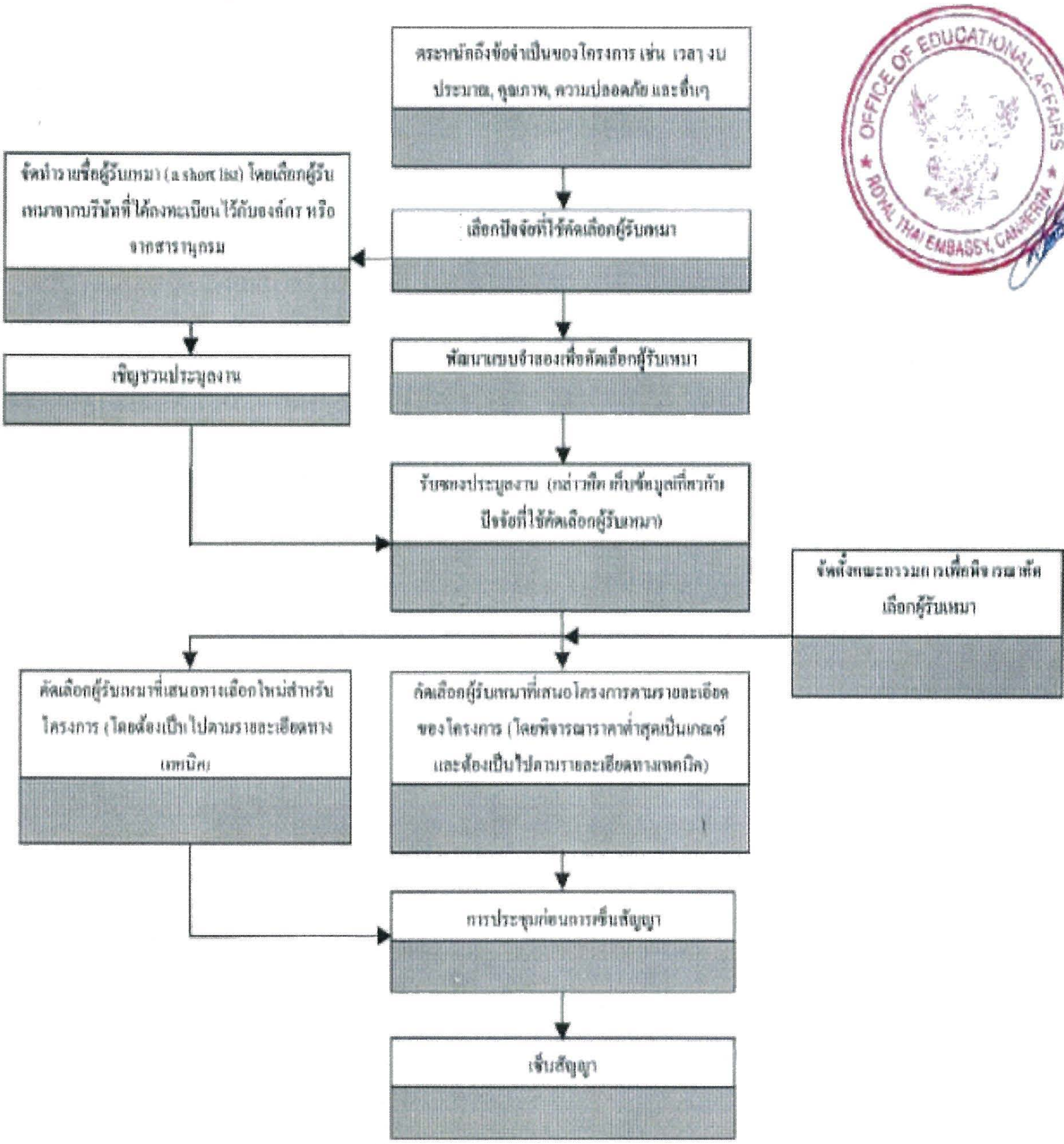
6.1 ถ้าท่านเห็นด้วยกับแต่ละขั้นตอนกรุณาปล่อยพื้นที่แรเงาว่างไว้ ถ้าท่านไม่เห็นด้วยกรุณาปรับแก้ตามความต้องการ



กระบวนการการคัดเลือกผู้รับเหมาโดยทำ prequalification

คำแนะนำ: ....

6.2 ถ้าท่านเห็นด้วยกับแต่ละขั้นตอนกรุณาปล่อยพื้นที่เว้นว่างไว้ ถ้าท่านไม่เห็นด้วยกรุณาปรับแก้ตามความต้องการ



กระบวนการการคัดเลือกผู้รับเหมาโดยเลือกจากผู้รับเหมาที่ลงทะเบียนไว้กับองค์กร (ตามลำดับขั้น)

คำแนะนำ: ....

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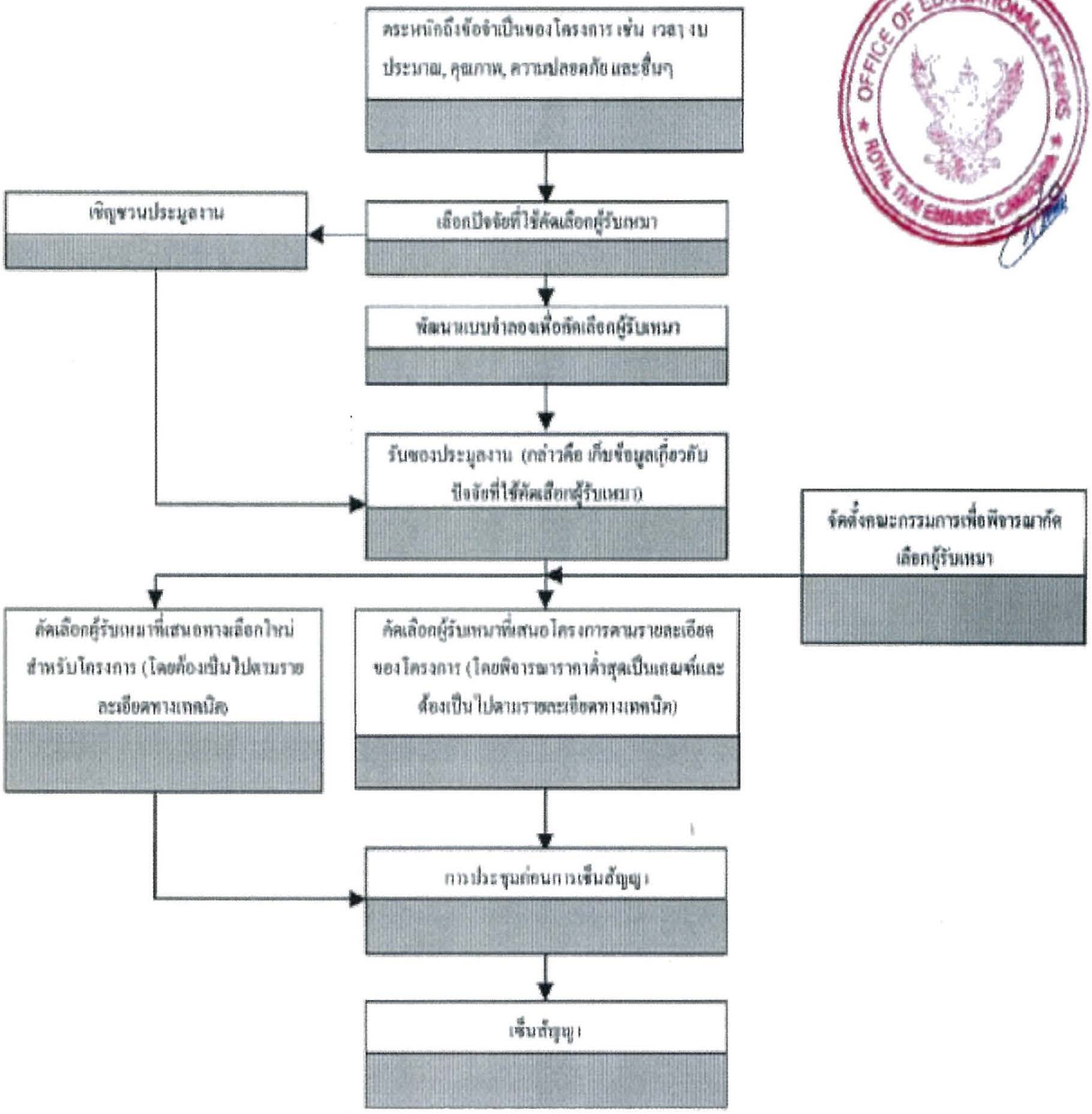
18

6.3 ถ้าท่านเห็นด้วยกับแต่ละขั้นตอนกรุณาปล่อยพื้นที่เว้นว่างไว้ ถ้าท่านไม่เห็นด้วยกรุณาปรับแก้ตามความต้องการ



กระบวนการการเปิดประมูลทั่วไปโดยไม่มีการคัดเลือกผู้รับเหมาเบื้องต้น

คำแนะนำ: ....

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19

ง. แบบจำลองความคิดที่ใช้คัดเลือกผู้รับเหมา

คำแนะนำการตอบ: กรุณาเขียน √ ใน ☐ ตามความเป็นจริง (**อาจเขียน√ มากกว่า 1 แห่ง ถ้าเหมาะสม**)

7. แบบจำลองใดตามข้างล่างนี้ที่ท่านใช้ในการคัดเลือกผู้รับเหมา?

☐ ดุลยพินิจส่วนบุคคล

☐ แบบจำลองการใส่น้ำหนัก, ตัวอย่างเช่น

คะแนนรวมทั้งหมด = ผลรวมทั้งหมดของ (น้ำหนักของปัจจัย × คะแนนของปัจจัย)

คะแนน หมายถึง ปริมาณของปัจจัยของผู้รับเหมา ซึ่งไม่คำนึงถึงความเสี่ยงและความไม่แน่นอน

☐ แบบจำลองอรรถประโยชน์(Utility), ตัวอย่างเช่น

ค่าอรรถประโยชน์รวม = ผลรวมทั้งหมดของ (น้ำหนักของปัจจัย × ค่าอรรถประโยชน์ของแต่ละปัจจัย)

ค่าอรรถประโยชน์ หมายถึง ค่าความพึงพอใจ(ปริมาณอันหนึ่ง) ต่อปัจจัยของผู้รับเหมา ซึ่งคำนึงถึงความเสี่ยงและความไม่แน่นอน

☐ โปรแกรมคอมพิวเตอร์, ตัวอย่างเช่น

ระบบผู้ชำนาญการ หรือระบบปัญญาประดิษฐ์ (Expert Systems or Artificial Neural Networks)

☐ อื่นๆ โปรดระบุ..
....
....

Appendix B3

A verification of translation

Office of Educational Affairs, Royal Thai Embassy
74-76 Hopetoun Circuit, Yarralumla ACT 2600
Phone : 02 62811371 Facsimile : 02 62853071
E-mail : educationthai@hotmail.com

To Whom It May Concern:

This is to certify that the document "Multicriteria and multidecision makers in tender evaluation" by Mr. Jakrapong Pongpeng, Physical Infrastructure Centre, School of Civil Engineering, Queensland University of Technology has been correctly translated into Thai by Mr. Pongpeng. I have personally viewed both documents, in English and Thai and will vouch that it can be classed as a direct translation. Please do not hesitate to contact me for further verification.

Yours sincerely,

Mr. Wiboon Chulerttiyawong
Minister Counsellor (Education)
21 December 2001

Appendix B4

Coding manual

Section A Some characteristics of you and your organisation

Q no.	Variable	Description	Coln. width	Possible numbers and their meaning	Notice
1.1	Currposn	Current position	25	A position in the organisation	Identify position
1.2	Workdurn	Working duration in the position	2	1-99 years	Identify the true number
1.3	Contprep Teneval Conselec Otherfun	Current function	1	1 Contract preparation 2 Tender evaluation 3 Contractor selection 4 Other	Choose one or more
1.4	Edubacgd	Educational background	1	1 Architect 2 Civil engineer 3 Quantity surveyor 4 Other	Choose only one
2.1	Sector	Sector of the organisation	1	1 Public 2 State enterprise 3 Private 4 Other	Choose only one
2.2	Business	Business category of the organisation	1	1 Owner 2 Consultant 3 Architecture 4 Project manager 5 Engineering 6 Contractor 7 Other	Choose one or more

Q no.	Variable	Description	Coln. width	Possible numbers and their meaning	Notice
2.3	Buildwks	Avge annual number of building works	1	1-999	Identify the true number
2.3	Civilwks	Avge annual number of civil works	1	1-999	Identify the true number
2.3	Services	Avge annual number of service works	1	1-999	Identify the true number
2.3	Mainnanc	Avge annual number of maintenance works	1	1-999	Identify the true number
2.3	Others	Avge annual number of other works	1	1-999	Identify the true number
2.4	Anconval	Annual contract value ($M)	4	1-9999 Million dollars	Identify the true number
2.5	Minconva	Minimum contract value ($M)	4	1-9999 Million dollars	Identify the true number
2.5	Maxconva	Maximum contract value ($M)	4	1-9999 Million dollars	Identify the true number

Note: 0 Don't answer or missing value

Section B The criteria influencing the selection of a contractor

Q no.	Variable	Criteria and measures	Coln. width	Possible numbers and their meaning	Notice
3.1.1	FS311	Financial ratios	1	1 Very low importance or not at all 2 Low importance 3 Medium importance 4 High importance 5 Very high importance 0 Don't answer or missing value	Choose only one
.	FS3111	Gross profit	1	DITTO	
.	FS3112	Asset turnover ratio	1	DITTO	
.	FS3113	Financial leverage ratio	1	DITTO	
.	FS3114	Working capital ratio	1	DITTO	
.	FS3115	Quick asset ratio	1	DITTO	
3.1.2	FS312	Banking arrangements	1	DITTO	
.	FS3121	Current banking organisation	1	DITTO	
.	FS3122	Length of time with that bank	1	DITTO	
.	FS3123	Backing preparation from that bank	1	DITTO	
.	FS3124	A line of credit to the contractor from the bank	1	DITTO	
.	FS3125	Interest rate charged by the bank	1	DITTO	
.	FS3126	Collateral for security to the bank	1	DITTO	
3.1.3	FS313	Credit ratings	1	DITTO	

Q no.	Variable	Criteria and measures	Coln. width	Possible numbers and their meaning	Notice
.	FS3131	Average length of time that the contractor pays subs/suppliers	1	DITTO	
.	FS3132	Conditions in bank guarantee	1	DITTO	
3.2.1	QMS321	Quality system selection	1	DITTO	
.	QMS3211	AS 3900 series	1	DITTO	
.	QMS3212	ISO 9000 series	1	DITTO	
3.2.2	QMS322	Quality system implementation	1	DITTO	
.	QMS3221	Progressive steps of implementing a quality system	1	DITTO	
3.2.3	QMS323	Quality system audits	1	DITTO	
.	QMS3231	Documented processes in place ready to address standard elements	1	DITTO	
.	QMS3232	Documented processes being followed by the contractor	1	DITTO	
.	QMS3233	Documented processes being effective and suitable	1	DITTO	
3.3.1	HR331	Personnel planning	1	DITTO	
.	HR3311	A personnel chart	1	DITTO	
3.3.2	HR332	Personnel development	1	DITTO	
.	HR3321	In-house training	1	DITTO	
.	HR3322	Supervisor coaching	1	DITTO	
3.3.3	HR333	Personnel maintenance	1	DITTO	
.	HR3331	Competitive incomes/welfare	1	DITTO	
.	HR3332	Social reputation of contractor	1	DITTO	

Q no.	Variable	Criteria and measures	Coln. width	Possible numbers and their meaning	Notice
.	HR3333	Promotion	1	DITTO	
3.4.1	PR341	Performance	1	DITTO	
.	PR3411	Past performance	1	DITTO	
.	PR3412	Current performance	1	DITTO	
3.4.2	PR342	Health and safety	1	DITTO	
.	PR3421	Health and safety plan	1	DITTO	
.	PR3422	Health and safety control	1	DITTO	
3.5.1	PrC351	Procurement plans	1	DITTO	
.	PrC3511	Material schedule	1	DITTO	
.	PrC3512	Subcontractor schedule	1	DITTO	
3.5.2	PrC352	Delivery control	1	DITTO	
.	PrC3521	Warehouse procedures	1	DITTO	
.	PrC3522	Distribution procedures	1	DITTO	
.	PrC3523	Receipt of goods	1	DITTO	
3.5.3	PrC353	Subcontractor control	1	DITTO	
.	PrC3531	General conditions of subcontractors	1	DITTO	
.	PrC3532	Special conditions of subcontractors	1	DITTO	
.	PrC3533	Interaction between the contractor and subcontractors	1	DITTO	
.	PrC3534	Methods of reviewing drawings and change orders	1	DITTO	
.	PrC3535	Communication line	1	DITTO	
.	PrC3536	Power leverages	1	DITTO	
3.6.1	PlE361	Plant/equipment acquisition	1	DITTO	

Q no.	Variable	Criteria and measures	Coln. width	Possible numbers and their meaning	Notice
.	PlE3611	A list of plant/equipment	1	DITTO	
.	PlE3612	A plan of renting or leasing plant/equipment	1	DITTO	
3.6.2	PlE362	Plant/equipment maintenance	1	DITTO	
.	PlE3621	Programmed maintenance	1	DITTO	
.	PlE3622	Spare parts stocking	1	DITTO	
3.7.1	EnC371	Project planning	1	DITTO	
.	EnC3711	Master plans	1	DITTO	
.	EnC3712	Detailed plans	1	DITTO	
.	EnC3713	Resource plans	1	DITTO	
.	EnC3714	Budgeting	1	DITTO	
.	EnC3715	Contingency plans	1	DITTO	
3.7.2	EnC372	Project execution	1	DITTO	
.	EnC3721	Communication of the plans to involved people	1	DITTO	
.	EnC3722	Technical ability	1	DITTO	
3.7.3	EnC373	Project monitoring	1	DITTO	
.	EnC3731	Continuously reporting	1	DITTO	
.	EnC3732	Analysed reporting	1	DITTO	
3.7.4	EnC374	Ability to adjust a project	1	DITTO	
.	EnC3741	Weekly actions	1	DITTO	
.	EnC3742	Monthly actions	1	DITTO	
3.8.1	PM381	Project management experience	1	DITTO	
.	PM3811	Problem solving skills	1	DITTO	
.	PM3812	Management of conflict	1	DITTO	

Q no.	Variable	Criteria and measures	Coln. width	Possible numbers and their meaning	Notice
.	PM3813	Previous and current position	1	DITTO	
3.8.2	PM382	Communication skills	1	DITTO	
.	PM3821	Observation skills	1	DITTO	
.	PM3822	Analysis skills	1	DITTO	
.	PM3823	Persuasive skills	1	DITTO	
3.8.3	PM383	Adaptability	1	DITTO	
.	PM3831	Tolerance for ambiguity and changes	1	DITTO	
.	PM3832	Balance ability between conserving and challenging traditional operations or behaviours	1	DITTO	

Section C Tender evaluation procedures

Q no.	Variable	Description	Coln. width	Possible numbers and their meaning	Notice
4	TEproced	Tender evaluation procedures	1	1 Selective tendering with PQ 2 Selective tendering without PQ 3 Open tendering 4 Negotiated tendering 5 More than one procedure used	Choose only one
5	NoDMTE	Number of DM in evaluating tenders	1	1 One 2 More than one 0 Don' know	Choose only one

Q no.	Variable	Description	Coln. width	Possible numbers and their meaning	Notice
6.1	SelTEPQ	A selective tendering process with PQ	1	1 Not adjusted 2 Slightly adjusted 3 Highly adjusted	Choose only one
6.2	SelTE	A selective tendering process without PQ	1	DITTO	
6.3	Opente	An open tendering	1	DITTO	

Section D Tender evaluation models

Q no.	Variable	Description	Coln. width	Possible numbers and their meaning	Notice
7	TEmodel	Tender evaluation models	1	1 Personal judgment 2 Weighting models 3 Utility models 4 Computer programs: ES, ANN 5 Other	

Appendix C

Some data analysis results

Table C1 Criterion comparison of importance index across sectors

Criteria	Importance index (Mean/STD)		
	Overall	Government	Private
Project planning	5.81	6.07	5.53
Project monitoring	5.70	6.07	5.25
Project management experience	5.45	5.27	5.74
Ability to adjust a project	4.73	4.78	4.70
Performance	4.69	5.09	4.27
Project execution	4.57	4.51	4.79
Personnel planning	4.49	4.41	4.45
Delivery control	4.37	4.11	4.78
Plant/equipment acquisition	4.16	4.05	4.31
Adaptability	4.05	3.77	4.65
Health and safety	4.01	3.56	4.79
Financial ratios	3.87	3.26	5.15
Subcontractor control	3.78	3.09	5.65
Quality system audits	3.76	3.44	4.32
Plant/equipment maintenance	3.72	3.53	4.04
Communication skills	3.67	3.44	4.18
Banking arrangement	3.64	3.68	3.57
Personnel maintenance	3.57	3.35	3.98
Credit ratings	3.55	3.35	3.81
Procurement plans	3.51	3.15	4.23
Personnel development	3.32	3.01	3.94
Quality system selection	3.21	2.94	3.64
Quality system implementation	3.21	2.98	3.60

Table C2 Criterion comparison of ranking order across sectors

Criteria	Ranking order		
	Overall	Government	Private
Project planning	1	1	3
Project monitoring	2	2	4
Project management experience	3	3	1
Ability to adjust a project	4	5	9
Performance	5	4	14
Project execution	6	6	6
Personnel planning	7	7	11
Delivery control	8	8	8
Plant/equipment acquisition	9	9	13
Adaptability	10	10	10
Health and safety	11	12	7
Financial ratios	12	18	5
Subcontractor control	13	20	2
Quality system audits	14	15	12
Plant/equipment maintenance	15	13	17
Communication skills	16	14	16
Banking arrangement	17	11	23
Personnel maintenance	18	17	18
Credit ratings	19	16	20
Procurement plans	20	19	15
Personnel development	21	21	19
Quality system selection	22	23	21
Quality system implementation	23	22	22

Table C3 Measure comparison of importance index across sectors

Measure	Importance index (Mean/STD)		
	Overall	Government	Private
Master plans	5.22	5.06	5.57
Continuously reporting	4.93	4.93	4.91
A list of plant/equipment	4.82	4.67	4.99
Past performance	4.82	5.06	4.62
Problem-solving skills	4.80	4.78	4.95
Resource plans	4.67	4.55	4.91
Weekly actions	4.59	4.56	4.72
Management of conflict	4.47	4.28	5.01
Technical ability	4.44	3.78	6.34
Detailed plans	4.43	4.07	5.13
Receipt of goods	4.34	4.20	4.55
Warehouse procedures	4.29	4.07	4.60
Methods of reviewing drawing and change orders	4.29	4.06	4.80
Previous and current position	4.25	3.76	4.93
Budgeting	4.17	3.57	6.06
Monthly actions	4.16	4.33	3.99
Analysis skills	4.11	3.65	5.18
Observation skills	4.04	3.52	5.36
Distribution procedures	4.03	3.70	4.49
Analysed reporting	4.01	3.97	4.07
Tolerance for ambiguity and changes	3.99	3.60	4.81
Balance ability between conserving and challenging traditional operations or behaviours	3.97	3.61	4.46
A line of credit to the contractor from the bank	3.93	3.87	3.94
Persuasive skills	3.87	3.49	4.59
Social reputation of contractor	3.85	3.82	3.83
Material schedule	3.83	3.50	4.49
A personnel chart	3.82	3.84	3.76
Current performance	3.79	4.16	3.41
Communication of the plans to involved people	3.77	3.32	4.95
A plan of renting or leasing plant/equipment	3.74	3.60	3.97
Communication line	3.69	3.46	4.25
Conditions in bank guarantee	3.68	3.44	4.19
In-house training	3.63	3.24	4.32
Promotion	3.63	3.34	4.08

Table C3 (continued)

Measure	Importance index (Mean/STD)		
	Overall	Government	Private
Documented processes being followed by the contractor	3.63	3.53	3.76
Contingency plans	3.62	3.19	4.86
Documented process in place ready to address standard elements	3.62	3.53	3.82
Interaction between the contractor and subcontractors	3.60	3.05	4.72
General condition of subcontractors	3.59	3.06	4.92
Competitive incomes/welfare	3.57	3.16	4.36
Documented processes being effective and suitable	3.51	3.16	4.15
Health and safety plan	3.48	3.16	4.08
Supervisor coaching	3.43	3.12	4.03
Special conditions of subcontractors	3.41	2.90	4.60
Health and safety control	3.40	3.06	3.95
Subcontractor schedule	3.40	3.00	4.22
Average length of time that the contractor pays subs/suppliers	3.39	3.15	3.97
Progressive steps in implementing a quality system	3.38	3.09	3.98
Backing preparation from that bank	3.28	2.99	3.77
Programmed maintenance	3.16	2.94	3.51
Financial leverage ratio	3.09	3.05	3.16
A plan of renting or leasing plant/equipment	3.05	3.06	3.03
Length of time with that bank	3.01	2.95	3.06
Working capital ratio	2.97	2.81	3.24
Spare parts stocking	2.97	2.91	3.05
Asset turn over ratio	2.96	2.77	3.29
Collateral for security by the bank	2.95	2.85	3.08
Gross profit	2.85	2.69	3.21
Current banking organisation	2.84	2.71	3.07
Quick asset ratio	2.82	2.60	3.13
Interest rate charged by the bank	2.76	2.80	2.75
ISO 9000 series	2.71	2.54	3.03
AS 3900 series	1.86	1.85	1.86

Table C4 Measure comparison of ranking order across sectors

Measure	Ranking order		
	Overall	Government	Private
Master plans	1	1	3
Continuously reporting	2	3	14
A list of plant/equipment	3	5	8
Past performance	4	2	20
Problem-solving skills	5	4	10
Resource plans	6	7	13
Weekly actions	7	6	18
Management of conflict	8	9	7
Technical ability	9	20	1
Detailed plans	10	12	6
Receipt of goods	11	10	24
Warehouse procedures	12	13	21
Methods of reviewing drawing and change orders	13	14	17
Previous and current position	14	16	11
Budgeting	15	26	2
Monthly actions	16	8	38
Analysis skills	17	22	5
Observation skills	18	29	4
Distribution procedures	19	21	26
Analysed reporting	20	15	36
Tolerance for ambiguity and changes	21	25	16
Balance ability between conserving and challenging traditional operations or behaviours	22	23	27
A line of credit to the contractor from the bank	23	17	43
Persuasive skills	24	31	23
Social reputation of contractor	25	19	44
Material schedule	26	30	25
A personnel chart	27	18	47
Current performance	28	11	50
Communication of the plans to involved people	29	35	9
A plan of renting or leasing plant/equipment	30	24	41
Communication line	31	32	30
Conditions in bank guarantee	32	33	32
In-house training	33	36	29
Promotion	34	34	34

Table C4 (continued)

Measure	Ranking order		
	Overall	Government	Private
Documented processes being followed by the contractor	35	28	48
Contingency plans	36	37	15
Documented process in place ready to address standard elements	37	27	45
Interaction between the contractor and subcontractors	38	48	19
General condition of subcontractors	39	45	12
Competitive incomes/welfare	40	38	28
Documented processes being effective and suitable	41	40	33
Health and safety plan	42	39	35
Supervisor coaching	43	42	37
Special conditions of subcontractors	44	54	22
Health and safety control	45	44	42
Subcontractor schedule	46	49	31
Average length of time that the contractor pays subs/suppliers	47	41	40
Progressive steps in implementing a quality system	48	43	39
Backing preparation from that bank	49	50	46
Programmed maintenance	50	52	49
Financial leverage ratio	51	47	54
A plan of renting or leasing plant/equipment	52	46	60
Length of time with that bank	53	51	58
Working capital ratio	54	56	52
Spare parts stocking	55	53	59
Asset turn over ratio	56	58	51
Collateral for security by the bank	57	55	56
Gross profit	58	60	53
Current banking organisation	59	59	57
Quick asset ratio	60	61	55
Interest rate charged by the bank	61	57	62
ISO 9000 series	62	62	61
AS 3900 series	63	63	63

Table C5 Criteria/measures indicated as statistical differences between the two sectors

Criteria and measures	Mann-Whitney U	Significant (2-tailed)
Financial ratios	1427.000	0.033*
Banking arrangement	803.500	0.601
Credit ratings	1200.500	0.442
Quality system selection	960.500	0.139
Quality system implementation	1429.500	0.026*
Quality system audits	1231.500	0.164
Personnel planning	1527.500	0.764
Personnel development	1163.500	0.052
Personnel maintenance	1215.000	0.091
Performance	1432.000	0.216
Health and safety	1449.000	0.162
Procurement plans	1269.000	0.078
Delivery control	1475.000	0.291
Subcontractor control	1294.500	0.099
Plant/equipment acquisition	1509.500	0.487
Plant/equipment maintenance	1503.000	0.220
Project planning	1487.000	0.219
Project execution	1254.500	0.028*
Project monitoring	1484.000	0.358
Ability to adjust a project	1391.000	0.468
Project management experience	1517.000	0.136
Communication skills	1141.500	0.014*
Adaptability	1268.000	0.018*
Gross profit	1626.500	0.007*
Asset turn over ratio	1804.500	0.071
Financial leverage ratio	1823.000	0.085
Working capital ratio	1872.500	0.144
Quick asset ratio	1975.500	0.397
Current banking organisation	1889.000	0.029*
Length of time with that bank	2032.500	0.117
Backing preparation from that bank	1972.000	0.050
A line of credit to the contractor from the bank	2342.000	0.735
Interest rate charged by the bank	2037.000	0.125
Collateral for security by the bank	2080.500	0.177
Average length of time that the contractor pays subs/suppliers	1774.500	0.005*
Conditions in bank guarantee	1938.000	0.034*
AS 3900 series	2474.000	0.950
ISO 9000 series	2095.500	0.095
Progressive steps of implementing a quality system	1912.000	0.034*
Documented process in place ready to address standard elements	2069.000	0.090
Documented processes being followed by the contractor	2266.000	0.403
Documented processes being effective and suitable	2191.500	0.244
A personnel chart	2388.500	0.761
In-house training	2086.000	0.102

Table C5 (Continued)

Criteria and measures	Mann-Whitney U	Significant (2-tailed)
Supervisor coaching	2109.500	0.131
Competitive incomes/welfare	1975.500	0.035*
Social reputation of contractor	2414.500	0.748
Promotion	2356.000	0.563
Past performance	2047.000	0.051
Current performance	2396.000	0.687
Health and safety plan	2150.000	0.143
Health and safety control	2311.500	0.444
Material schedule	2095.500	0.084
Subcontractor schedule	2175.500	0.172
Warehouse procedures	2382.500	0.638
Distribution procedures	2395.500	0.682
Receipt of goods	2307.000	0.425
General condition of subcontractors	1930.000	0.016*
Special conditions of subcontractors	2049.000	0.057
Interaction between the contractor and subcontractors	2127.500	0.117
Methods of reviewing drawing and change orders	2039.500	0.067
Communication line	1802.000	0.003*
Power leverage	2170.000	0.227
A list of plant/equipment	2203.000	0.257
A plan of renting or leasing plant/equipment	2155.000	0.187
Programmed maintenance	2260.000	0.329
Spare parts stocking	2486.500	0.993
Master plans	1950.000	0.017*
Detailed plans	2258.500	0.313
Resource plans	2131.500	0.117
Budgeting	1626.500	0.000*
Contingency plans	1615.500	0.000*
Communication of the plans to involved people	1788.000	0.002*
Technical ability	1859.500	0.005*
Continuously reporting	2483.000	0.980
Analysed reporting	2214.000	0.231
Weekly actions	2239.000	0.257
Monthly actions	2227.000	0.250
Problem-solving skills	2014.500	0.051
Management of conflict	1743.500	0.001*
Previous and current position	1859.000	0.005*
Observation skills	1777.500	0.002*
Analysis skills	1825.000	0.005*
Persuasive skills	1791.000	0.003*
Tolerance for ambiguity and changes	1921.500	0.018*
Balance ability between conserving and challenging traditional operations or behaviours	2191.000	0.237

* statistical difference at the 5% level of significance

Table C6 Factor loadings extracted by the principal component analysis

Component Matrix[a]

	Component											
	1	2	3	4	5	6	7	8	9	10	11	12
FS3113 Financial leverage ratio	.283	-.546	-8.91E-02	8.261E-02	.339	.214	7.216E-02	-2.20E-02	-.151	-9.88E-02	7.449E-02	1.920E-02
FS3122 Length of time with that bank	.448	-.381	-4.15E-02	1.063E-02	.444	.111	.314	-3.29E-02	.128	-1.84E-02	.152	6.568E-02
FS3123 Backing preparation from that bank	.498	5.433E-02	-.128	.116	.642	-1.99E-02	.170	.157	2.893E-02	-1.15E-02	-2.61E-02	-2.11E-02
FS3124 A line of credit to the contractor from the bank	.339	7.155E-02	.142	.293	.573	1.593E-02	.366	8.541E-02	.166	-.161	-.105	-.150
FS3131 Average length of time that the contractor pays subs/suppliers	.627	-.232	.167	.135	.169	.188	8.075E-02	-8.03E-02	.140	3.168E-02	-8.19E-02	.156
FS3132 Conditions in bank guarantee	.420	-.314	.147	-.103	.342	.139	-.324	4.487E-02	-3.73E-02	.243	-1.59E-02	.172
QMS3221 Progressive steps of implementing a quality system	.596	-.231	-.250	.446	-4.33E-02	-9.51E-02	-4.46E-02	2.527E-02	5.300E-02	-6.43E-04	.102	-2.50E-02
QMS3231 Documented process in place ready to address standard elements	.681	-.190	1.486E-02	.356	-1.91E-02	-.158	-.276	.140	4.515E-02	-5.78E-02	.112	-9.32E-02
QMS3232 Documented processes being followed by the contractor	.622	-9.83E-02	-8.47E-03	.337	9.372E-02	-.176	-.460	.180	-3.31E-02	-.143	.121	.106
QMS3233 Documented processes being effective and suitable	.679	-5.44E-02	-8.60E-02	.383	7.837E-03	-9.53E-02	-.333	.221	5.645E-02	-5.65E-02	.183	8.856E-02
HR3311 A personnel chart	.489	1.807E-02	.302	.240	-5.13E-02	.138	.161	8.245E-02	-.228	.163	7.300E-02	-.460
HR3321 In-house training	.700	-.238	-4.52E-02	.240	-.159	-2.11E-02	3.125E-02	-.295	-.269	8.228E-02	-2.26E-02	2.719E-03
HR3322 Supervisor coaching	.681	-.185	-4.32E-02	.251	-6.89E-02	-3.42E-02	1.260E-02	-.331	-.287	.207	-8.86E-04	-.124
HR3331 Competitive incomes/welfare	.720	-.237	.130	.189	-8.58E-02	9.945E-02	-2.29E-02	-.333	-1.70E-02	8.115E-02	-8.89E-03	-1.84E-02
HR3332 Social reputation of contractor	.563	-.142	.194	.126	-.251	4.276E-02	-2.00E-02	-5.53E-02	.231	.369	9.976E-02	.237
HR3333 Promotion	.677	-.284	.168	.103	-.121	.152	-1.81E-03	-.264	3.926E-02	.142	5.206E-02	.106
PR3411 Past performance	.532	.264	.383	.283	-7.59E-02	7.208E-03	-1.08E-02	.119	.278	.145	-.231	6.718E-03
PR3412 Current performance	.503	.153	.199	.246	-4.66E-02	-.231	.197	7.797E-02	.277	.154	-.183	5.690E-02
PR3421 Health and safety plan	.755	-.101	-.212	.150	-.191	-.212	.125	7.665E-02	-8.27E-02	-.147	-1.95E-02	-5.06E-02
PR3422 Health and safety control	.674	-5.10E-02	-.256	.163	-.170	-.259	.284	5.072E-02	-9.41E-02	-.183	-7.12E-02	-2.45E-02
PRC3511 Material schedule	.733	-.110	-.194	-7.87E-02	-6.69E-02	-1.70E-02	-.130	9.751E-02	.168	-6.76E-02	-2.88E-02	-.192
PRC3512 Subcontractor schedule	.730	-.127	-.141	-.156	-6.54E-02	5.389E-02	-.153	9.655E-02	.123	3.478E-02	-.129	-.188
PRC3521 Warehouse procedures	.620	-.263	.263	-.143	-5.87E-02	-.351	.158	.111	-.245	-.111	5.433E-02	9.960E-02
PRC3522 Distribution procedures	.645	-.251	.206	-.272	-1.75E-02	-.380	.167	6.513E-02	-.228	-5.33E-02	5.764E-03	.129
PRC3523 Receipt of goods	.567	-.160	.285	-.186	2.670E-02	-.462	.147	7.726E-02	-5.53E-02	1.528E-02	.141	.232
PRC3531 General condition of subcontractors	.779	-.218	8.521E-02	-.205	-4.56E-02	-.149	8.886E-02	-.213	.162	-.120	-.178	-.115
PRC3532 Special conditions of subcontractors	.741	-.244	-3.42E-04	-.266	-6.82E-02	-.122	5.465E-02	-.143	.287	-7.62E-02	-.135	-.155
PRC3533 Interaction between the contractor and subcontractors	.684	-.213	4.437E-02	-.189	-.186	-5.28E-02	9.310E-02	-.178	.328	-4.18E-02	-8.11E-02	-.121
PRC3534 Methods of reviewing drawing and change orders	.570	-.219	-.156	-.312	.149	-.134	-.322	.126	3.773E-02	-.117	-.109	-5.88E-02
PRC3535 Communication line	.685	-.149	-.120	-.368	5.692E-02	1.228E-02	-.198	1.008E-02	-3.25E-02	8.881E-02	-.202	-.135
PRC3536 Power leverage	.607	-.253	2.046E-02	-.261	.227	.105	-.230	3.358E-02	4.739E-02	7.583E-02	7.630E-02	-.149
PLE3611 A list of plant/equipment	.442	.260	.602	-.227	-6.55E-02	9.651E-02	-7.41E-02	.169	-8.33E-02	-1.46E-02	5.895E-02	-.202
PLE3612 A plan of renting or leasing plant/equipment	.541	7.431E-02	.565	-.116	-7.60E-02	.112	-8.22E-02	.199	-8.38E-02	-1.68E-03	.164	-.161
PLE3621 Programmed maintenance	.658	-1.90E-03	.244	-7.62E-02	-8.25E-02	-.121	-7.55E-02	-6.45E-02	-3.35E-02	-.253	9.667E-02	6.363E-02
ENC3711 Master plans	.578	.499	-6.45E-02	.199	-8.24E-02	7.592E-02	-4.16E-02	-1.71E-02	4.591E-02	-.199	1.102E-02	-.184
ENC3712 Detailed plans	.638	.507	-.125	1.005E-02	-6.36E-02	3.895E-02	-1.61E-02	-.128	.163	-.126	.144	3.308E-02
ENC3713 Resource plans	.638	.520	-5.71E-02	3.847E-02	-.119	9.856E-02	4.673E-02	-.186	4.446E-02	-.174	.202	-1.55E-02
ENC3714 Budgeting	.698	8.910E-02	-7.71E-02	-.128	.136	.208	-.141	-.354	-2.85E-02	-4.76E-02	.135	5.945E-02
ENC3715 Contingency plans	.673	-4.81E-02	-.211	-9.57E-02	-1.76E-02	.222	2.283E-02	-.210	-9.79E-02	-.275	3.471E-02	2.776E-02
ENC3721 Communication of the plans to involved people	.652	.329	-.192	-.161	8.684E-02	-4.21E-02	-.105	1.548E-02	1.053E-02	.146	.212	-7.13E-02
ENC3722 Technical ability	.582	.268	-.279	-.101	6.750E-02	-.146	-1.18E-02	5.282E-02	.216	.240	-6.83E-03	.130
ENC3731 Continuously reporting	.451	.657	-6.77E-02	-8.78E-02	6.171E-02	-.292	7.910E-03	-8.22E-02	1.598E-02	5.829E-02	2.979E-02	.156
ENC3732 Analysed reporting	.521	.508	2.269E-02	-.196	.267	-.160	-2.66E-02	-.243	1.307E-02	2.653E-02	.232	6.022E-02
ENC3741 Weekly actions	.621	.438	-.119	-1.38E-02	.251	-.128	2.034E-02	-1.04E-02	-.281	.198	-.117	-7.59E-02
ENC3742 Monthly actions	.617	.399	-5.86E-02	-2.00E-02	.216	-9.91E-02	2.632E-02	-9.62E-02	-.236	.289	-.161	-9.17E-02
PM3811 Problem solving skills	.693	.279	.214	9.334E-02	-8.42E-03	.220	-2.70E-02	4.652E-02	4.851E-02	-.106	-.134	.159
PM3812 Management of conflict	.651	.320	.169	4.300E-03	-1.87E-02	.289	-4.23E-02	8.974E-02	-.217	-.166	-.198	.134
PM3813 Previous and current position	.578	.131	.198	2.241E-02	4.669E-02	.305	-8.94E-02	-1.86E-02	-.105	-.244	-.369	.301
PM3821 Observation skills	.687	-3.89E-03	-.289	-7.92E-02	-.177	.148	.135	.235	-.137	.138	-.149	.157
PM3822 Analysis skills	.731	2.448E-03	-.358	2.653E-03	-.150	8.671E-02	4.634E-02	.234	-6.55E-02	.106	-.172	-4.57E-02
PM3823 Persuasive skills	.728	-2.37E-02	-.278	-.116	-.226	.193	7.507E-02	.192	-.111	5.390E-02	-6.06E-02	.135
PM3831 Tolerance for ambiguity and changes	.674	1.825E-02	-8.15E-02	-.130	-.167	.300	.288	.267	-2.54E-02	4.490E-02	.303	1.903E-02
PM3832 Balance ability between conserving and challenging traditional operations or behaviors	.637	-7.31E-02	-8.07E-02	-.201	-9.20E-02	.335	.280	.210	.145	6.356E-02	.290	5.970E-02

Extraction Method: Principal Component Analysis.

a. 12 components extracted.

Table C7 Rotated factor loadings by *varimax* rotation

Rotated Component Matrix[a]

	Component											
	1	2	3	4	5	6	7	8	9	10	11	12
FS3113 Financial leverage ratio	-.261	.157	.311	.153	.165	9.722E-02	.476	-4.69E-02	7.593E-02	-.275	.194	-1.58E-02
FS3122 Length of time with that bank	-5.70E-03	.204	.251	.235	4.632E-02	.194	.669	-4.91E-02	-2.83E-02	-1.25E-02	.173	-.143
FS3123 Backing preparation from that bank	.307	.136	-1.95E-02	.116	.202	8.408E-02	.713	-7.07E-03	7.897E-02	3.872E-02	.116	.211
FS3124 A line of credit to the contractor from the bank	.145	2.282E-02	5.161E-03	-6.30E-02	7.996E-02	2.456E-02	.803	.146	.125	.213	-.143	6.189E-02
FS3131 Average length of time that the contractor pays subs/suppliers	4.090E-02	.237	.383	.180	.153	.136	.374	8.027E-02	.287	.255	.201	-9.47E-02
FS3132 Conditions in bank guarantee	-1.84E-02	.261	.180	4.733E-02	.197	.117	.196	9.203E-02	.148	9.882E-03	.641	7.441E-02
QMS3221 Progressive steps of implementing a quality system	7.471E-02	.169	.402	.239	.600	6.175E-02	.202	-8.95E-02	-3.29E-02	.137	-9.90E-02	4.547E-02
QMS3231 Documented process in place ready to address standard elements	9.769E-02	.268	.279	9.469E-02	.711	.159	.125	.178	4.534E-02	.152	1.891E-02	2.811E-02
QMS3232 Documented processes being followed by the contractor	.179	.174	.141	1.196E-02	.805	.183	8.247E-02	7.870E-02	.189	4.440E-02	.160	2.150E-02
QMS3233 Documented processes being effective and suitable	.218	.149	.178	.201	.787	.106	.101	8.233E-02	.118	.142	.101	-1.06E-02
HR3311 A personnel chart	5.818E-02	3.788E-02	.378	.169	.137	2.248E-02	.194	.641	-2.90E-02	.112	-.135	.249
HR3321 In-house training	.121	.193	.728	.184	.274	.238	4.374E-02	3.582E-02	.146	2.982E-02	-4.27E-02	.161
HR3322 Supervisor coaching	.186	.189	.751	.122	.245	.161	8.464E-02	.101	2.999E-02	2.815E-02	1.730E-03	.255
HR3331 Competitive incomes/welfare	.124	.296	.692	.114	.215	.138	.119	.150	.181	.165	7.065E-02	-4.16E-02
HR3332 Social reputation of contractor	9.856E-02	.123	.422	.303	.187	.165	-8.72E-02	.101	2.029E-02	.490	.273	-.153
HR3333 Promotion	6.816E-02	.260	.633	.214	.158	.177	8.003E-02	.135	.168	.202	.187	-.135
PR3411 Past performance	.224	9.395E-02	.112	3.653E-02	.207	1.615E-02	8.445E-02	.329	.279	.663	-3.68E-03	5.446E-02
PR3412 Current performance	.223	9.693E-02	.126	7.695E-02	.161	.206	.168	9.104E-02	7.910E-02	.635	-.109	8.057E-02
PR3421 Health and safety plan	.196	.323	.307	.347	.418	.337	.102	-2.95E-03	.100	8.967E-02	-.297	.140
PR3422 Health and safety control	.203	.247	.276	.339	.313	.365	.161	-9.36E-02	9.558E-02	.103	-.413	.168
PRC3511 Material schedule	.209	.605	.158	.303	.358	7.732E-02	9.589E-02	.103	6.265E-02	8.289E-02	-4.64E-02	3.571E-02
PRC3512 Subcontractor schedule	.167	.640	.176	.313	.260	5.787E-02	5.682E-02	.142	.113	.106	5.470E-02	.122
PRC3521 Warehouse procedures	3.632E-02	.225	.207	.154	.180	.756	.101	.208	.103	3.163E-02	-9.73E-03	6.725E-02
PRC3522 Distribution procedures	.100	.312	.192	.165	8.781E-02	.784	9.566E-02	.135	8.860E-02	2.877E-02	5.044E-02	.106
PRC3523 Receipt of goods	.181	.174	.114	9.602E-02	.137	.776	.107	.113	-1.41E-02	.182	.126	-4.00E-02
PRC3531 General condition of subcontractors	.178	.672	.363	8.990E-02	5.461E-02	.365	.167	9.712E-02	.161	.185	-8.90E-02	-4.39E-02
PRC3532 Special conditions of subcontractors	.154	.749	.276	.161	6.351E-02	.282	.142	6.905E-02	6.054E-02	.201	-5.76E-02	-9.33E-02
PRC3533 Interaction between the contractor and subcontractors	.130	.641	.333	.198	3.805E-02	.220	7.094E-02	9.135E-02	5.218E-02	.271	-9.01E-02	-.181
PRC3534 Methods of reviewing drawing and change orders	.126	.655	-3.34E-02	9.729E-02	.303	.229	7.668E-02	-4.47E-03	.121	-.117	.201	.106
PRC3535 Communication line	.195	.686	.163	.218	9.666E-02	.162	3.302E-02	9.951E-02	.146	-3.29E-02	.211	.234
PRC3536 Power leverage	.128	.551	.168	.165	.189	.109	.209	.230	2.665E-02	-9.11E-02	.353	1.347E-02
PLE3611 A list of plant/equipment	.235	.154	-3.37E-02	3.939E-02	-2.90E-02	.215	-4.98E-02	.752	.231	.132	8.837E-02	-1.01E-02
PLE3612 A plan of renting or leasing plant/equipment	.141	.154	8.888E-02	.134	.130	.260	1.168E-02	.728	.184	.120	.137	-6.67E-02
PLE3621 Programmed maintenance	.271	.285	.217	6.193E-02	.251	.412	2.642E-02	.255	.272	3.908E-02	-3.08E-02	-.164
ENC3711 Master plans	.559	.138	.110	.145	.291	-.130	5.781E-02	.249	.263	.119	-.315	3.664E-02
ENC3712 Detailed plans	.718	.181	.121	.231	.190	-2.00E-02	2.652E-02	9.268E-02	.210	.134	-.154	-.136
ENC3713 Resource plans	.711	.103	.217	.240	.148	-3.66E-03	1.392E-02	.197	.239	5.367E-02	-.229	-.152
ENC3714 Budgeting	.510	.341	.423	.158	.106	3.056E-02	.138	7.262E-02	.255	-.132	.188	-.121
ENC3715 Contingency plans	.292	.375	.371	.312	.140	9.028E-02	.152	-3.77E-03	.337	-.219	-8.88E-02	-9.38E-02
ENC3721 Communication of the plans to involved people	.650	.279	8.358E-02	.297	.201	6.367E-02	5.172E-02	.143	-3.62E-02	6.233E-03	.116	9.956E-02
ENC3722 Technical ability	.548	.285	1.507E-02	.309	.160	8.214E-02	6.811E-02	-.149	-2.06E-02	.284	.124	.125
ENC3731 Continuously reporting	.807	1.470E-02	-6.61E-02	3.876E-02	5.438E-02	.194	-4.42E-02	-1.82E-02	.111	.202	-5.22E-02	.125
ENC3732 Analysed reporting	.826	.114	7.362E-02	-1.95E-02	2.452E-03	.184	.137	.114	4.699E-02	3.563E-03	.113	-4.20E-02
ENC3741 Weekly actions	.643	.116	.136	.126	.103	.128	.178	.125	.139	4.807E-02	4.121E-02	.500
ENC3742 Monthly actions	.610	.147	.225	9.425E-02	2.841E-02	9.875E-02	.148	.142	.121	.126	8.297E-02	.491
PM3811 Problem solving skills	.365	.144	.162	.221	.186	7.310E-02	.128	.262	.538	.275	3.204E-02	-2.26E-02
PM3812 Management of conflict	.346	.104	.129	.259	.126	8.975E-02	6.265E-02	.302	.650	6.252E-02	6.503E-03	.140
PM3813 Previous and current position	.172	.171	.165	.122	9.460E-02	9.903E-02	.113	.104	.790	.120	8.933E-02	4.368E-02
PM3821 Observation skills	.181	.262	.180	.659	.153	.160	1.830E-02	-4.43E-02	.253	.111	2.154E-02	.278
PM3822 Analysis skills	.207	.388	.179	.573	.283	5.377E-02	5.409E-02	-8.32E-03	.168	.118	-7.33E-02	.329
PM3823 Persuasive skills	.201	.318	.210	.667	.191	.150	-2.13E-02	2.689E-03	.267	4.091E-02	1.212E-02	.158
PM3831 Tolerance for ambiguity and changes	.228	.153	.162	.767	9.981E-02	.158	.150	.289	7.229E-02	1.672E-02	-1.10E-02	-9.38E-02
PM3832 Balance ability between conserving and challenging traditional operations or behaviors	.182	.248	.144	.733	3.059E-02	.118	.213	.209	4.285E-02	6.631E-02	8.512E-02	-.212

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 14 iterations.

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