COMPUTER AIDED DECISION SUPPORT SYSTEM FOR THE SELECTION OF SUBCONTRACTORS IN BUILDING REFURBISHMENT WORKS

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Executive Summary

The growth in building refurbishment (BR) works and related activities are creating new and interesting financial questions. The management domain of refurbishment, however, remains one of the least understood sectors in Architecture, Engineering and Construction (AEC) practice. The differences between refurbishment and new-build projects are insufficiently recognized and managed as such.

Refurbishment projects differ from new-build projects with regard to several issues. Refurbishment projects are often subject to management and planning constraints. It is well known that refurbishment projects are perceived to be more difficult to manage, and involve higher risks and uncertainties than new-build projects. Refurbishment projects are more labor intensive than new-build projects, and they typically involve several trade subcontractors. Overall, these features have consequences for the selection and control of project resources of all types: human, technical, managerial, method, and contractual.

The contractual relationship between main contractors and subcontractors is the major feature of these activities; time and cost over-runs, and contractual disputes are common in these projects because of improper selection of subcontractors. Subcontractors perform vital roles in these projects. Currently, however, there is a lack of knowledge relating to the selection of subcontractors for building refurbishment projects. The process of selecting subcontractors consists of a wide range of criteria that are often qualitative, subjective, and imprecise in nature. Typically, the task is performed in an unstructured, intuitive manner with considerable reliance on the experience or the judgment of senior staff members. Therefore, there exists the need to develop an advanced decision tool that is a more formalized and structured approach in the form of computer aided decision support systems (CADSS), to aid in this process.

The aim of this research is to develop a formalized and structured approach to the selection of subcontractors for building refurbishment projects. This approach will be embedded in an automated decision support system to assist the main contractors in selecting potential subcontractors for building refurbishment works. The subcontractor selection can be processed intelligently using a CADSS by the hybrid model (combination of mathematical model and basic principle of rule-based reasoning) in a knowledge base system (KBS) package. Management of KBS involves knowledge acquisition. Knowledge is captured from the literature and construction experts, formalization and modeling of knowledge, and then the knowledge store, and retrieve through software. The incorporation of knowledge (subjective, qualitative, and quantitative information) into a KBS adds more dimensions to enhance the credibility of the overall process for the BR subcontractor selection.

The research result presents a comprehensive evaluation of decision alternatives for engaging subcontractors in BR projects and to present a CADSS which is called subcontractor selection decision support system (SSDSS). The system provides valuable guidelines to decision-makers, as well as assists them in making decisions pertaining to selecting their subcontractors for refurbishment contracts. Such system will lead indispensable to the future practice of AEC.

Keywords: *Building refurbishment, Decision-making, Decision support system, Subcontractor selection.*

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List of abbreviations

AEC	: Architecture, Engineering and Construction
AI	: Artificial Intelligence
BCA	: Building and Construction Authority
BQ	: Bills of Quantities
BR	: Building Refurbishment
BK	: Background Knowledge
CADSS	: Computer Aided Decision Support System
CBR	: Case Based Reasoning
CL	: Conventional Language
DE	: Domain Expert
DF	: Decision Factor
DSS	: Decision Support System
ES	: Expert System
GUI	: Graphical User Interface
HDB	: Housing Development Board
HL	: High-level Language
HRM	: Human Resource Management
IDSS	: Intelligent Decision Support Systems
IT	: Information Technology
KA	: Knowledge Acquisition
KBS	: Knowledge Based Systems
KBES	: Knowledge Based Expert Systems
KE	: Knowledge Engineer
LISP	: List Processing
MADM	: Multi Attribute Decision Making
MODM	: Multi Objective Decision Making
NUS	: National University of Singapore
OO	: Object Oriented

OED	: Office Estate Development
PC	: Personal Computer
PROLOG	: Programming in Logic
RBR	: Rule Based Reasoning
SCAL	: Singapore Contractors Association Ltd
SLOTS	: Singapore List of Trade Subcontractor
SSDSS	: Subcontractor Selection Decision Support Systems
VB	: Visual Basic
WC	: Weighting Criteria
WSM	: Weight Sum Model

Chapter 1
INTRODUCTION

1.1 Background

Building Refurbishment (BR) work is defined as the process for the extensive repair, renewal and modification of a building to meet economic and/or functional criteria equivalent to those required of a new building (Mansfield, 2002; Highfield, 2000).

The actual process of BR is fraught with enormous technical and managerial problems. Managing BR projects may be similar to new works; however, they also have several differences. The difficulties lie in obtaining reasonable estimates of cost and time because of poor information about existing building conditions. The degree of contingency allowance made at various estimating stages progressively reduces, but will always tend to be greater than in a new-build project (CIRIA, 1994). BR projects are perceived to be more risky than new-build projects (Reyers and Mansfield, 2001). Estimating and tendering for BR projects carry a higher risk in the face of such uncertainties (Teo, 1990; Quah, 1989). The decisions must often be made on the basis of incomplete and imprecise information during tender preparation.

In the management of BR projects, the level of management during construction, and the need for communication among the project team members (including clients and tenants) is far greater than for a new-build project. BR works can be tricky since BR projects are highly labor intensive, and usually involve small packages of work with several trade subcontractors involved (Okoroh and Torrance, 1999).

All these features will affect the management of the BR projects in numerous ways, and create different demands for management strategies and the professional team than would be expected on a new-build project.

1.2 Motivation

There are many motives to inspire this research, such as the significance of economical, technical, and managerial aspects of the BR works. The refurbishment and re-use of buildings is now recognized as a distinct sector of the construction industry (RECC, 2002). In Singapore, for instance, the upgrading of housing estates on a large scale by the government through the Housing and Development Board (HDB) and other private estates, as well as refurbishment works have become a significant component of local construction activities (Low, 1996).

The growth in BR works and related activities has created new and interesting financial questions. According to statistics, the refurbishment sector constitutes 20% of the building construction industry's workload in Singapore (BCA, 2001), 49% in the United Kingdom (Egbu, 1999a; Highfield, 2000), and more than 50% in the United States (Lee and Aktan, 1997). The actual number is likely to be more than these figures because the statistics do not often take into account "do-it-yourself" (DIY) works, which are carried out by many owners themselves. This figure will increase significantly since the building stock increases consistently every year, and eventually, more obsolescent or old buildings will need to be refurbished.

Both national and international refurbishment markets will be fiercely more competitive in the future. Large contractors are increasingly entering the refurbishment market through direct entry by creating subsidiary divisions (Egbu, 1999b). One of the main factors that gave rise to the rapid increase of BR works is the building location. Most of the "old buildings" are often in strategic locations (e.g. CBD area) and need to be upgraded to maintain their competitive position in the property market. This involves providing tenants with both the image and the level of customer service that the modern office user demands. Finally, the current global financial crisis will also further fuel competition in this area.

BR projects differ from new-build projects in several aspects. BR projects now are generally accepted to be of higher risk than new-build projects (Quah, 1988; Teo, 1991), more complex (Egbu, 1997) and need greater coordination (CIRIA, 1994). BR projects are often subject to planning and management constraints (Egbu, et al 1999a; Marosszeky, 1991). During the planning stage, the task is more akin to detect the work (building diagnostic); the actual condition of the existing building is difficult to capture completely (Friedman and Oppenheimer, 1997; Axelrod, 2000). These uncertainties have consequences for the selection and control of project resources and contracts (CIRIA, 1994).

In high-risk projects, such as BR works, good communication skills are vitally important among both contractors and subcontractors. The contractual relationship between main contractors and subcontractors is the major feature of these activities. The success of the contractor is determined largely by the quality of subcontractors engaged. For example, the majority of construction work is subcontracted (Riding, 1996); which leads to time and cost over-runs. Contractual disputes are common in BR projects because of improper selection of subcontractors (Greenwood, 2001); many faults by a subcontractor are due to them being awarded a job they cannot manage. On the other hand, there are some cases where good subcontractors have been given inappropriate contracts leading to poor results.

Hence, the subcontractors play a major role in the construction industry. The contributions of subcontractors are significant in the construction industry in many countries, for instance, in the UK construction industry, over 90% of the construction work is now sub-contracted (Gray and Flanagan, 1996); in Singapore, approximately 47.7% of site work is sub-contracted (BCA, 2001). These trends are likely to continue, driven by the following technological, political, social and economic changes (Hughes and Murdoch, 1997; Lee, 1997):

1. Technological progress leads to greater specializations,
2. Changes in work patterns and career structures have led to expectations for more autonomy and personal control,

3. The economic situation has caused large firms to subcontract all but their core business,
4. The construction industry has been more susceptible to these changes than other industries.

Subcontractors dominate construction work; consequently, engaging suitable subcontractors is an essential element for the success of BR projects. A contractor needs subcontractors of sufficient caliber and with appropriate resources to execute the BR works at a fair price and with high quality. Faulty subcontractor work may be liable under the main contract and it may tarnish the main contractor’s reputation. In today’s highly competitive, global operating environment, it is impossible to produce low cost, high quality products successfully without the contribution of satisfactory subcontractors.

BR projects remain, however, one of the least understood sectors in Architecture, Engineering and Construction (AEC) practice (Egbu, 1997). The distinctions between BR and new-build projects are insufficiently recognized and managed. Extensive research in this area has been conducted in the United Kingdom and other European countries. However, the current literature has largely concentrated on the client-main contractor relationship, with little reference to the main contractor-subcontractor relationship (Kumaraswamy and Matthew, 2000). In Singapore, although BR work is presently recognized as a distinct sector of the construction industry, very few publications relating to this field exist.

1.3 The Need for a New Decision Making Tool(s)

The decision-making process in the construction industry is more of an art than a science (Hatush and Skitmore, 1997; Holt, 1998). Observations show that most processes for subcontractor selection are made informally (Okoroh and Torrance, 1999; Shash, 1997; Wickwire, 1995). Typically, the task is performed in an unstructured, intuitive manner with considerable reliance on the experience or the judgment of the staff members (Holt, et al., 1994). Most of the selection tasks are measured simply by the lowest price (Kashiwagi and Byfield, 2002; CIB, 1998). These findings are not surprising; Skitmore (1989) states that in the construction industry, there appears to be little use for any formal decision making system.

Currently, the process of subcontractor selection consists of a wide range of criteria for which information is both qualitative and subjective, and sometimes based solely on financial considerations. There is no accepted global standard to evaluate and select the best subcontractor for BR projects (Yeap, 2000; Okoroh and Torrance, 1999; Lee, 1997, 1996; Loh, 1998). However, even with an extensive list of criteria, main contractors still need a method and the tools to consider a number of criteria, and to make optimum decisions in so far as the selection of subcontractors is concerned.

Considering all these aspects, decision-making is a daunting task (Ashworth, 1996; Cole and Sterner, 2000; and Woodward, 1997). Such problems cannot be easily solved using manual or conventional decision-making techniques alone. What is needed is a more scientific method of investigating and analyzing these problems and arriving at an optimum decision. The decision making tool is formulated as a guideline for decision-makers, so that they can make consistent decisions. It is difficult to make economically responsible decisions without an appropriate decision making tool (Tiwari and Baneree, 2001; Harrison, 1999; Turban and Aronson, 2001).

Hence, there is a need to develop a formalized and structured approach to the selection of subcontractors for building refurbishment projects. One of decision making tool to handle this process is a computer aided decision support system (CADSS). The proposed CADSS for subcontractor selection is called the Subcontractor Selection Decision Support System (SSDSS). The model should be suitable in order to assist the main contractors in Singapore.

1.4 Justification for Using Computer Aided DSS

There are many reasons to justify the use of CADSS and developmental efforts in the selection and appointment of subcontractors in BR works, such as imprecise information, non-permanent staff, and the considerable potential of CADSS.

In BR works, there are numerous tasks where decisions are shaped by experience-based capabilities, the future workload of a firm and its general policy. The decision-makers are often required to make a choice on the basis of incomplete and imprecise information during the tender preparation stage (Okoroh and Torrance, 1999). In such a situation, one is likely to find that decision-makers often rely heavily on relatively unstructured methods in arriving at a decision.

Because temporary staffing experts are not permanent; they leave organizations for many reasons, taking their specialist knowledge with them. It requires many years of experience and industrial practice to achieve the status of an expert. The CADSS can act as an archive for such knowledge, thereby providing a means of capturing and storing some limited, but possibly very valuable expertise of previous staff.

A CADSS is valuable in that it helps managers make decisions by presenting information for, and interpretations of, various alternatives (Carlson and Turban, 2002; Bidgoli, 1997; Pal, 2000; Turban and Quaddus 2002; and Shim et al., 2002). The CADSS proposes a computational methodology (concept) hinging on the principle of Knowledge Based System (KBS) techniques. KBS technology provides the tools for collecting, modeling and representing that knowledge in a decision-aid system which brings about benefits to the contractors. The state-of-the-art CADSS combines Graphical User Interface (GUI) with powerful "behind-the-scene" efficient computational technology (Sriram, 1997).

Future generation DSS research has been observed to focus on the theory and application of soft computing management (Beynon, et al., 2002; Bolloju, et al., 2002; Carlson and Turban, 2002; Nemati, et al., 2002; Power and Kaparti, 2002; Power, 2000; Shim et al, 2002; Turban and Anson, 2001; Wang et al., 2002; Zleznikow, 2001).

The concept of the modern DSS approach has been applied to research in the AEC sector (Hew and Awbi, 2001; Konoglu and Arditi, 2001; Reed and Gordon, 2000). In practice, several models were founded in the planning and cost analysis areas (e.g. Mohammed and Celik, 2002), and assessing loan applications (e.g. Brandon, 1998). However, very few modern DSS have been developed in the construction management field, i.e. for procurement systems.

Based on these reasons, the BR subcontractor selection task can reasonably be handled adequately by the CADSS. The ability of CADSS in solving problems has led to cost saving, faster, decision process, and high competitive advantage. The CADSS is needed to aid tedious, but significant, decision making processes in subcontractor selection.

1.5 Research Problems

The literature review (see Chapter 3) found that: (1) many studies were in the artificial intelligence areas, but few studies were on the procurement systems domain; (2) globally, there were only a few publications on subcontractor selection, and hardly any studies were concerned with the selection of subcontractors for refurbishment projects; (3) none of the previous studies had focused on the viewpoint of contractors in Singapore; and (4) there were other gaps in subcontractor selection for BR projects.

The features of BR work have consequences with regard to the difficulties in selecting subcontractors, such as: (1) incomplete information; (2) decisions having to be made quickly; and (3) unavailability of appropriate tools for guidance. Because of these constraints, the main contractor faces difficulties in making decisions consistently and accurately; their decisions may be based solely on their judgments and experience, consequently, there are often oversights in making decisions. Based on these difficulties, the research problems are:

1. The knowledge of the selection task, including model factors, criteria, attributes, and their set ranking to engage subcontractors in BR works are undefined.
2. The framework for knowledge acquisition, storage, and retrieval of information for subcontractor selection in BR works need to be re-defined and applied using computer software.

The research problems can best be summarized in the following statement:

How can the knowledge of the selection task, including factors that influence decision-making, be differentiated, and in what way can such knowledge and factors be represented in a CADSS for use in selecting subcontractors for building refurbishment works?

1.6 Objectives

This research seeks to develop a formalized and structured approach to the selection of subcontractors for building refurbishment projects. The process of subcontractor selection is embedded in a CADSS, which is called the "subcontractor selection decision support system" (SSDSS). The SSDSS provides guidelines for the decision-maker to evaluate alternatives that optimally meet the technical, economic and non-economic considerations of the main contractor.

This present research is an initiative to identify and capture knowledge, logical relations, and heuristic rules used by decision-makers, as well as to embody them in a decision support tool as a way of assisting and automating the processes of subcontractor selection for BR projects. The incorporating of subjective, qualitative, and quantitative information into a KB adds more dimensions to enhance the credibility of the overall process for subcontractor selection.

Hence, the research will pursue the following objectives:

1. To review previous studies of subcontractor selection both in Singapore and abroad.
2. To review the current situation regarding subcontract practices of BR works within the Singapore construction industry.
3. To identify and classify significant factors that main contractors should consider during decision-making in subcontractor selection for BR projects.
4. To analyze the contributing (ranking) factors and define an appropriate set of model factors, criteria and sub-criteria (attributes) for subcontractor selection.
5. To develop a framework for the SSDSS, to apply the framework using computer software and to validate the SSDSS.

1.7 Research Hypotheses

It would appear that almost all criteria for subcontractor selection rely on the price factor. However, this present research is based on the general hypothesis that:

There is a combination of criteria, apart from price, which main contractors should consider when selecting subcontractors for BR projects.

This general hypothesis is elaborated in three main hypotheses as follows:

H1. Main contractors select subcontractors for BR projects based on the project specifications.

H2. Main contractors select subcontractors for BR projects based on the subcontractor's profile.

H3. Main contractors select subcontractors for BR projects based on their special considerations.

1.8 Scope and Definition

The accuracy of the keyword definitions is crucial. Mansfield (2002) suggests that because of the comparative lack of precision in using a range of terms, it might further blur the boundaries between the tasks. Some definitions concerning refurbishment, decision-making, and IDSS areas have been recognized, but it's difficult to get an acceptable universal definition. The scope and definitions of the keywords are clarified in this section.

1.8.1 Refurbishment

Refurbishment comes from the word "re", to do again, and "furbish", to polish or rub up (Douglass, 2002). In a longer definition, some publications define refurbishment as construction work to an existing facility to update or change the facilities, which it provides, and may include, or be carried out in connection with some new-facility extensions of accommodation. The types of work include reconstruction, upgrading, renewal, restoration, alteration, conservation, rearrangement, conversion and expansion. The type of construction can be general building and/or civil engineering work.

Refurbishment has become a generic, interchangeable term, apparently indistinguishable from other specialist activities (Mansfield, 2002). There are many terms used in practice to describe refurbishment, different terms being used from country to country; some of the more common being upgrading, conversion, repair, retrofit, adaptation, and renovation.

Of these terms, refurbishment or upgrading is commonly used in Singapore (BCA, 2003), Europe and other Commonwealth countries, while renovation or retrofit is popular in the United State and various other countries (CIRIA, 1994). Douglas (2002) used the broad term adaptation to include refurbishment, rehabilitation, remodeling, renovation, retrofitting and restoration.

The Building and Construction Authority (BCA) in Singapore uses the term "repairs and decorations" for the classification of work related contractors in the directory of registered contractors. However, this classification covers contractors for any upgrading work without building structure alterations (BCA, 2003), mostly cleaning and painting work. This is similar to the definition by Rosenfeld and Shohet (1999) that refurbishment is considered to prolong the effective life of the facility, without substantial changes in its original characteristics, although it may include some limited acts of remodeling and modification of sub-systems.

In this research, refurbishment, retrofit, and renovation terms were used interchangeably, and defined as: extensive repair, renewal and modification of a building to meet economic and/or functional criteria equivalent to those required for a new building. This could involve the installation of current building system standards: structures, envelopes, interiors and layouts, ventilation and lighting systems, using standard materials for a new building.

This research focuses on building refurbishment works in the construction industry in Singapore.

1.8.2 Subcontract Relationships

Under the standard form of contract, there are three broad categories of subcontract relationships: nominated, domestic, and named subcontractors. This present research focuses on the selection of domestic subcontractors, because the selection process of this approach is entirely dependent on the influence of the main contractors. In this case, the essential contribution of the subcontractor is to carry out specific BR works, which may include design work; bringing in skilled labors, materials, special plants and machinery. For the appointment of the suppliers, or other specialists, or even other types of work, this selection model may also be utilized, after making some adjustments in the selection criteria; however, that is not within the scope of this study.

1.8.3 Decision-Making

All managerial activities revolve around decision-making, which is a process of choosing among alternative courses of action for attaining goals (Moore and

Tomas, 1976; Simon 1977; Smith, 1998). This research focuses on the scenario where the main contractor has to select potential BR subcontractors subject to time pressure.

The phases of problem solving and decision-making are found in the literature. However, there is no consensus to differentiate between them (Turban and Aronson, 2001). Some consider the entire three phases (intelligence, design, and choice phases) as problem solving, with the choice phase as the actual decision-making. Others view phases one to three as formal decision-making, ending with a recommendation, whereas problem solving additionally includes the actual implementation of the recommendation. In this research, the decision-making and problem solving processes are used interchangeably.

1.8.4 Computer Aided Decision Support System

A computer is an electronic device, operating under the control of instruction stored in its own memory unit, which can accept data (input), process data arithmatically and logically, produce output from the processing, and store the results for the future use. A computer allows a decision maker to perform large numbers of computation very quickly and at a low cost (Turban and Aronson, 2001).

In this research, CADSS is defined as interactive computer-based information systems that utilize decision-making rules and models, coupled with a comprehensive database to help main contractors select a subcontractor. CADSS is a tool for decision makers to extend their capabilities, but not to replace their judgment. They are geared toward decisions where judgment is required or for decisions that cannot be completely supported by algorithms (Drummond, 1996; Zeleznikow and Nolan, 2001).

This present research is an automated tool, which involves multidisciplinary project management, and computer science research that applies CADSS methods and technologies to deal with the selection of potential subcontractors for BR works.

A computer system is designed and implemented to take care of the screening, shifting and filtering of data, information and knowledge (Carlson and Turban, 2002). Knowledge base is a component of the subcontractor selection decision support system (SSDSS) which handles those tasks.

A KBS is a computer system that attempts to replicate specific human expert intelligent activities (Mockler and Dologite, 1992). KBS is a methodology that combines qualitative and quantitative criteria in the form of heuristic or rule of thumb to aid in decision-making (Sriram, 1997). A KBS attempts to model an expert so that his knowledge in a specific domain is always readily available to users for the purposes of decision-making, diagnosing, forecasting and other applications. More details of "computer aided decision support system" are discussed in Chapter 2.

1.9 Contributions and Limitation of the research

The contributions and limitation of the research are discussed in Chapter 9.

1.10 Structure of the Thesis

This thesis is organized in nine chapters. Chapters 2 and 3 provide comprehensive literature review on decision-making, computer aided decision support systems, building refurbishment works, and other relevant studies. These chapters also discuss the existing practice of building refurbishment and procurement process, and finally, identify the knowledge gaps.

Chapter 4 discusses the research methodology, describing the strategy of data collection and analysis. It also covers the techniques of model development.

Chapter 5 presents the theoretical framework for the factors that influence the selection of potential subcontractors for BR projects. This chapter discusses the criteria used, and the relationships of the criteria in logical mapping. It also analyzes and presents an appropriate procurement strategy for the selection of BR subcontractors.

Chapter 6 presents the findings of the fieldwork that consists of knowledge acquired through interaction with domain experts. The findings of the fieldwork provide a comprehensive elucidation; it is divided into two chapters (Chapter 6 and Chapter 7). This chapter discusses the analysis of the interviews with the main contractors in Singapore.

Chapter 7 discusses the analysis of the questionnaire responses from the main contractors in Singapore.

Chapter 8 discusses the model development and application. This chapter also explains the model validation to ensure the robustness of the model.

Chapter 9 summarizes the main findings of this research and suggests proposals for future research.

Chapter 2
COMPUTER AIDED DECISION SUPPORT SYSTEMS

2.1 Introduction

The research result provides a comprehensive evaluation of decision alternatives for engaging subcontractors in BR projects and to present a CADSS. To develop CADSS, the construction of a knowledge base, which reflects the heuristics aspect of domain expert (DE), is the main activity. The knowledge acquisition (KA) stage is concerned with the most critical issues.

In the knowledge acquisition stage, three types of knowledge were captured from documented sources and several DEs, i.e. criteria and attributes (facts), processes and expertise (concepts and rules), and weighting criteria of subcontractor selection (rules). Knowledge from documented sources was captured through literature review; while the expertise of the subcontractor selection process was captured from the DEs through interviews.

The literature review examines decision theories, computer science, with specific reference to computer aided decision support system, the features of building refurbishment, and other relevant studies. To present the theoretical framework of the research, besides these reviews, other concepts from supply-chain management, human resource management, and personnel selection were reviewed.

In order to provide a comprehensive discussion, this review was divided into two chapters (Chapter 2 and 3). This chapter reviews attitude with regard to the principle of decision-making, the outline of the fundamental structure of KBS, and the computer systems.

Chapter 3 comprises review of refurbishment studies, including the current practice of subcontractor selection. In the last section of this chapter, knowledge gaps are identified, and the research problems and hypotheses are formulated.

2.2 Decision-Making

In BR project management, there are numerous decisions that should be made, for example, in the procurement strategy, when the quotations have been received and a decision must be made regarding which quotation to accept. It involves the development and consideration of a wide range of necessary and sufficient decision criteria, as well as the participation of many decision-making parties (Brook, 2001).

The anatomy of decision-making associated with subcontractor selection can be explained through the following topics: types of decisions, decision-making processes, and challenges in decision-making.

2.2.1 Types of Decisions

Decision-making problems involve numerous issues, depending on the properties, that one wants to highlight (Kaymak, 2002). Business decisions can be divided into three categories: (1) strategic decisions, (2) administrative decisions, and (3) operating decisions. These categories typify the management approach to decision-making, by relating decisions to the functional divisions of the organization (Simon, 1977). Strategic decisions are seen as being made by senior managers, whose decisions influence policies and affect the organization's relationship with its external environment. Administrative and operating decisions are carried out by middle management (Chicken, 1994; Simon, 1977).

In this sense, selection of a subcontractor and contract strategy should be made by senior staff or the management. The term, contract strategy, is used to describe the organizational and contractual policies chosen for the execution of a specific project. For a refurbishment project, the strategy must take into account uncertainty (coupled with high client involvement) as well as possible continued occupancy and the technical problems associated with renewing an existing asset (CIRIA, 1994; Egbu, 1997).

The strategy must establish cooperative working relationships between the parties at an early stage of the project, and maintain them thereafter. It also requires a level of flexibility appropriate to the site, uncertainty, and complexity of the project. The main contract between the employer and main contractor will affect the relationship of the main contractor and sub-contractors. These features will impinge upon the criteria of subcontractor selection for BR projects.

2.2.2 Decision-Making Process

Making decisions is a key action taken in the selection process. In decision theory, several steps for the selection process have been proposed, for example, decision-making involves three interacting sub-processes that precede the actual decision, including: (1) gathering information; (2) generating, contemplating; and (3) evaluating alternative courses of action, as well as processes of implementation and evaluation that should follow a decision once it is made (Turban and Aronson, 2001). These activities can be classified into three phases, which are called, the "three phases of Simon's model": intelligence, design, and choice (Kersten, 1999; Simon, 1977). These steps can also be regarded as a three-stage process of option identification, evaluation, and selection (Kersten, 1999; Chicken, 1994).

In human resource management (HRM) literature, Roe (1989) proposed a major function of decision-making procedures that is understandable and most commonly used, and may be relevant to subcontractor selection. Roe (1989) proposed the following four stages:

1. *Information gathering*: obtaining information about job openings, job contents, job requirements, etc. and on physical, behavioral and biographical characteristics of applicants.

2. *Prediction*: transforming, information on (past and present) applicant characteristics into a prediction about their future behavior, and the resulting contributions to organizational goals.
3. *Decision making*: transforming predictive information on applicants into a preferred action.
4. *Information supply*: producing information on applicant characteristics, predicted behavior, plans for action (decisions), etc.

A structure of these functions and their logical interactions are depicted in the flowchart as shown in Figure 2.1.

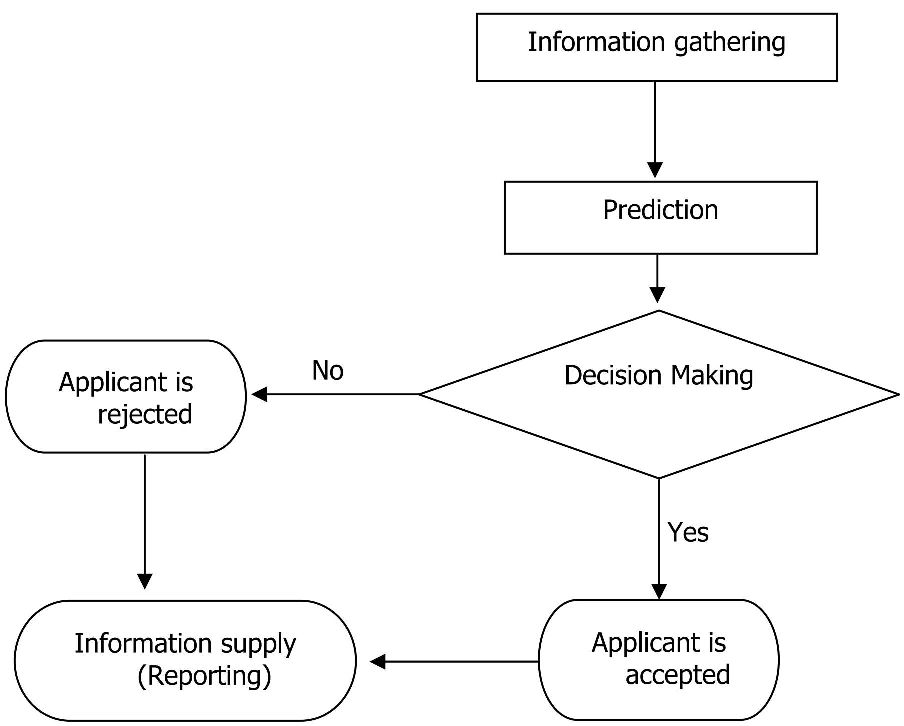


Figure 2.1 Flow diagram of selection procedures

Selecting subcontractors is essentially about the decision-making process that occurs within the overall procurement strategy. The process of evaluating and selecting a subcontractor starts with a sourcing request. A sourcing request can originate from any one number of scenarios: a new BR project may require the evaluation of a subcontractor; the main contractor may be dissatisfied with the current subcontractor's service that creates a need to evaluate an alternative subcontractor, or the main contractor's strategy is to maintain competitiveness through competitive subcontractors. Many other sourcing request scenarios can also be listed, but those described above are representative of the origins of such requests.

In general, making decisions in the management of BR projects, as well as new-build projects may be similar. However, the features of new-build and BR projects are quite different. The risks and level of uncertainties are higher in BR than in new-build projects. These features will drive the decision-maker to handle BR projects in different ways. The selection procedures model in Figure 2.1 represents a basic structure of practical decision making for selecting alternatives. It is a framework of the SSDSS model development, which involves the comparison of the evaluated criteria with the attributes of subcontractor performance.

2.2.3 Challenges in Decision- Making

Selecting subcontractors for a BR project is a management responsibility, which is characterized by nonlinear and complex tasks, uncertain situations, technical and non-technical information which must be considered, and involvement of both qualitative or judgmental, and quantitative decisions. The decision-making task relies heavily on judgment (Shim, et al., 2002). The process is often performed without the aid of a computer to manipulate the types of data presented in the selection decisions (Holt, et al., 1995).

In practice, it is difficult to make decisions for several reasons: First, a human mind is limited in its ability to process and store information. People may have difficulties recalling information in an error free fashion when it is required (Janis and Mann, 1977). Human decisions tend to be biased because of numerous factors, both internal (human ability) and external (environmental) aspects.

Second, the number of available alternatives is much larger today than ever before because of improved technology and competitive pressure (CIRIA, 1997; Gray and Flanagan, 1996).

Third, competition is not merely based on price, but also on quality, timeliness, customization of products, and customer support. The ability of contractors to meet requirements of the main contract will affect selection of a subcontractor (Grundberg, 1997).

Fourth, there are continuous changes in the fluctuating environment, client requirements, hence more uncertainty. Finally, because of time restraints, decisions must be made quickly. No matter what the procurement method used, after the main contract is awarded, the main contractor has to put together his project team, including subcontractors before a commencement letter is issued. In practice, this short period may be less than a week.

Because of these constraints, it is difficult to rely on judgment, intuition, and the trial and error approach to management. Therefore, an innovative decision support tool, which assists the decision-maker in overcoming these internal and external issues, is essential. Using Decision Support System (DSS) tools to support decision-making can be extremely rewarding and effective in making appropriate decisions (Beynon, 2002; Carlson and Turban, 2002; Drummond, 1996). Decision support tools for the future should base on the principle of a computerized (automation) system.

2.3 Decision Support Systems (DSS)

Decision support systems (DSS) are computer-based systems used to assist and aid decision makers in their decision making processes (Kersten, 1999). Little (1970) proposed that a DSS be "a model-based set of procedures for processing data and judgments to assist a manager in his decision making". Other definition by Keen and Scott-Morton (1978) that DSS couple the intellectual resources of individuals with the capabilities of computers to improve the quality of decisions. It is a computer-based support for management decision makers who deal with semi-structured problems.

The DSS technique used is dependent on the problems to be solved. Some problems are structured and can be solved by using traditional quantitative models, such as the mathematical model. Other problems include semi-structured or unstructured problems, which cannot be handled by conventional methods. The conventional methods are not appropriate for handling the often vague and non-quantitative objectives and constraints.

The decision-making procedure varies with each problem to be solved, and a decision theory provides decision makers with a wide range of instruments that can be applied to uncover existing relationships and to help represent, analyze, solve and evaluate decision problems. Chicken (1994) proposed various analyses of decision support techniques, for instance, public debates, risk analysis, forecasting, regression, decision trees, cognitive mapping, game theory, multivariate analysis, etc. Chicken (1994) exposed fundamental limitations, and potential rules of the techniques. However, the guidance is not simply assistance; the project cases proposed are mostly constructed in the 1970s, which utilized conventional methods, and not an automated model. In addition, the main idea of the guidance is specifically for project risk assessment.

Turban and Aronson (2001) rephrased Gorry and Scott's (1971) decision support framework so that it can be used easily for classifying problems and selecting appropriate tools. The framework in Table 2.1 is actually a combination of Simon's (1977) and Anthony's (1965) models. The left side of Table 2.1 is based on Simon's (1977) idea that the decision-making process falls along a continuum that ranges from highly structured (program) to highly unstructured (non-program) decisions. Structured processes are routine and typically involve repetitive problems for which standard solution methods exist. Unstructured processes are fuzzy, complex problems for which there is no short-cut solution.

The second half of the framework is based on Anthony's (1965) idea, which defines three broad categories that encompass all managerial activities: (1) "Strategic planning", defining long-range goals and policies for resource allocation; (2) "Managerial control", the acquisition and efficient use of resources in the accomplishment of organizational goals; and (3) "Operational control", the efficient and effective execution of specific tasks.

Based on Table 2.1, the technology support needed may range from DSS, Expert System (ES), management science, and Neural Network techniques (see "boxes" in Table 2.1).

Table 2.1 Decision Support Frameworks

Type of Decision	Type of Control			Technology Support Needed
	Operational Control	Managerial Control	Strategic Planning	
Structured	Accounts, Receivable, Order-Entry	Budget analysis, Forecasting	Financial management, Distribution system	MIS, OR, Transaction processing
Semi-structured	Production, Inventory, Control	Budget preparation, Project scheduling	Building new plant, Merger and Acquisition, Quality assurance	DSS, KMS
Unstructured	Approving application, Buying	Negotiation, Recruiting, Lobbying	R&D planning, New technology development	IDSS, ES, Neural Network
Technology Support Needed	MIS and Management Science	Management science, DSS, ES	ES, Neural network, KMS	

Based on the framework in Table 2.1, it can be understood that using a DSS as a stand-alone system, although it has strengths in some functions, may have limitations in others. Therefore, a system that integrates knowledge with database management systems, graphics, qualitative and quantitative methods and/or other modeling techniques is of utmost importance to provide decision makers with an efficient decision making process. DSS should provide the basic features of computer-based systems (for example, adaptability, ease of use, and data integration).

In this present research the DSS is called computer aided decision support systems. The integrated CADSS model, which consists of Knowledge-Based System and a database, is applied to and called the subcontractor selection decision support system (SSDSS). The next section discusses the outlines of the CADSS.

2.4 Computer Aided Decision Support System (CADSS)

A DSS is usually built to support the solution of a managerial control problem, e.g. negotiations, lobbying, and recruitment/selection tasks. Decision support is called "intelligence" if an intelligent agent (artificial intelligence = AI) is included in the system (Jackson, 1999; Mockler and Dologite, 1992).

Several names were used to describe the intelligent agent, including "software agents" (Murch and Johnson, 1999). The term "agent" is derived from the concept of agency, referring to employing someone to act on your behalf (Turban and Aronson, 2001). A human agent represents a person and interacts with others to accomplish a predefined task.

Turban and Aronson (2001) suggest that DSS are usually developed for complex situations, which require both qualitative and quantitative techniques. Subcontractor selection for refurbishment projects is complex, and a managerial control type of problem.

The subcontractor selection process appears as a proper domain to treat the decision support model, which is characterized by the following:

1. Many factors to be considered
2. Multiple decision makers are involved

3. Interdisciplinary subjects, and
4. Uncertainty.

The CADSS is built to fulfill two key functions: (1) screening, shifting and filtering of a growing overflow of data, and (2) support of an effective and productive use of information systems. Soft computing has been designed and implemented to take care of the screening, shifting and filtering of data, information and knowledge (Carlsson and Turban, 2002).

2.4.1 Heuristics

Heuristics are included as a key element of CADSS in the definition, which deals with ways of representing knowledge with rule-of-thumb tactics. Heuristics are decision rules governing how a problem should be solved. People often use heuristics consciously to make decisions. By using heuristics, one does not have to rethink completely what to do every time a similar problem is encountered (Turban and Aronson, 2001). For this research, the heuristics express the informal judgmental knowledge in selecting a subcontractor.

In conventional programming, data is generally provided and processed in an algorithmic manner. Repetitive processes are copied onto data in the correct form and type. CADSS has the ability, as well as carrying out algorithmic processing, to operate with uncertain data or ranges of data. Data can be provided in many forms to the system, which will attempt to deduce as much as it can from this input data, using the information contained in the knowledge bases and the inference mechanisms provided.

2.4.2 Knowledge Separation

In CADSS, the knowledge is distinctly separate from the control mechanisms or inference engine. The knowledge can be stored in a structured format, for example, knowledge bases or rule-sets, and separate inference mechanisms operate on this data to produce results. Both knowledge bases and the inference mechanisms may be modified independently of each other. More information regarding this topic can be seen in Medsker, et al. (1995); Mockler and Dologite (1992); Prerau (1990); Sriram, (1997); and Turban and Aronson (2001).

Rowlinson (1999) criticized that one of the problems with a majority of conventional computer-based systems is that the logic behind the advice given is not readily apparent. Park (1999) also criticized specifically that the common KBS applied mostly the "black box" approach. This approach would be extremely difficult to maintain because the whole knowledge base has to re-program to adapt even for the slightest change.

2.5 Decision Analysis Techniques

In building refurbishment projects, subcontractor evaluation is characterized by time pressure, uncertain condition and incomplete information regarding the existing building conditions. Furthermore, the number of factors and variables to be considered is significant, which may make the evaluation by the main contractors difficult.

These factors are probably not of equal importance; each subcontractor may fulfill each variable to a different degree. For example, one subcontractor may have experience, but proposes a higher quotation price. On the other hand, another subcontractor may offer a lower price, but he has less experience. The decision makers, with their limitations, may thus find it difficult to decide which subcontractor is the most suitable. In this case, the weighting criteria analysis tool is needed, in which each decision parameter and its relative weight is of an important degree and is determined by the main contractor's strategy. Analytical decision tools can help the decision makers to overcome their limitations by providing a consistent and structured framework for weighting factors (Kaymak, 2002; Moore and Thomas, 1976).

Generally, a decision problem involves the examination of a set of potential alternatives over a set of criteria (both qualitative and quantitative). For this present research, a framework for a computerized hybrid decision support tool was introduced to analyze subcontractors' characteristics and capabilities in the light of their suitability to fulfill the BR project requirements. The hybrid model is a method that integrates several techniques into a one-package system. As the decision process proceeds, quantification of the factors will be computed by a quantitative (mathematical) model, while the qualitative problems will be handled by KBS through rule-based reasoning.

2.5.1 Mathematical Model

A mathematical model is a family of tools designed to help solve managerial problems in which the decision maker must allocate scarce resources among competing activities to optimize a measurable goal (Turban and Aronson, 2001).

For this present research, the mathematical model is needed to quantify the weight of the factors/attributes, and to identify the most optimum combination of the factors (subcontractors' attributes). Numerous sub-classes of mathematical techniques can be used in weighting criteria. Because of the vast literature available regarding selection tasks, the methodology chosen is referred to in the literature, which was based on the requirement of the model selection.

The requirements for an effective methodology of model selection are based on a simple mathematical operation that is easy to follow and understand even by a non-scientist, with the result of it being sufficiently accurate and widely used. Beside the requirement of simple mathematical operations, the preferred method should also be able to handle multi-level attributes in a hierarchy tree (see also the criteria of effective DSS in section 2.7). By realizing these requirements, contractors would be expected to use the model.

There are three techniques, which are commonly used in the selection tasks process: neural network (NN), Fuzzy sets model, linear programming (LP), and multi criteria decision-making (MCDM). Based on the model requirements, the NN and Fuzzy set methods were not considered. Although they are popular in scientific research, they involve complex mathematical calculations and computer programming (Mak et al, 1996). Holt (1998) noted that the practitioners might be reluctant to apply these techniques because of their complex nature. Ling (1998) noted that these techniques do not have a unique method to drive the importance weights.

Another technique is LP technique that is popularly used for the decision-making process. The LP technique maximizes or minimizes a linear function subject to linear system of constraints (Griffis and Farr, 2000). This technique has also been applied in the AEC area, for instance Gustafson (2001). However, LP is appropriate to make decisions on design alternatives, not in the selection of candidates. In selection of design alternatives, the alternatives are not predetermined; on the other hand, in the selection of a candidate, the alternatives are predetermined. Furthermore, Russell (1992) explained that requiring decision makers to supply probability that each rating would occur in a linear model is complicated and not likely to be of much use in the application of candidate selection.

The MCDM is powerful in solving central decision problem, which is how to evaluate and rank the performance of a set of choices in terms of the decision criteria. The MCDM abilities comply with the requirements of the effective model. This technique also utilizes relatively simpler mathematical calculations than the earlier techniques. Based on these reasons, the MCDM was applied in this research.

There are three steps in utilizing any the MCDM technique involving numerical analysis of alternatives:

1. Determine the relevant criteria and alternative.
2. Attach numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria.
3. Process the numerical values to determine a ranking of each alternative.

The MCDM technique has been widely applied in many research studies (Yoon and Kim, 1989; Park and Kim, 1997; Humpreys, et al., 2003), including several applications in the AEC area, for example, see Russell (1992); Holt, et al. (1994); Krassadaki and Siskos (2000); Ling, et al. (2003), etc.

However, the MCDM technique has some sub-classes; the appropriate analysis technique needs to be chosen from these sub-classes. According to many authors, the MCDM can be classified in many ways, for example, it may be broadly classified in terms of multi-objective decision-making (MODM) and multi-attribute decision-making (MADM) (Triantaphyllou, 2000). The MODM is a problem-solving technique in which the objectives are not predetermined, and it is therefore commonly used for design (that is, designing the best option with respect to purchaser objectives). Such an approach is unrealistic for subcontractor selection. For these reasons, MODM is not considered further in this research.

Conversely, MADM is most widely applied (Triantaphyllou, 2000); the MADM is capable of helping to select (identify) optimum choices with respect to the same objectives where the decision alternatives are predetermined (Yoon and Kim, 1989). Fellow, et al. (1983) suggested that MADM is a methodology that can be used as a tool to measure objectivity in an otherwise subjective area of management. This is relevant to the characteristic of factors to be considered in subcontractor selection for BR projects.

The MADM also has some sub-classes. Although Holt (1998) argued that absolute classification of some selection methodology is not possible, Chen and Hwang (1991) have proposed the most common MADM classification based on the type of information available (see Figure 2.2). More information concerning this topic can be found in Park and Kim (1997), Triantaphyllou (2000), and Yoon and Kim (1989).

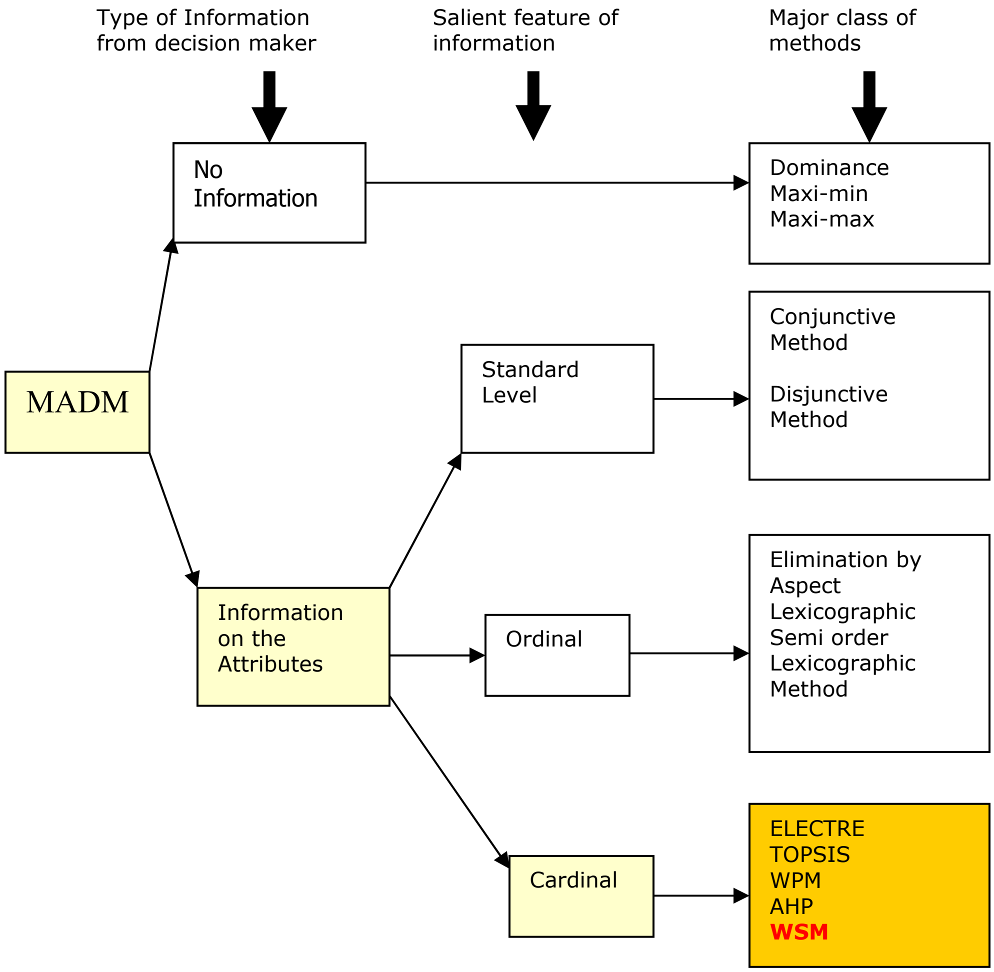


Figure 2.2 Taxonomy of MADM
(Source: adapted from Chen and Hwang, 1991)

The appropriate analysis technique may be selected through the taxonomy of MADM. Norris and Marshal (1995) suggested that, in principle, any MADM, which requires cardinal weighting of attributes, could utilize one of the following techniques: Elimination and Choice Translating Realty (ELECTRE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Weighted Product Model (WPM), Analytical Hierarchy Process (AHP) model, and Weighted Sum Model (WSM). Based on the taxonomy of Figure 2.2 and the characteristics of the subcontractor selection process for a BR project, these methods may be applied appropriately.

The ELECTRE method is especially convenient when there are decision problems that involve a few criteria with a large number of alternatives (Triantaphyllou, 2000). However, disadvantages of the ELECTRE are that the technique is sometimes unable to identify the most preferred alternative, and is unrealistic for the problem of subcontractor selection.

In the TOPSIS method, the ideal solution has to be identified in advance. The basic concept of this method is that the selected alternative should have the shortest distance from the ideal solution and farther distance from the negative-ideal solution in some geometrical sense (Triantaphyllou, 2000). This method is also unrealistic for the problem of subcontractor selection. Because of these reasons, the ELECTRE and TOPSIS methods were not considered in this research.

Another method is the WPM, which is sometimes called dimensionless analysis because its structure eliminates any units of measurement. It is a sophisticated technique, which can be used in single and multi-dimensional MCDM. An advantage of this method is that instead of the actual values, relative ones can be used (Triantaphyllou, 2000). However, this comparatively sophisticated technique has not been widely utilized because many decision makers are not familiar with its complexity. Ling (1998) found that no construction-related research used this method. Because of these reasons, this method was not used in the research of subcontractor selection for BR projects.

The last two methods are the WSM and AHP method, which are the most widely used. Both methods are also called the additive weighting method. The basic logic of the additive weighting method is cardinal alternative scores and cardinal attribute weights.

Cardinal Alternative Scores. Additive weighting methods use cardinal numerical scores, which characterize the overall desirability of each alternative. These desirability scores, D_i (for each of the m alternatives, i= 1, ... m), can then be used to rank the alternatives, to identify a subset of most preferred alternatives, or to select the single most preferred alternative.

Cardinal Attribute Weights. The relative importance of attributes to the decision maker is defined to be constant across alternatives, and is described using cardinal weights (w_k) which the decision maker assigns to each of the n attributes, k=1, ... n. The weights are generally normalized so that they sum to 1.

A comprehensive survey of MADM and applications found that additive weighting methods are probably the best known and most widely used of all MADM owing to their simple and intuitive logic, their multi-purpose functionality, and their incorporation of compensatory tradeoffs among attributes (Norris and Marshall, 1995). In the next sections, only the AHP method and the WSM are evaluated.

2.5.1.1 Analytical Hierarchy Process (AHP) Method

Saaty (1980) popularized the AHP, and a number of special issues in refereed journals have been devoted to AHP and the use of pair-wise comparison in decision-making (Emblemsvag and Tonning, 2003). The AHP method has also been applied in a contractor selection model (e.g. Fong and Choi, 2000). However, some opponents of this model, for example, Belton and Gear (1983) criticized that the best alternative resulted is inconsistent. Render and Stair (2000) also argued that the AHP model involves a large number of calculations.

Ra (1999) criticized that the pair-wise comparison technique was a time-consuming process for the large numbers of decision elements. The explosion of pair-wise comparisons was another limitation of this technique. The number of pair-wise comparisons, which is the basis of this technique, is governed by the formula $n(n-1)/12$. Ra (1999) found that 45-paired comparisons were required for a ten-decision element, and 190 for 20 elements. The increase in paired comparisons is especially significant for large hierarchies. Ling (1998) also found that when 40 attributes were identified in her model, the numbers of pair-wise comparisons exploded to 780!

Decision-makers might lose interest in pair-wise comparisons because of the large number of comparisons required. Although some authors revised these limitations, e.g. Belton and Gear (1983) and Ra (1999), it is still debatable. For these reasons, the AHP method will not be used for this research.

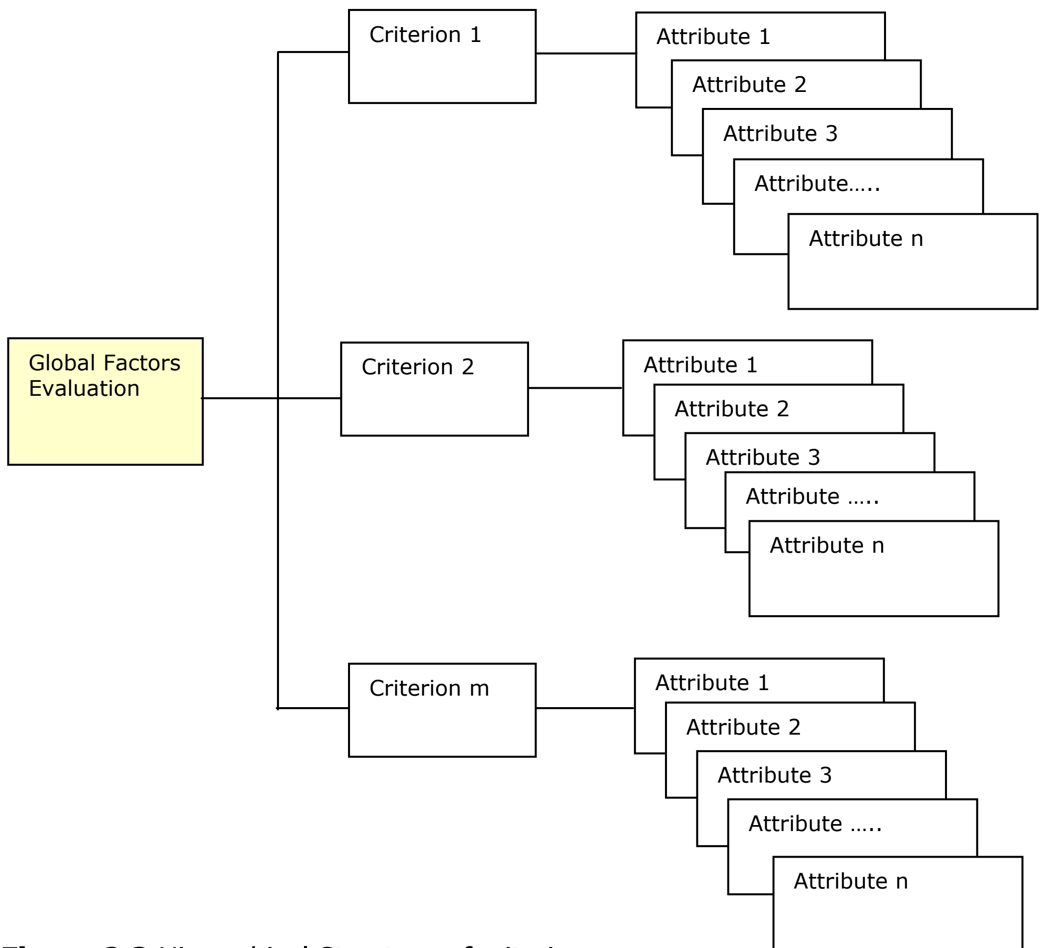


Figure 2.3 Hierarchical Structure of criteria

2.5.1.2 Weighted Sum Method (WSM)

The WSM has been widely applied in many research fields (Park and Kim, 1997; Triantaphyllou, 2000; Yoon and Kim, 1989). A simpler approach based on WSM multiple criterion decision-making has been applied to several models, including in AEC areas, such as Russell (1992); Holt, et al. (1994); Triantaphyllou, et al. (1997); Raju and Pillay (1999); Krassadaki and Siskos (2000); Oliveira and Lourenco (2002); Ling, et al. (2003), etc.

In principle, the WSM is quite similar to the AHP method. The only difference is that in the AHP method, the factors' weight and evaluation are computed by the number of pair-wise comparison matrix, while in the WSM, the evaluation factors do not use pair-wise comparison. The following section describes WSM in detail.

The basic conventions' terms are alternatives, weighted elicitation method, and multi attributes. Usually "alternatives", options, or candidates represent the different choices of an action available to the decision maker. "Weight elicitation methods" are important to contractors as decision-makers because it expresses the importance of each attribute relative to the others. "Multi attributes" are also referred to "decision criteria". Attributes represent the different dimensions from which the alternatives can be viewed. The factor consists of criteria and attributes of alternatives (subcontractors).

In a case where the number of criteria is large, criteria may be arranged in a hierarchical manner. That is, some criteria may be major ones. Each factor may be associated with several criteria. Similarly, each criterion may be associated with several attributes and so on. A hierarchical structure of criteria and their weights is shown in Figure 2.3.

Decision Matrix

The hierarchical structure in Figure 2.3, as a MADM problem, can be easily expressed in a matrix format, as shown in Table 2.2. The decision matrix A is an (*m* x *n*) matrix in which element a_{ij} indicates the performance of alternative A_i when it is evaluated in terms of decision criterion C_j (for *i*=1, 2, 3, ….., *m* and *j* = 1, 2, 3, …*n*). It is also assumed that the decision-maker has determined the weights of relative performance of the decision criteria (denoted as w_j, for *j*= 1, 2, 3, ……, *n*). This information is summarized in definition: *Let A = { A_i , for i= 1, 2, 3, ….., n} be a set of decision alternatives and C = { c_j , for j= 1, 2, 3, …, m} a set of criteria according to which the desirability of an action is judged. Determine the optimal alternative A^* with the highest degree of desirability with respect to all relevant criteria c_j.*

Table 2.2 A typical decision matrix

	Criteria				
	C_1	C_2	C_3	……..	C_n
Alternatives	(w_1	w_2	w_3	……..	w_n)
A_1	a_{11}	A_{12}	a_{13}	……..	a_{1n}
A_2	a_{21}	a_{22}	a_{23}	…….	a_{2n}
…..	….	….	….	……..	………
……	….	….	…..	……..	……..
A_m	a_{m1}	a_{m2}	a_{m3}		a_{mn}

The typical decision matrix can be formalized by a mathematical equation, as shown in Equation 2.1.

$$A_{i(WSM-score)} = \sum_{j=1}^{n} a_{ij} w_j \quad \text{for } i=1, 2, 3, \ldots, m \ldots\ldots\ldots(2.1)$$

The WSM is probably the commonly used approach, especially in single dimension problems (Triantaphyllou, 2000). If there are *m* alternatives and *n* criteria then, the best alternative is the one that satisfies the following expression:

$$A^{*}_{(WSM-score)} = \max_{i} \sum_{j=1}^{n} a_{ij} w_j \quad \text{for } i=1, 2, 3, \ldots, m \ldots\ldots\ldots(2.2)$$

where:

$A^{*}_{(WSM\text{-}score)}$	: is the *WSM* score of the best alternative.
n	: is the number of decision criteria
a_{ij}	: is the actual value of the *i-th* alternative in terms of the *j-th* criterion
w_j	: is the weight of importance of the *j-th* criterion

It appears that the procedure of the WSM is easier than the other models and does not pose any unnecessary mathematical sophistication. This may be an advantage to apply the technique for the subcontractor selection model because the main contractors may be reluctant to utilize a complicated mathematical model. Holt (1994) noted that MADM is a term also known as "simple scoring MCDM", and because of its simplicity, it is the most widely used in the industry.

Other advantages of adopting the WSM for subcontractor selection are:

1. Simplicity of model, its ease of understanding and use by construction practitioners.
2. Provision for a systematic, structured approach to the evaluation of subcontractors against the same planned and weighted criterion.
3. The calculated score of each subcontractor provides a basis for comparison and rational decision-making. Therefore, this process eliminates unwillingly biased decisions and guesswork.
4. The model provides traceable documentation, explaining why subcontractors are selected. This is valuable when record keeping of the selection process is required due to a nominated or named subcontractor.

Based on these advantages, the multi-criteria decision making (MCDM) with WSM rating technique is most appropriate for the research on subcontractor selection for BR projects.

2.5.2 Knowledge Based System (KBS)

KBS is an interactive computer program incorporating judgmental experience, rules of thumb (heuristics), intuition and other expertise to provide knowledgeable advice to decisions in a specific domain by mimicking the decision-making process of human experts (Sriram, 1997; Turban and Aronson, 2001). With a knowledge base and the ability to draw inferences from it, a computer can be put to practical use as a problem solver or decision maker. Figure 2.4 illustrates the concepts of a computer application. By searching the knowledge base for the potential facts and relationships, the computer can find one or more alternative solutions to a given problem.

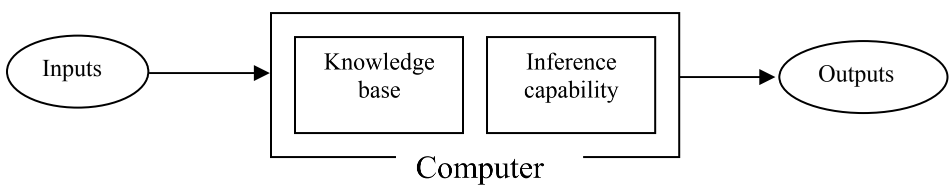


Figure 2.4 Concepts of computer system, Knowledge Base and Inference capability

Generating the KBS for BR subcontractor selection involves capturing the knowledge problem solving regarding the selection of subcontractors for BR works. The KBS should consist of heuristics aspects of the subcontractor selection process for BR projects. One of the effective ways to capture the heuristics can be realized through the application of integrated databases and knowledge base (Mohammed and Celik, 2002; Brandon and Ribeiro, 1998; Sriram, 1997).

Once the decision parameters are established, the alternative subcontractors can be rated with respect to the decision parameters. A subcontractor's score is calculated as a weighted sum of ratings over all decision parameters. The magnitude or rank order of the scores can then be used to select the subcontractor. In order to make the decision in subcontractor selection, however, strategy (knowledge) is needed. These strategies are stored in knowledge based system.

A number of KBS that have already been deployed or are in the development stage have shown how some of the concepts and models of artificial intelligence (AI) (such as case-based reasoning (CBR), rule-based reasoning (RBR), model-based reasoning (MBR), etc.) can be usefully integrated and combined with other computer technologies to produce and deliver powerful decision aiding systems in the construction industry (Brandon and Ribeiro, 1998). Pal and Palmer (1999) support three important approaches in the development of KBS: (1) Rule-based reasoning (RBR); (2) Case-based reasoning (CBR); and (3) Hybrid (i.e. a combination of RBR and CBR or integration other reasoning methods).

Two subsets of KBS are usually used, rule-based reasoning (RBS) and case-based reasoning (CBR). In the next section, both subsets will be explained briefly.

Rule-based reasoning (RBR)

In RBR systems, the specialized domain knowledge is represented as a set of IF <*prediction(s*)> THEN <*conclusion(s*)> rule format. Representation schemes utilize a set of rules to store the domain knowledge. This is sometimes known as production rules. These rules take the form of IF <*situation, condition, pattern*>; THEN action and the manner in which these rules are executed, or fired, are driven by the inference mechanism.

The IF clause or precondition is matched against a series of facts held in the context of the system, and those rules that apply are fired, producing a new set of facts. These new facts can then be matched against other rule preconditions to achieve the solution to the domain problem (Pal and Palmer, 2000). Rule-based systems can be standalone or be a subset of a larger system. The general reasoning process of rule-based system is shown in Figure 2.5.

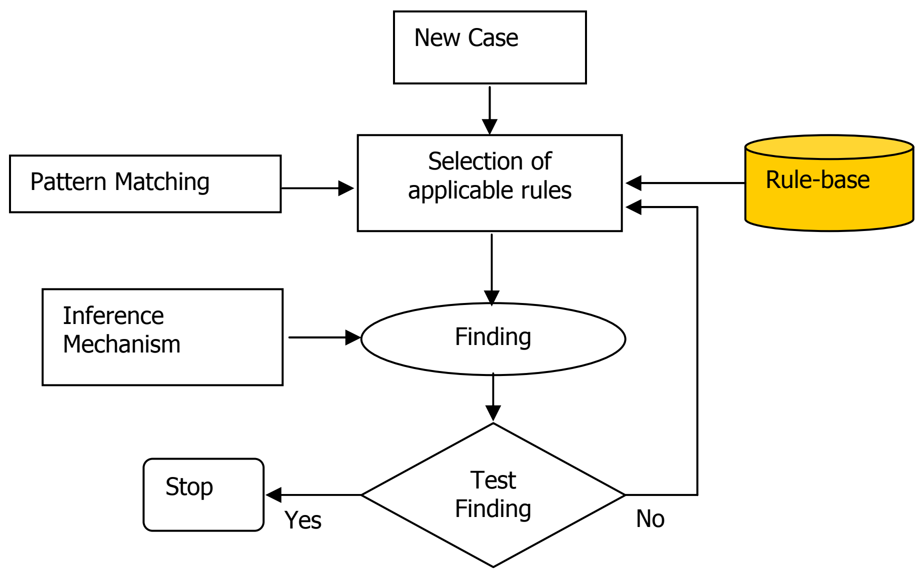


Figure 2.5 RBR process

Case-based reasoning (CBR)

CBR is a problem solving approach that relies on past, similar cases to discover solutions to problems, to modify and critique existing solutions and explain anomalous situations (Humpreys, 2003). In other words, people re-use all their past problem-solving experience to deal with a new case.

CBR is a rich and knowledge-intensive method for capturing past experiences, enhancing existing problem solving methods and improving the overall learning capabilities of machines. CBR systems provide decision-support to decision-makers through an interactive question and answer session. In CBR, a new problem or situation case is compared with a library of stored cases, i.e. a case-base. Each case contains information regarding a specific problem situation and its solution. CBR systems have shown significant promise for improving management decisions in problem areas that are complex, unstructured and knowledge-poor (Cook, 1997; Humpreys, et al, 2003).

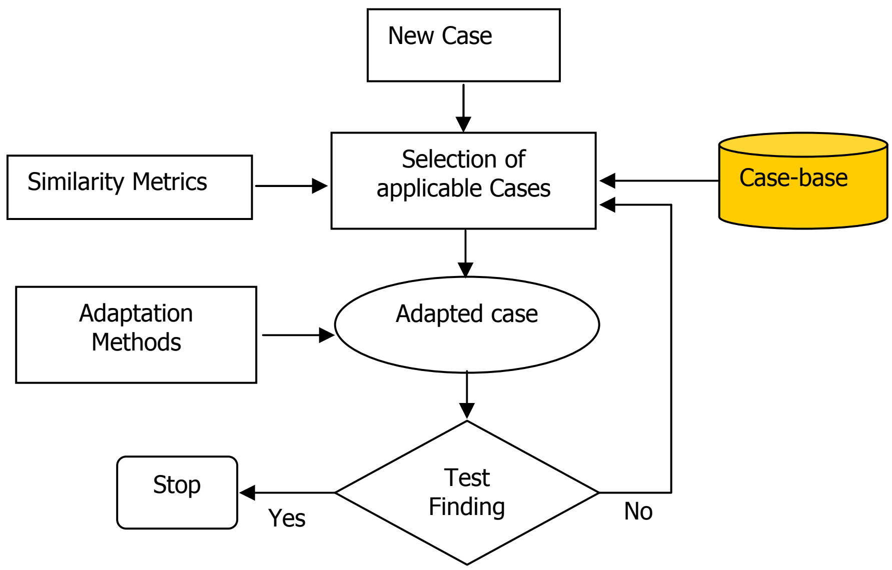


Figure 2.6 CBR process

The advantages of the CBR approach are: existing data and knowledge are leveraged; and the system has ability to learn from experience. The more cases are stored, the more potential the system has to solve similar case. The general reasoning process of case-based system is shown in Figure 2.6.

Situation or problem of each BR project is specific, and may be difficult to compare and identify the similarity of BR works. In this research, KBS, case based reasoning is not considered and only rule-based reasoning is utilized in the system.

2.6 DSS Trends in the Next Decade

Decision support theory is a wide-ranging research field. A review of the direction of new DSS is important in understanding the research trends in this field. The new trend of DSS theory will be applied in this present research.

The builders of traditional DSS have regularly used game theory and operations research; they have rarely used statistical techniques to build computer aided decision support systems (Zelesnikow and Nolan, 2001). Zelesnikow and Nolan (2001) advised that soft computing techniques could be integrated with symbolic techniques to provide for efficient decision making in knowledge-based systems.

Some DSS experts forecast that the research direction of the modern decision support system for the next decade should be focused on the theory and application of soft computing in management (Beynon, et al, 2002; Bolloju, 2002; Burstein, 2001; Carlson and Turban, 2002; Nemati, 2002; Shim, et al., 2002). This forecasting is promising since today's advanced, highly capable computer systems are inexpensive, plentiful and a powerful support to decision makers. The inadequacy of computing techniques is often due to difficulty of use and lack of user friendliness (Smith, et al., 1998; Tung and Quaddus, 2002).

In the AEC domain, the automation system has been a subject of considerable research in recent years (Anumba and Ruikar, 2002a). Specifically, in building designs, some recent modern decision tools have been developed, for example, see Caldas and Norford (2002); Chase (2002); Dijkstra and Timmermans (2002); Kavakli (2001); Simondetti (2002); Wang and Duarte (2002); Yang and Peng (2001); and Yang, et al. (2001); etc.

Although Pollack and Rees (1991) have introduced the potential for automation systems in the interpretation of building contracts since 1991, research in automation system in the construction management domain is not as extensive as in the building design domain. Several recent studies have been deployed in

AI areas, for example, see Kumaraswamy and Dissanayaka (2001); Mohamed and Celik (2002); Shen, et al. (2003); Tah and Carr (2002); and Zbayrak and Bell (2003); etc.

The aim of this research is to develop a formalized and structured approach to the selection of subcontractors for building refurbishment projects. The selection process is embedded in CADSS model, which integrates database and knowledge-based systems (KBS). This research objective is in line with DSS trends in the next decade.

2.7 Criteria for Effective CADSS

Because of the rapidly increasing complexity and availability of large amounts of data for input into the decision-making process, modern organizations will benefit from computer-assisted decision making. The operational control has been supported by computer since the 1960s (Shim, et al., 2002); however, it remains unclear why the decision makers are still reluctant to utilize computer-decision support systems. Beynon, et al. (2002) noted that computerized tools were rarely used for strategic decision-making.

Smith, et al. (1998) argued that CADSS would be used only if they offer the benefit of improved decision-making in return for a reasonable amount of time and energy and with minimal frustration. Hence, the CADSS should fulfill the following prerequisites:

1. Using the CADSS should be fun; so that users will actually look forward to using the computer to help them make decisions.
2. It should be especially user-friendly.
3. The user should not become frustrated while using the computer.
4. Displays should be simple, yet meet the demands of decision making while providing the support that the user desires.
5. The computer DSS should be sophisticated enough to provide even the most analytical users the support they expect while maintaining an intuitive approach for non-technical users.

6. This sophistication should be made transparent to the user.

These prerequisites will be adopted as the basic requirements for the SSDSS proposed.

Chapter 3
BUILDING REFURBISHMENT WORKS

3.1 Introduction

The development and implementation of IDSS requires an understanding of the domain, managerial decision-making, and associated levels of reasoning and problem solving (Kersten, 1999) in the selected field. This chapter presents a review of the literature on building refurbishment (BR) works, existing practice of subcontractor selection, and related topics. The chapter will also establish how potential subcontractors for BR projects are selected and the factors that influence the decision-making process.

Based on the review of books, and journals, hardly any studies and/or publications on the selection of subcontractors for BR projects were found. This is not surprising; Egbu (1997) and RECC (2002) stated that the BR project remains one of the least understood sectors in AEC practices. The review, however, also found some academic publications that may be relevant to BR works. For the purpose of this research, the discussions of related studies were classified into four headings: studies on refurbishment works; studies on procurement systems; studies on criteria for subcontractor selection; and studies on subcontractor practices in Singapore.

3.2 Studies on Refurbishment Works

There were some earlier studies regarding refurbishment works that were captured in prominent publications, for instance, see Balaras (2002); Brandon and Ribeiro (1998); Caccavelli and Jean-Louis (2000); Egbu (1999a; 1999b; 1998; 1997; 1994); Flourentzos and Roulet (2002); Flourentzos, et al. (2000); Gilleard (2002); Gustafson (2001; 2000a; 2000b); Holm (2000a; 2000b); Ismail, et al. (1999); Lee and Leeuwen, et al. (2000); Marosszeky (1991); Quah (1988); Rosenfeld and Shohet (1999); Teo (1990), etc. Among these academic publications, Egbu (1999a; 1999b; 1998; 1997; 1994) produced the most comprehensive papers in the refurbishment field, covering skills on management education and training for refurbishment works in the construction industry.

However, none of the above studies provide an automated decision support model for subcontractor selection. Although they were non-specific about the subcontractors for BR works, the knowledge and skills for researching BR works were enriched.

3.2.1 The Nature of Building Refurbishment

A basic characteristic of building refurbishment is that the building is not created anew by the project, although it may be completely refurbished. Marosszeky (1991) noted two important features of BR projects. First, unlike a new project, where the planner starts with a vacant site and sets out to define user needs, a refurbishment project's starting point is a building. The second factor is that in most refurbishment projects, the building is tenanted.

During the planning stage, the approach to design differs fundamentally between new-build and refurbishment projects (Highfield, 2000). New building design is a design-heavy process. BR design, by contrast, is an exploration-heavy process, often requiring more time examining the actual building than in drafting and calculating (Leeuwen, et al., 2000). Ismail, et al. (1999) noted that in the majority of refurbishment projects, the work commenced on site even if design is incomplete. They found that 50% of refurbishment projects commenced work on site with only 60% of the design being complete.

During the construction stage, occupancy and use of the building may continue during the project to a varying extent. BR often involves working on confined sites with restricted access (such as in inner-city areas), sometimes with abutting buildings in continuing operations and including cases where operational use of the building itself needs to continue during refurbishment. Access to and within the site is often restricted and can cause problems which arise from shared access with other contractors, organizations, the public, the occupants and neighbors.

3.2.2 BR Project Management

Based on the nature of BR works, it is clear that refurbishment projects are more complex than new-build projects. These features have an effect on the management of BR projects in many ways, by making different demands on managers and the professional team than would be expected on new-build projects (Egbu, et al., 1998, 1999b). A classification of various aspects concerning refurbishment projects is illustrated in Figure 3.1.

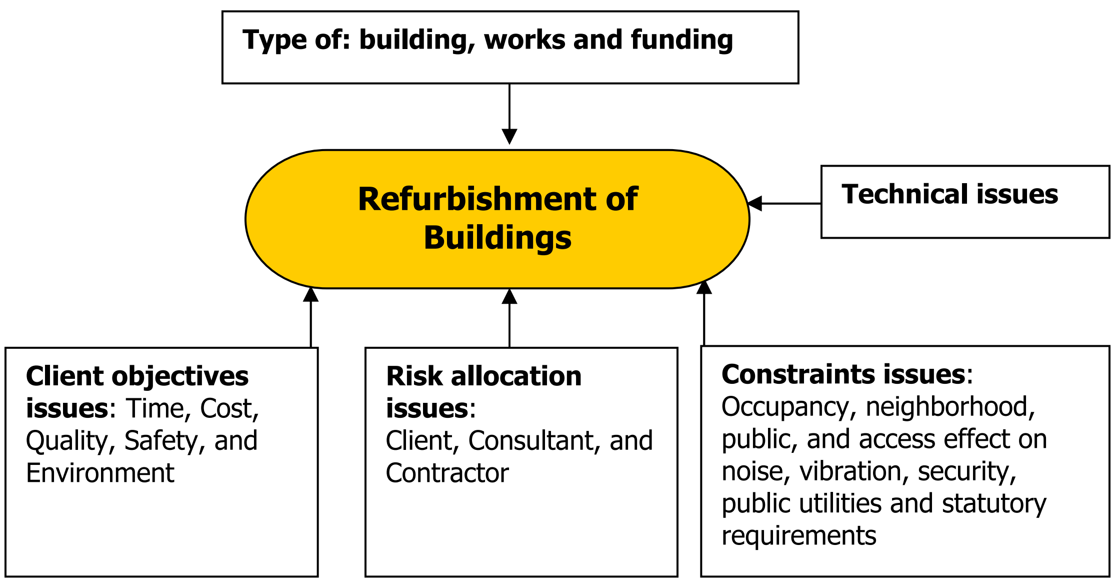


Figure 3.1 Classification of Refurbishment Project Management

In most BR projects, there are potentially higher levels of uncertainties than with a new-build project. Quah (1988) and Teo (1991) found that estimating and tendering for BR refurbishment projects carry a higher risk in the face of such uncertainties than a new-build project. The risk is primarily because clear specifications are important for procurement procedures, but are difficult to realize in a refurbishment project. Discovery of unforeseen conditions is possible for almost all of the refurbishment period, data on the building may be difficult to locate and may require several different types of investigations.

A major difficulty is in determining the optimum scale of the works. Diagnostics of existing buildings are not an easy task, and will impose ill defined and insufficiently understood constraints on the various options and the costs of achieving them. In many cases, the contractors have been appointed, although the work specifications and/or procurement procedures are not, as yet, ready (Marosszeky, 1991). Quah (1989) suggested that the allocation of risks between contractual parties should be specifically tailored, due to the unique and uncertain nature of the project.

Because the building may be tenanted while refurbishing, it will add to the cost and time of the project and can lead to many problems and uneconomical works (Tan, 2003; Douglass, 2000). There are likely to be greater levels of consultation between the client and builder in the refurbishment of an occupied property.

The scheduling needs to be realistic because of the presence of tenants and the need to enable them to continue with their business (Johnstone, 2001). This implies that a significant amount of refurbishment works has to be undertaken out of normal office hours, thereby extending the duration of the project.

Interaction between the old buildings, temporary works, existing services, and new construction will affect unique construction methods. Planning and programming throughout most of the refurbishment period are required, as will interaction with neighboring assets, processes, activities and people.

These difficulties can be reduced through appropriate selection of contract strategies. Cognizance must be taken of the subtle differences between refurbishment and a new-build project. The client/tenants need to have a continuous and intimate involvement with the projects. Because the building already exists, the client/tenants will have a greater understanding of the building's attributes (Douglas, 2002; Egbu, et al 1998). CIRIA (1994) suggested that because of the knowledge and skills of specialist contractors and subcontractors, during a refurbishment project, they should be engaged at an early stage such that they can contribute to the planning stage.

CIRIA (1994) suggested typical management responses regarding the nature of building refurbishment projects: exhaustive preparation; extremely detailed programs and resource lists; extensive communication of the plans and progress; realistic contingencies in plans, programs and resources; and organizing to allow quick reactive management responses. To ensure efficiency in project control on refurbishment works, Egbu, et al. (1998) suggested:

1. Better and/or more extensive management control, since the problems to be overcome can be more unexpected, frequent and pervasive.
2. Rapid decision-making and communication.

These suggestions have consequences regarding the selection of planning and control techniques, combinations of project organizations, types of contracts, forms of contracts, contractor/subcontractor selection procedure and so forth.

3.3 Studies on Procurement Systems

All procurement systems have the same goals; they want a project more or less at a reasonable cost and quality, within a reasonable time and with reasonable security (Wangemann, 2001). The tendering system aims to achieve this goal by ensuring the simultaneous selection of an appropriate subcontractor to deliver the project, the mechanism for delivery, the price to pay and the legal framework. The only difference then between procurers is in the strategic choice of subsystem components. It is expected therefore that the criteria involved will be consistent across all procurers, with only the emphasis changing between procurers and projects according to the strategies employed.

Mohsini and Davidson (1991) found that building procurement is the key to improved performance. Smith and Dancaster (2000) also noted that choosing a strategy for the selection process significantly impacts the main contractor-subcontractor relationship. Currently, there are tendencies shifting from price being the only criterion (low bid procurement) to multiple performance criteria or performance-based system (Kashiwagi and Byfield, 2002; Kumaraswamy, 2000). Therefore, it assumes that any strategy is applied to meet the best subcontractor needed.

Generally, contractual relationships between contractor and subcontractors can be divided into three categories, namely nominated, domestic, and named subcontractors. A subcontractor may be selected by conventional bills of quantities approach in two ways: (1) by competitive bidding, (2) by negotiation, or by partnering (alliance-relationship). Nominated and named subcontractors are usually selected through competitive bidding, and domestic subcontractors are selected either through the competitive way or by other approaches (CIB, 1997). These approaches may be elaborated into three categories, such as one-stage, two-stage, and negotiation approaches (Aqua Group, 1999; Rougvie, 1987). In the one-stage approach, tender documents are sent to a suitable number of subcontractors, who must price all items of work identified by the design team (Cox and Townsend, 1998).

The one-stage approach may be inappropriate for refurbishment works where there are so many uncertainties and opportunities for extra claims inherent in the works. The cooperative climate suggested for refurbishment works may not be created, and the lowest tender price will not necessarily mean lowest eventual total cost.

In practice, if the two-stage approach is utilized, the first stage is called pre-qualification. There are two techniques commonly utilized in pre-qualification (the first stage), namely the pre-qualification formula and subjective judgment.

Pre-qualification Formula

Contractors are pre-qualified by calculating the maximum capability of each contractor. Maximum capability is defined as the maximum amount of uncompleted work (in progress) that the contractor can have at any one time. For example, in the case of the government's projects in Indonesia, to determine the maximum allowable works volume for a given contractor during the pre-qualification process, the applicant's net current assets from a current financial statement are multiplied by 10. The work volume obtained in this manner is also regarded as the "maximum financial capacity". Then, final ratings are determined by modification of the financial capacity (Dulung, 1991). However, this approach has a limitation in that the good subcontractor may be rejected in the first screening. The judgment procedure may be influenced by biases of the decision makers. These procedures can lead to incorrect decisions due to the lack of a rational or systematic approach.

Subjective Judgment

In some instances, individuals performing the pre-qualification base their decision on subjective judgment and experience, and not on a structured approach. However, judgment may be influenced by biases of the decision maker such as previous experience with the candidate's work (Russell, 1988; Lee, 1997).

Both the pre-qualification formula and subjective judgment can become valuable methods for selection tasks if they are supported by a systematic approach. Otherwise, decision-making is only based on an unstructured and intuitive manner.

The two-stage approach seems ideal for a normal situation, where adequate information or time is available for the tender process. However, if a contractor is given insufficient information and time for the preparation of tenders, such as in the BR situation, the effectiveness of this approach will suffer.

The negotiation approach means the client develops a tender price by discussion with a candidate (or in some occasions, a small number of subcontractors without formal competition). The main advantage of the negotiation method is that the subcontractor is generally selected on the basis of a good track record doing the type of work required for the particular project. However, the negotiation seems informal with no standard processes, and it is also time consuming to arrive at a decision. The spirit of healthy competitive practices should be one aspect in the selection process.

Other alternative procurement strategies, i.e. management-based methods, such as order and specification, cost reimbursement and fee, target cost, etc, are not included in the discussion for several reasons. In the application of these strategies, research has found that there is likely to be a problem with post-contract administration and cost control, and doubts whether the resulting bills of quantities could be used for management purposes (Aqua Group, 1999).

The conventional bill of quantities approach is more popular than other methods. Approximately 50% of the current capital construction programs in the UK are still procured in the conventional way (Kumaraswamy and Walker, 1999). In Singapore, construction procurement also follows mostly the conventional procurement method (Ofori and Debrah, 1998). Another survey revealed that the lack of knowledge and expertise of contractors in the organization of non-conventional methods stopped them from attempting to experiment with the non-conventional approach (CIRIA, 1994).

Based on these reasons and the nature of the BR project, the conventional tendering approach seems inappropriately used in the selection of subcontractors for the BR project. However, the market consists of an adequate number of subcontractors to be selected. Currently, there are 4,000 subcontractors in Singapore, with 1,200 of them registered under eight different trades associations (Guevarra, 2003). It is virtually impossible to select from these large numbers of subcontractors by conventional or simple judgment techniques; hence, the formal decision techniques are needed.

The two-stage approach seems appropriate to BR projects. However, the process of two-stage tender will require more time for preparing, mailing, opening, and evaluating bids than the one-stage approach. Indeed, the time for tender preparation in subcontractor selection for BR projects is very short, so much so that the tender procedure may take place informally.

CIRIA (1994) suggested that any procedures applied should be carried out in the same spirit of good competitive practice although specific procedures will vary. The appropriate procurement system for selecting subcontractors in BR projects is discussed in Chapter 5.

3.4 Studies on Criteria for Subcontractor Selection

There are several publications relating to "subcontractor selection for general construction project", and "purchasing supply management" that may be relevant for the selection of BR subcontractors. These have proposed some criteria to select subcontractors or suppliers, but none of them concerned the construction industry in Singapore. Indeed, the location is a significant aspect, because the criteria used in decision-making can depend on many associated aspects (Rowlinson, 1999) such as characteristics of the project, site location, organization's objectives, etc.

3.4.1 Decision Criteria for General Subcontractor Selection

Relevant publications on the selection of subcontractors/suppliers were found and reviewed.

Tseng and Lin (2002) in Taiwan proposed a web-based DSS to help contractors select proper subcontractors. The selection model utilized three main criteria, namely:

1. Expected return.
2. Planned performance dispersion.

3. Comprehensive risk (including tender price and duration).

PCCB (2002) in Hong Kong suggested that the tender assessment criteria should aim at promoting healthy competition by placing suitable weights on price, past performance and quality. The following criteria may be used in tender evaluation of subcontractors:

1. Previous experience on jobs of similar nature.
2. Adequacy and professional competence of key management and supervisory staff.
3. Availability of capital and labor resources to undertake the subcontract on top of other on-going commitments.
4. Quality of technical proposal with particular reference to compliance with tender requirements.
5. Track record of past performance.
6. Price and payment terms.

Andrews (2000) and CIB (1997) in the UK have suggested several criteria for selection of subcontractors for general construction projects. Andrews (2000) suggested that factors affecting the choice of subcontractors could include:

1. Competitive price
2. Reliability
3. Quality of work
4. Speed of completion
5. Experience.

Likewise, the CIB (1997) added the following criteria for assessing the subcontractor:

1. Quality of work
2. Performance record
3. Overall competence
4. Health and safety record
5. Financial stability

6. Appropriate insurance coverage
7. Size and resources
8. Technical capability
9. Organization ability.

In the area of “purchasing and supply management”, several studies on supplier selection were also carried out, such as Dzever, et al. (2001); Erridge (1995); Humpreys, et al. (2003); Leenders and Fearon (2002); Pooler and Pooler (1997); and Vokurka, et al. (1996). They suggested the following criteria for selecting suppliers:

1. Competitive price
2. Total cost reduction
3. Quality standard
4. Delivery time
5. Geographical location
6. Method of payment
7. Term of payment
8. History
9. Facility and technical strength
10. Financial status.
11. Organizations and management
12. Reputation
13. Procedure compliance
14. Labor relation.

These studies have proposed the decision criteria for selection of general subcontractors/suppliers not specifically for BR subcontractor. Other gaps, their criteria were incomplete, and not supported by any explanation of logical relationships. Furthermore, they did not propose any automated decision support system.

Only Tseng and Lin (2002) have proposed an automated model for selecting subcontractors through a web-based (E-commerce) facility. However, this model may be difficult to apply, because the participants (subcontractors) have to provide basic requirements of IT application. In fact, IT application is relatively slow in the construction industry (Love, et al., 2000; 2001). The evidence in practice is that computers are not heavily used in the construction industry (CIRIA, 1994; Stewart and Sherif, 2001), especially by small subcontractors (Ng, et al., 2001).

3.4.2 Decision Criteria for BR Subcontractor Selection

As mentioned earlier, although there were some studies on the selection of subcontractors for general construction projects, there were hardly any publications on BR subcontractor selection. Only Okoroh (1992) carried out a study on the selection of refurbishment subcontractors in the UK. The study has proposed the following selection criteria:

1. Competitive bids
2. Geographical area
3. Work design experience
4. Safety policy
5. Site meeting
6. Quality of workmanship
7. Trade reference
8. Technical competence
9. Work program implementation
10. Contact address
11. Relationship
12. Honesty and reliability
13. Financial strength
14. Prompt or delayed treatment of invoice.

Despite the proposed criteria above, the study has several limitations:

<u>Little attention in Theoretical Foundation</u>

The theoretical framework of the earlier study was more focused on the process of knowledge acquisition (KA) for the model than the theoretical background of the criteria. The criteria and the hierarchy proposed were captured through empirical study, and gave little attention to explain the logical relationships of the criteria.

<u>Critics for Repertory Grid Analysis</u>

The knowledge of the earlier study was captured from multi domain experts, and its criteria hierarchy was developed through the repertory grids analysis (RGA). This method, derived from psychology, use an approach called the classification interview (Turban and Aronson, 2001). RGA is a way of producing a person's mental map on some topics. This approach was widely recognized as a way of getting access to the subjective meanings individuals attach to their work (Kelly, 1969). However, Tzafestas and Tzafestas (1997) observed that the repertory grid approach is more suitable for modeling an individual than averaging a statistical comparison across several experts. Boose (1986) also criticized that the repertory grid is limited in application to declarative types of knowledge. Procedural, strategic, and causal knowledge is difficult to represent with this technique. Furthermore, Nwana, et al. (1994) noted that the biggest problem of the method was that it can elicit only simple classification from the experts and it has difficulty in expressing causal, procedural and strategic knowledge. The classification associations produced were also frequently spurious.

<u>Complex Calculation</u>

The earlier study utilized a fuzzy-set to analyze the rank weight of the criteria. Although Fuzzy-set analysis has been employed in numerous research areas and is popular among scientists, Buede and Maxwell (1995) argued that Fuzzy-set causes rank disagreements and produce a less consistent result. Ling (1998) also criticized that Fuzzy-set involves complex mathematical calculations and does not have a unique method to derive importance weights. Lastly, the complexity of the Fuzzy-set will hinder the main contractors from applying the model produced, since the end-users (non-scientists) may be reluctant to utilize a complicated mathematical model.

Inflexible ES Shell

The earlier model did not develop the ES shell specifically. In fact, the process of selecting the right ES shell for particular application is often a very difficult task because the technical terms are not always used consistently; most of the ES shells in the market are very different both in terms of their internal structures and of the kind of applications for which they were intended; most of them were built to handle restricted problem areas and may not be flexible in other problem domains (Stylianou, et al., 1995). Therefore, the ideal way to find an appropriate ES shell is to build the shell specifically for the system. However, this approach would require the knowledge engineers to have skills in soft computer languages.

Poor User Interface

The earlier model was constructed using computer programs in the 1990s, when advanced software available was limited; the model was developed based on the DOS operating system. The weaknesses of this operating system are complex coding and time-consuming model development, and poor user interface because of DOS limitations. Currently, in the new generation of computers, this operating system is no longer used.

3.5 Subcontract Practices in Singapore

The literature review found that it was relatively difficult to find any academic publications on subcontract practices, and particularly, studies regarding the selection of subcontractors for BR works in Singapore.

For the construction industry in Singapore, the practice of procurement follows predominantly the conventional procurement approach, with a main contractor responsible for undertaking the works (Ofori and Debrah, 1998). Most of the tradesmen and workers are employed directly by the trade subcontractor or *"kepala"* (Lee, 1997). The main contractor subcontracts nearly all the labor and trade requirements. Consequently, this situation does not encourage main contractors to provide direct employment to construction workers.

In Singapore, the types of subcontracts can be divided into three categories, namely materials suppliers, labor only subcontractors or *"kepalas"*, and subcontractors who supply both materials and labor. Within categories, subcontractors can be divided further into nominated or domestic according to their ways of engagement. Nominated subcontractors are usually employed in trades where a large portion of their work requires special machinery and plant, for example, excavation, piling, electrical engineering installation, etc. (Ofori and Debrah, 1998; Loh, 1998). Domestic subcontractors are commonly engaged in labor-intensive trades, such as formwork, roofing, brickwork, tiling, painting and landscaping, which are labor intensive.

According to the main contract conditions of the Singapore Institute of Architects, Article 15(2) (SIA, 1999), the main contractor has a right to engage domestic subcontractors. The domestic subcontractors should be engaged with the written consent of the architect. In practice, however, architects do not usually withhold their consent and the main contractors seldom seek such approval (Loh, 1998). If the selection of domestic subcontractors was carried out informally, and without supervision of the client representative or architects, the main contractor may select inappropriate subcontractors, and the SSDSS, therefore, becomes more desirable.

3.6 Knowledge Gaps

Competitive pressures make the job of decision-making in subcontractor selection difficult. Competition is not merely based on cost, but also on quality, timeliness, customization of products, and customer support. Selecting subcontractors for a BR project is characterized by nonlinear and complex tasks, uncertain situations, technical and non-technical information considerations, and the need for both qualitative and quantitative techniques. On the other hand, the human mind has limitations in its ability to process and store a lot of information. People may have difficulties in recalling information in an error free fashion when it is needed. Hence, decision support tools for the future should be based on principles of automation systems that can be effectively used in the early stages of BR works.

The literature review (Chapters 2 and 3) found that: (1) there are many studies on KBS, but few KBS applications in the project management domain; and (2) although there were several articles on subcontractor selection, there was no previous study on selecting subcontractors for refurbishment projects, except one study (Okoroh, 1992) that was carried out in the UK.

Despite the review of literature that revealed the existence of various KBS studies, criteria, information, and tender methods, many gaps still remain. These gaps may be grouped under four subsections, namely (1) computer model, (2) subcontractor organization, (3) subcontractor selection procedure, and (4) decision criteria for subcontractor selection.

3.6.1 Computer Model

The concept of the modern DSS approach has been applied to research in the AEC sector, especially for building design (Hew and Awbi, 2001; Konoglu and Arditi, 2001; Reed and Gordon, 2000). However, automation system research in the construction management domain is not as extensive as research in building design. Very few CADSS have been developed in the construction management field, such as for procurement systems. In practice, although selecting subcontractors is characterized by nonlinear and complex tasks, the task is mostly decided by judgment (Holt, 1995; Russell, 1992). Therefore, the CADSS approach is needed in the construction management field to aid the tedious, but significant, decision-making processes.

Much conventional computer software exists were built to handle restricted problem areas and may not flexible for other problem domains. Park (2003) and

Rowlinson (1999) criticize that one of the problems with conventional computer-based systems and most common KBS are that they often appear to work as "black boxes", and the logic behind the advice given is not readily apparent. The users cannot partially replace rules to control the decision making process. This approach would be extremely difficult to maintain because the whole knowledge base has to re-program to adapt even for a slight change.

3.6.2 Subcontractor Organization

The BR contractors and subcontractors have strong unions in the UK or European countries (Egbu, 1998; Ismail, et al., 1999; Okoroh, 1992). One of the advantages of this situation is that the main contractor may find it easier to award the contract to a potential subcontractor. Strong unions will encourage skills and organizational improvement. On the other hand, in Singapore, there is no clear organized and systematic production sector in the construction industry like in the UK (Lee, 1997).

Lee (1997) criticized the loose subcontract practices used in Singapore and the various informal arrangements made. Although there is a category of building renovation and retrofitting under the BCA's contractor directory, this classification only covers the contractors for any upgrading works that do not involve building structure alteration (BCA, 2003). It also covers mostly contractors for cleaning and painting works; the general building contractors still dominate large refurbishment projects in Singapore.

A substantial proportion of the work on any project is actually carried out by the trade subcontractors, leaving the main contractor the task of overall management and control. In some smaller projects, the main contractor may directly employ workers to carry out the works. Most of the trade subcontractors are, therefore, an important contributor in the construction industry. However, the subcontractors' arrangements in Singapore make it nearly impossible to identify the real employers of construction workers due to the pools of workers shared among sites and "*kepalas*" (Lee, 1997). These pools of labor, the employers and workers, are often not identified. They are disorganized and many are “fly-by-night” operations. These situations place the main contractor in a difficult position. They, especially in a tight labor market, often have little choice to select the subcontractors available.

In order to overcome these problems, the Singapore Contractors’ Association Limited (SCAL) founded the Singapore List of Trade Subcontractors (SLOTS) in 1992. The SLOTS idea was directed at the welfare of workers, work productivity and improving the subcontractor quality. However, this scheme does not appear effective yet because: (1) some subcontractors were reluctant to register. Proper organization means they will have to pay higher wages and proper welfare benefits to all workers that consequently lead to higher quotes to main contractors. (2) Subcontractors are currently still able to obtain jobs even if they do not join SLOTS. Only government institutions have so far implemented SLOTS membership as a requirement in their contracts (Loh, 1998).

3.6.3 Subcontractor Selection Procedure

Assessing potential subcontractors for their general skills and performance is an important part of any selection process. In general, three selection procedures exist, the one-stage, two-stage, and negotiation approaches. The selection of general subcontractors is carried out mostly through conventional tender in the one-stage approach. However, this is not a suitable tender procedure for BR subcontractors. The two-stage approach may be appropriate for BR projects, but it has some limitations and cannot be applied for the straightforward selection of BR subcontractors. For example, the method cannot be applied when the time for selection is limited; indeed, this is one of the characteristics of BR works.

Subcontractor selection is a strategic decision. However, in practice, this process is often decided by the middle level staff, such as the estimators. If there is no guidance in making decisions, the decision may not be the best decision for the company because the policy and strategic plan of the company may not be considered in the decision.

Without automation tools, it is difficult for the main contractor to make decisions accurately and consistently. The main contractor may face difficulties in conveying the detailed processes of decision-making for the selection of subcontractors because apart from price, their decisions may be based solely on their judgments and past experience. Because of this condition, the main contractor may make mistakes when coming to their decisions.

3.6.4 Decision Criteria for Selecting Subcontractors

The review on decision criteria for selecting subcontractors has excerpted the numbers of criteria commonly used in subcontractor selection. The sources (authors) and the common criteria used in subcontractor selection are summarized in Table 3.1.

Although the review of the literature revealed the existence of various criteria for selecting subcontractors, there is no consensus yet on a common set of and weighting for the decision criteria; the main contractors mostly do not have acceptable decision-making methods to differentiate the high performers and the low performers. This is not surprising. Skitmore (1989) concluded that decision models are not popular in the construction industry.

The review also found that hardly any earlier studies have presented the logical relationships between the criteria. These previous studies proposed criteria based only on empirical work, but they paid less attention to a theoretical framework that extracts the hierarchy and relationship of the criteria. The empirical model is firmly based on statistical analysis of survey results. A problem with this approach is that although the statistical analysis may give an indication of what is current practice, it does not necessarily indicate good practice (Rowlinson, 1999). Another major conceptual limitation is that one can only ascertain *relationships*, but never be sure about underlying *causal* mechanism (Stat-Soft Inc., 2003).

Table 3.1 Criteria for selecting subcontractors

Authors	Key Criteria	Focus on
Lin (2002)	1) Expected return, 2) Planned performance dispersion, 3) Comprehensive risk (including tender price and duration).	Selection of general Subcontractor for E-commerce
Andrews (2000)	1) Price, 2) Reliability, 3) Quality of work, 4) Speed of completion, 5) Experience	Selection of general Subcontractors
CIB (1997)	Pre-qualification: 1) Quality of work, 2) Performance record, 3) Overall competence, 4) Health and safety record, 5) Financial stability, 6) Appropriate insurance coverage, 7) Size and resources, 8) Technical and organization ability, 9) Tender Price	Selection of general Subcontractors
Okoroh (1992)	1) Competitive bids, 2) Geographical area, 3) Work design experience, 4) Safety policy, 5) Site meeting, 6) Quality of workmanship, 7) Trade reference, 8)Technical competence, 8) Work program implementation, 9) Contact address, 10) Relationship, 11) Honesty and reliability, 12) Financial strength.	Selection of BR Subcontractors

The earlier studies adopted criteria that were derived from questionnaire surveys and these surveys dealt with responses from a range of respondents within the construction industry. Such studies were very much country-dependent and depend on the particular time at which they were developed (Rowlinson, 1999); what was acceptable in terms of criteria and performance in the UK in 1990 might be totally irrelevant to circumstances in Singapore in 2003 when this present study commenced the fieldwork. These findings are not surprising. Altink, et al. (1997) criticized that most studies paid attention to idiosyncratic criteria and less attention was paid to the way in which criteria were actually derived and developed.

These knowledge gaps not only justify the need for some revision to existing practices but more-over, the remedial measures advocated will help serve as a basic design of the selection method proposed. The model proposed should appropriately be applied to assist decision makers in the Singapore environment. The important component of the model proposed is a set of decision-making techniques that can help balance criteria/objectives with a range of solution alternatives. The result of the present research is expected to develop a CADSS for selecting subcontractors for a building refurbishment contract that integrates database and knowledge-based systems (KBS). This major aim is in line with current trends regarding both the DSS and AEC areas.

Since there is no information concerning the selection process of subcontractors for BR works in Singapore, the knowledge will be captured through interviewing and sending questionnaires to the experts from the construction industry in Singapore. This topic will be covered in Chapter 6 and 7.

Chapter 4
RESEARCH METHODS

4.1 Introduction

This Chapter describes the overall research strategy and the techniques adopted for data collection, analysis, and development and validation of the model developed.

As shown in the previous chapters, hardly any studies have systematically analyzed the issue of subcontractor selection for BR projects. Consequently, there is no well-defined methodology for guiding this research. Thus, the methodological challenges are to establish a methodology for this research, and moulding that methodology into a viable method given the constraints that exist in data collection and analysis.

In the following sections, the research methods applied in this present study are presented. In the first section, the research strategy, and outlines of the research method are described. The next sections explain the components of each research stage.

4.2 Research Strategy

The aim of the research is to develop an IDSS, which is called the subcontractor selection decision support system (SSDSS). The research methods used were selected according to the type of research and information needed (Fellows and Liu, 1997; Marakas, 1999). This research is a development type model that involves making assumptions and conceptualization of the problems and its abstraction to quantitative and/or qualitative forms that would reflect the reality.

For modeling purposes, an analytical framework was constructed by reviewing the literature and knowledge of current subcontractor selection for BR projects.

The knowledge was collected from an AEC industry survey through interviews and postal questionnaires. The procedures in gathering and analyzing data, and developing the model referred to a systematical development of the DSS modeling process. A hierarchy of research and development (R&D) project procedures, which was proposed by Bock (2001) and Korman (2001), was adapted in this research. The research strategy consists of three main stages:

1. Knowledge acquisition
2. Criteria examination, and
3. Model development and validation.

The three stages for this research strategy are illustrated in Figure 4.1.

This research concerned the collection of general data and information regarding selection of subcontractors for BR projects. In data collection, three fieldworks were carried out, i.e. interviewing the experts, posting questionnaires to the main contractors, and applying and validating the model. Application is focused primarily in Singapore where the case study is located. This is supplemented by a thorough investigation of the different approaches adopted by main contractors in managing BR subcontractors. The SSDSS was applied and validated to measure the robustness and effectiveness of the model.

4.2.1 First Stage: Knowledge Acquisition

The first stage began with the formulation of research questions, objectives, significance, scope, and limitations. This stage clarified research ideas and defined the parameters of the research. Subsequently, knowledge acquisition was carried out where knowledge from documented sources and experts was extracted.

Knowledge can be collected from many sources (Turban and Aronson, 2001; Sriram, 1997). In this research, two knowledge sources are used, namely academic literature and domain experts (DEs), which were elicited through literature review and interviews with domain experts. The main work of the literature review has been done and discussed in Chapter 2 and 3.

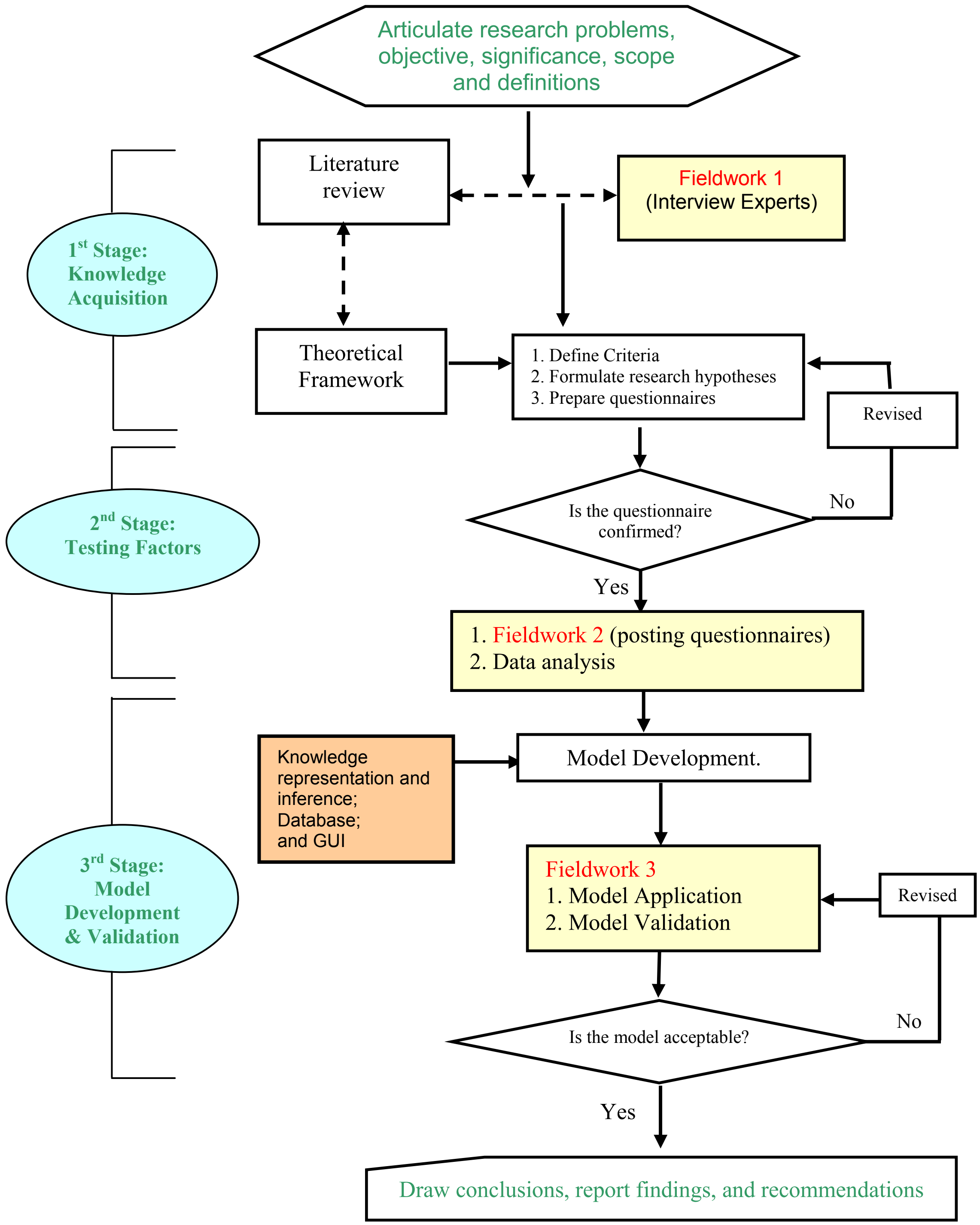


Figure 4.1 Flow chart of research strategy

Through academic literature, the features of building refurbishment, decision theory, and computer science, with specific reference to AI, the concept of this study was reviewed. Relevant studies were also evaluated to identify factors considered in subcontractor selection. The theoretical framework for the model was based on concepts from supply-chain management, human resource management, organizational behavior, and personnel selection. The outcomes of the literature review were analyzed systematically, and the knowledge gaps were identified. Subsequent to this stage, the statements of research problems were generated.

In this stage, the first fieldwork was carried out. The purpose of the first fieldwork was to capture knowledge, and to identify significant factors and a structure that main contractors should consider in selecting the reliable subcontractors for BR projects in Singapore. The knowledge or expertise was captured from DEs through personal interviews. The method of interview is discussed in Section 4.4.1.

The DEs were individuals selected from chief contractors' staff who have experience in managing subcontractor selection for BR projects. The number and quality of the domain experts is critical for the success of KBS implementation. Determining the DEs used followed the recommendations suggested by Medsker, et al. (1995); Prerau (1990); Puuronen and Terziyan (1999); Yoon and Guimaraes (1995), etc.

In this present research, multiple experts were interviewed individually as primary and secondary experts. This is similar to the Delphi method where the DEs do not necessarily meet each other but allow for a consensus viewpoint. More detail concerning this topic is discussed in the Detail of Knowledge Acquisition and Computer Techniques (Appendix 1).

4.2.2 Second Stage: Criteria Examination

The second stage was to check for the admissibility of criteria that main contractors should consider when deciding which subcontractors to select for BR projects. Since more than one DE was involved, there may be some disagreements, especially in weighting criteria. Therefore, the consensus and aggregation of the knowledge had to be made. This was conducted by posting questionnaires to BR contractors in Singapore. This was the second fieldwork that would examine the factors identified and their relative importance. The questionnaire is discussed in Section 4.4.2.

Before the questionnaires were posted, a pilot survey was conducted to confirm the severity of the problems identified, and to check whether the questionnaire contained all the criteria viewed as important features for subcontractor selection. The feedback from this pilot survey was used to refine the questionnaire.

Once confidence had been gained through the pilot questionnaires, these were sent to BR contractors. The sampling frame for main contractors was through personal contacts and building owners, such as NUS Office of Estate and Development (OED), Singapore Polytechnic, Ministry of Education, quantity surveying companies, etc.

The directory of contractors published by the Singapore Contactors' Association Limited (SCAL) was also a good source for identifying respondents; the contractors' names, addresses, key officers, recent and major past projects were stated in this directory (SCAL, 2003). Other sources for respondents were chosen from the "BCA Directory of Registered Contractors". Based on the discussion with the BCA staff, the contractors who had experience in BR projects could be traced from their work-head classification in the BCA contractor directory. Companies under both the "General Building" and "Renovations and Redecorations" work-heads are good indicators that the companies are ready for BR works and they may have experience in BR projects.

After the questionnaires were returned, they were edited, coded into a computer, and analyzed for significant factors using the Statistical Package for Social Sciences (SPSS). The significant factors identified from the analysis formed part of the knowledge and database of the SSDSS.

In order to determine the ranking of the weighting criteria, it was necessary to check and calculate the mean important rating of the decision criteria. The formula for calculating the weight of an attribute (W_h) is given by the Equation 4.1:

$$W_h = \frac{a_h}{\sum_{h=1}^{m} a_h} \qquad \text{...(4.1)}$$

where:

W_h is the weight attributes h;

h is the attribute reference, and there are m number of attributes under one criterion.

a_h is the mean importance rating of attribute h obtained from Equation 4.2.

$$a_h = \frac{1(n_1) + 2(n_2) + 3(n_3) + 4(n_4) + 5(n_5)}{(n_1 + n_2 + n_3 + n_4 + n_5)} \qquad \text{.............(4.2)}$$

where:

h : is the attribute reference,

a_h : is the mean importance rating attribute h, and

n_1, n_2, n_3, n_4, and n_5 are the number of respondents who indicated on the five-point Likert scale, the level of importance as 1, 2, 3, 4, and 5 respectively for attribute h, where 1 represent “very unimportant”, 2 for “unimportant”, 3 for “good to have”, 4 for “important”, and 5 for “very important”.

4.2.3 Third Stage: Model Development and Validation

The third stage was to develop, apply, and validate the model. The SSDSS was developed using intelligent systems, which consist of an automated DSS using the hybrid model (combination of mathematical model, rule-based, and case-based reasoning) in a KBS package. Management of KBS was to encode the heuristics knowledge. Some aspects of this topic have been discussed in Chapter 2 (Literature review).

For application and validation of the model, a hypothetical but realistic selection scenario regarding the selection of subcontractors was applied to explain the model comprehensively. This work example was also used for the model validation. In this stage, the third fieldwork was carried out. The experts were asked to try out the SSDSS and fill in the feedback form.

Validation is defined as the assurance that the built model was appropriate to solve real-world problems in the same way as the experts involved in its creation would do and the end users would expect. A rigorous validation process is essential to ensure that the KBS developed the intended performance. A poorly validated system may make poor decisions that can lead to a loss of confidence in the expert system, resulting in discontinued use and financial loss.

Several different approaches have been used to validate a particular KBS, such as those suggested by Hopkin, (1992); Juan, et al. (1999); O’Leary (1993); Ram and Ram (1996); and Rey and Bonillo (2000). Basically, validation falls into two broad categories: (1) informal, and (2) formal validation.

Informal validation is a long-term feedback process, which oscillates between DE, knowledge engineer (KE) and the target user. This project begins at project initiation and continues throughout software development. Formal validation usually begins once a prototype, which is thought to meet design objectives, has been developed. This research adopted the formal validation approach. This topic will be discussed intensively in Chapter 8. After the validation step, the appropriate SSDSS was refined and concluded.

The knowledge-based engineering process including method of knowledge acquisition will be discussed in Appendix 1 (Detail of Knowledge Acquisition Techniques).

Chapter 5
THEORETICAL FRAMEWORK FOR SSDSS

5.1 Introduction

In deductive research, an appropriate theory provides the framework for the research. The adopted theory provides the basic structural framework to identify and explain the factors, variables and relationships among them (Fellows and Liu, 1997).

In this chapter, an attempt is made to explore the extent to which the decision-making system can be justified in theoretical terms. The exploration of the quality of theoretical justification and a detailed assessment of the criteria and subcontractor selection methods are the basic theoretical framework for the discussion of the problems.

The theoretical framework will be discussed in the following order: (1) reviewing the factors influencing the success of BR projects; (2) formulating the mapping of these factors; (3) discussing each criterion and its attributes; (4) formulating a methodology for selecting subcontractors for BR projects. After generating the appropriate selection procedure and the hierarchy of factors, criteria and questions were summarized to gather information for the model input.

5.2 Factors Influencing Success of BR Projects

In developing the theoretical framework of decision criteria for selecting subcontractors for BR projects, it is necessary to review the critical factors influencing the success of BR projects.

CIRIA (1994) suggested that some of the key issues that should be considered carefully in handling BR projects are:

Client involvement

In a BR project, it is not sufficient to brief an architect and leave him to get on with it. The client needs to have a continuous and intimate involvement with the project, especially if he continues to remain in the building when refurbishment is underway.

Collaborative approach

Refurbishment work requires a close collaboration and a sympathetic relationship between the parties, the employers, architects, contractors, and subcontractors. In most cases, it is extremely difficult to define the exact scope of the work in advance, and because the traditional type of contract involves a general contractor appointed by competitive lump-sum tender, it is unlikely to be satisfactory.

Client's representative

To avoid chaos, it is essential for the client to appoint a single person as his representative through whom all communications with those undertaking the project should flow.

Authority and communications

Definite and clear lines of communication and authority are important, and for the simplest projects, it is advisable to appoint someone, either in-house or externally, with total responsibility to manage the whole project including design, programming, cost control and construction.

Building diagnostics

The purpose of the action is to find out the existing conditions of the building. A fundamental characteristic, which distinguishes refurbishment from new-build, is that there is an existing asset, and finding out what is already there, is a major task. Even if original drawings and specifications are still available, it is quite likely that substantial changes and renewals have been undertaken during the building's life. A preliminary investigation of the structure and sub-structure should always be made to minimize unpleasant surprises, which will occur once the work actually starts. The primary question is who will do this investigation, designer, contractor, or subcontractor?

Construction team

Although design and construction are dealt with as separate tasks for presentation purposes in refurbishment projects, they must be interactive and should be considered together. Early involvement of the construction team with the design team should be encouraged.

From these issues, it can be concluded that the smooth relationships among all the parties is crucial in the BR project. Collaboration between all parties, with confidence shared, must be the mainspring for the project, and over-mechanistic or adversarial approaches are a certain recipe for failure. This will strongly affect the methods of procurement and contract relationships that are used, but the most important aspects are the attitudes, experience, and capability for cooperation of all people involved.

5.3 Selection Criteria

According to HRM literature, in selected cases, "criteria" are used to define how the candidate should fulfill and perform in a certain job. Criteria may sometimes concern tasks, competencies, behaviors or capacities and personality requirements (Altink, et al., 1997). Criteria play a double role that formulates in a specific manner what individuals have to do; they also give standards with which we can evaluate whether these goals have been achieved.

Table 5.1 Criteria for Selecting Subcontractors

Criteria	Authors
1. Competitive bids; Price	Lin (2002); Okoroh (1992); CIB (1997); Andrews (2000);
2. Quality of workmanship	
3. Work experience	Okoroh (1992); Andrews (2000)
4. Time to complete	Andrews (2000)
5. Technical proposal	Okoroh (1992); CIB (1997); Lin (2002)
6. Reputation, Track record	Okoroh (1992); CIB (1997)
7. Relationship	
8. Financial stability	
9. Time to submit the quotation	Okoroh (1992)
10. Geographical area	Okoroh (1992); CIB (1997)
11. Safety policy	
12. Honesty and reliability	Okoroh (1992); Andrew (2000)
13. Planned performance	Lin (2002)
14. Insurance	CIB (1997)
15. Resources	
16. Site meeting	Okoroh (1992)
17. Contact address	
18. Work program	

Criteria are the foundation for procedures of selection. The requirements of a set of criteria are: they should be relevant (cover jobs and tasks), be clear to indicate the performance of management, and be adequately measurable (reliable, valid and acceptable). However, formulating adequate criteria in an unambiguous way can be a difficult task. Akkerman (1989) criticized that most researchers considered that a formulation of those criteria that can be measured is more important than those criteria that should be measured.

In subcontractor selection, the main contractor has to use selection criteria that relate to project requirements and his decision strategy. A central feature of selection criteria can be transformed into observable characteristics, skills, and habits of the candidates. The selection criteria can be communicated with a project team, in observing, predicting and evaluating performance and (future) achievements. The construction of criteria involves the development and consideration of a wide range of necessary and sufficient decision strategy as well as the participation of many decision-making parties (Brook, 2001).

5.3.1 Selection Criteria in Previous Studies

Several previous studies and publications on subcontractor selection (e.g. Andrews, 2000; CIB, 1997; Lin, 2002; Okoroh, 1992) have proposed sets of criteria (see Chapter 3). A list of 18 criteria was usually considered in selecting subcontractors. These criteria and the respective authors are shown in Table 5.1.

However, these sources have some limitations (see Chapter 3). For example, the proposed decision criteria have little rationalization, and the logical relationships of the criteria were not explained. Most of these models were not supported by an automation system. This finding is not surprising. Altink, et al (1997) criticized that most studies paid more attention to idiosyncratic criteria and less attention was paid to the way in which criteria were actually derived and developed.

Most of the previous studies adopted an inductive concept of learning to find examples of knowledge (facts) without giving much attention to justifying the logical consequences of the background knowledge. The empirical model is frequently based firmly on statistical analysis of the survey results. A problem can arise with this approach in that although the statistics may give an indication of what is current practice, it does not necessarily indicate good practice (Rowlinson, 1999). One other major conceptual limitation of all statistical techniques is that one can only ascertain *relationships*, but never be sure about the underlying *causal* mechanisms (Stat-Soft Inc., 2003).

5.3.2 Criteria Relationships

Statistical analysis is the most popular technique in studying the quantitative relationships of criteria. However, as mentioned earlier, the statistical technique is inadequate to explore the causal relationships of the criteria (Stat-Soft Inc., 2003; Mak, et al., 1996). In this present research, beside the statistical approach, the logical relationships of the criteria can be identified through grouping and mapping them in a logical diagram.

The causal relationships of the criteria can be mapped through two approaches namely: (1) relationships diagram approach (Bonini, 1999), and (2) causal approach (Lebas and Euske, 2002). The relationships diagram approach was used to explain the background knowledge for the relationships of the main contractor, subcontractor, and project characteristics to arrive at a decision.

The causal approach was used to explain logical relationships of the driving factors that affect the decision maker's objectives (Dulung, 2002). The importance of the causal model was to understand the organization and its interactions with the environment. After the logical relationships of criteria were identified, the admissibility of criteria was checked through postal questionnaires sent to the main contractors.

5.4 Background Knowledge

The literature review found that hardly any of the completed studies dealt with theoretical or conceptual issues. Although several AEC studies on selecting main/subcontractors from the client's point of view have proposed intensive criteria for selection models (e.g. Bubshait and Al-Gobali, 1996; Holt, et al., 1994; Russell, 1992; Tam and Harris, 1996), it may not be possible to apply these criteria directly for BR subcontractor selection because:

1. They differ in the decision makers' characteristics. As decision makers, the building owner's characteristics differ from the main contractor's characteristics; they have different objectives that will imply different strategies in making decisions.

2. The criteria mostly measure only one or two dimensions, such as main/sub contractor's characteristics and project specifications. They have little consideration for the decision maker's characteristics.

Hence, in this present research, the background knowledge constructed was not only based on the AEC literature but also on other fields such as decision-making theory, material and supply chain management, human resource management (HRM), economics and business management, etc. The knowledge from the buyer-supplier decision-making process can be imported into AEC from purchasing and supply chain management literature. The concept of personnel selection in HRM literature is also relevant for the selection of subcontractors.

The terms buyers, suppliers, and products in the buyer-seller business literature may be relevant to main contractors, subcontractors, and services suppliers in procurement for AEC areas. The only difference between the buyer-seller and main contractor-subcontractor interactions is the characteristics of the product. In the buyer-seller relationship, products can be inspected and compared in terms of quality, price and suitability before the purchase. On the other hand, the main product of the contractor-subcontractor relationship is normally purchased before it is built. The product cannot be returned or exchanged. However, the criteria for supplier and subcontractor selection may be comparable. Hence, it can be summarized that the task of a main contractor in evaluating the performance of a BR subcontractor shares similar characteristics with the situation described above.

In the supply chain management literature, a number of selected criteria have been proposed and grouped in accordance with three dimensions (Dzever, et. al., 2001). These relate to: (1) the product that is to be sold-bought, (2) the seller or provider, and (3) the buyer organization. The data to be collected for the selected criteria procedures also depend on these dimensions.

According to the HRM literature, in selection procedures, the data collection step should contain information about job openings, job contents, and other characteristics of the organization; it should also include physical, biographical and behavioral characteristics of the applicant (Roe, 1989). In a similar manner, the main contractors (as buyers) select subcontractors (as service providers) based on three dimensions namely: (1) main contractor's objectives, (2) project specifications, and (3) subcontractor's profiles.

In practice, the correlations of these dimensions in decision-making are complex. Main contractors develop specifications which may not only be based on their objectives and the project characteristics, but also based on the special considerations of the main contractors (e.g. culture and relationships). On the other hand, the subcontractor provides a quotation not only to comply with the project requirements, but also with the main contractors' characteristics and the subcontractor's objectives.

In order to develop a correlation model, it is necessary to define the input and output as:

1. Main contractor/Decision Maker's objectives (input)
2. Subcontractor's profiles and proposal (input)
3. Decision strategy and project specifications (output)

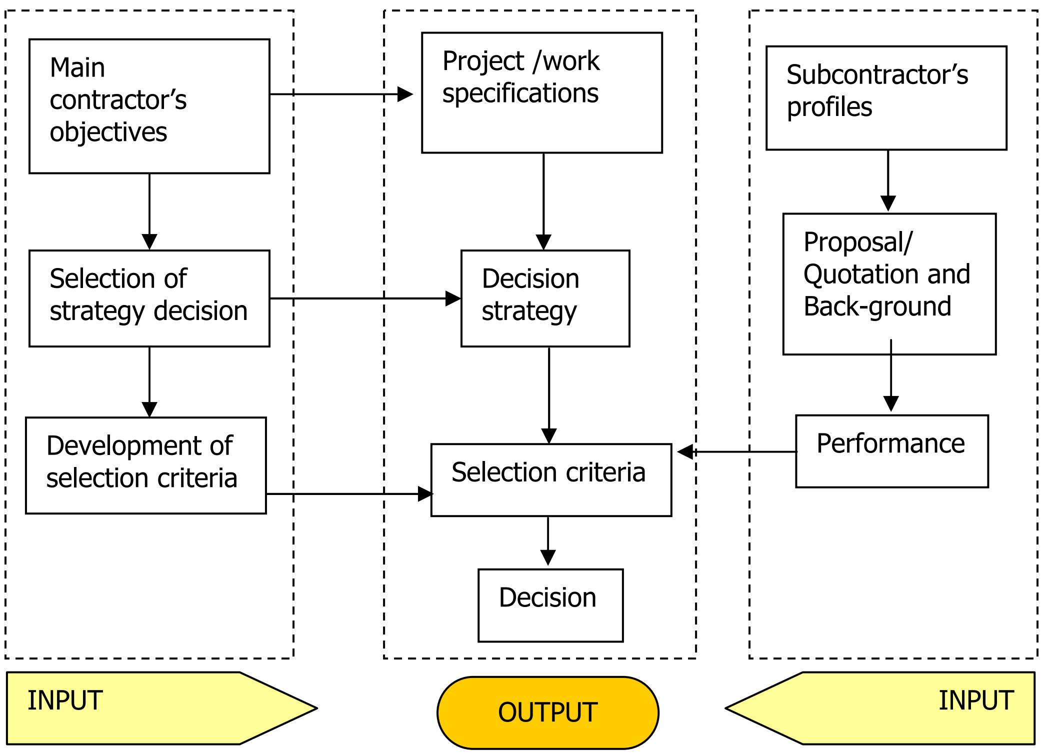


Figure 5.1 Main contractor – subcontractor relationships and selection process

A possible structure of the input/output processes and their logical interaction is presented in Figure 5.1. In the next three sections, each of these items will be discussed.

5.5 Main Contractor's Objectives (Input)

The main contractor, as a decision maker, has his own distinct objectives and functions within different decision-making environments. The main contractor's objectives influence the selection of decision strategy and criteria. However, as mentioned earlier, most previous studies on selecting contractors or subcontractors lacked consideration in the decision maker's dimensions.

According to the decision-making theory, a company's decision is driven by the company's objectives relating to market, production, financial, personnel, and organization's aims (Gruneberg, 1997). Liu (1994) also noted that organizational behavior is governed by organizational goals, and project goals can affect the act-to-outcome process. Altink, et al (1997) introduced organizational practice in the process of criterion development and observed that if the organization has set up an objective, then a similar type of objective can be applied to develop selection criteria. The advantage of this approach is that expectations are clearly communicated in the first encounter between the organization and the options available.

In a supply chain management study, Dzever, et al., (2001) found that the decision maker's objectives are important factors in the purchasing decision. They found that the purchase decisions were influenced by three broad considerations of buyer behavior, namely economic, technical, and social factors.

In another study, Leenders and Fearon (2002) suggested that the decision in selecting a supplier can also be based on the calculated risks. Research on assessing the risk behavior of the buyer shows that the perceived risk of contracting the work with an untried and unknown supplier is high. Chicken (1994) also explained that managing risk and making decisions are generally based on the three dimensions of commercial, technical and social-political factors.

In a construction contract, the main contractor may be willing to transfer the risk to a third party and prepare the contingency plan where a planned and organized alternative action can come into force when the risk occurs (Liebing, 1998). This is in-line with Elkington and Smallman's (2002) suggestion that the action that can be taken to make the risk acceptable are: prevention, reduction, transfer of the risk to a third party, and contingency plan. Kashiwagi and Bayfield (2002a) proposed a contractor selection model that uses the ability of contractors to minimize risk as one of the selection criterion. They added that the technical proposal of a contractor reflects the contractor's ways to minimize the risk.

There are three risks in subcontracting (Wangemann, 2000): (1) the subcontractor will default and the main contractor must take over the work; (2) the subcontractor cannot perform at the required rate and this delays the entire project, again requiring the main contractor's assistance or takeover; and (3) misunderstanding between the main contractor and subcontractor on the total inclusive elements of the subcontract.

The above conditions share similar aspects to a BR project environment that is less predictable than the new-build project with a higher level of risks and uncertainties (Egbu, 1997; Quah, 1988). The increased risks and uncertainties in such projects may disrupt the basic requirements for price certainty, project duration, and acknowledged quality standards (Egbu, 199b). These risks can be reduced only by making the right decision on subcontractor selection (Quah, 1988).

Based on these discussions, it can be deduced that the main contractor makes decisions for the selection of subcontractors based on four objectives:
1. Economical objectives.
2. Technical objectives.
3. Managerial objectives.
4. Socio-political objectives (Special objectives).
The next three sub-sections discuss these objectives.

5.5.1 Economical Objectives

The general objective of business is monetary advantage. The desired changes in levels of monetary resources are usually expressed in terms of profits or profitability. Calvert (1995) cited that profit is what is left after all costs and overheads have been deducted from the price. Ming, et al. (1997) added that business profitability is closely related to the willingness and ability of businessmen to invest and employ. Hence, logically, to gain the desired profit, businessmen need to maximize the returns by maximizing the sale price and economizing the costs.

The conventional economist's interpretation of company objectives is to maximize profits. In order to minimize production costs, organizations need to ensure that the resources used to produce the output are obtained at the lowest possible costs. This is one of the reasons in conventional procurement why the lowest price is the most dominant criterion (Kumaraswamy and Walker, 1999; Hatush and Skitmore, 1997). By choosing the lowest price, the contractors are expected to maximize profit because the quotation price will become part of the main contract price, which will affect the latter's competitiveness.

However, maximizing profit could increase risks because the profit is also a product of turnover multiplied by the profit margin, and it is difficult to increase the overall profit by maximizing one component without affecting the other components.

Profit is one of the objectives among many. Companies are being held accountable for the quality of peoples' lives and its value (Calvert, 1995). There are other subtle factors, such as reputation and public responsibility (safety), which must be fulfilled to ensure long-term profitability. Therefore, the economical objective should not be dominated by maximizing profit, but it should be balanced among profit, risks, and other objectives.

5.5.2 Technical and Managerial Objectives

Gruneberg (1997) noted that apart from making profits, other aims of the business include promoting the survival of the firm, customer satisfaction, and producing a high quality product or service. In order to provide a high quality product for the customers, the main contractors need a good service provider. One of the prerequisites to fulfill the customer's satisfaction is that the project specifications are met, in which the quality of specified works match closely with the quality of characteristics that are needed. The project objectives can be characterized as being one of two types: external and internal. External project objectives are imposed on a project by outside entities, which include government regulations.

Internal project objectives are within the sphere that influences the decision maker. They consist of several classical measurable performance parameters: cost of the projects, time required for completion, quality of the finished product, safety achieved during construction, and other un-measurable factors such as corporate strategy (Kagioglou, et al., 2001). The decision maker is therefore forced to deal with both internal and external objectives. The objectives will be reflected in the project specifications which the subcontractors should comply through their proposals.

The project specifications and the project proposals are discussed in Section 5.7 (Project Specifications).

5.5.3 Socio-political Objectives

The other factor in decision-making relates to socio-political objectives or the so called "special objectives". It should be recognized that some of the decisions could be based on subjective rather than objective criteria. Although people plan to run a business and organizations in a rational manner, they also have to deal with other people (socio-political relationships) when doing so. Consequently, it must be accepted that subjective judgments and non-objective criteria, such as a similar culture between the main contractor and subcontractor, could be used in the decision criteria.

5.5.3.1 Similar Culture

With the increase in economic globalization, some studies of selection criteria have also included factors such as culture (Walker, et al, 2003; Rahman, et al, 2002; Dzever et al, 2001; Barthorpe et al, 1999; Liu and Fellows, 1999; Rowlinson, 1999). In a broad sense, culture is acknowledged to be rooted in people's minds, ideas, beliefs and values. Culture affects the way that people make decisions, think, feel and act as a response to the opportunities and threats that affect the organization (Liu and Fellow, 1999). Druker and White (1996) explained that culture is the prevailing attitudes and beliefs within the organization that may have an impact on the way in which individuals perceive their role and responsibility. In this present research, the term culture was limited to similar language, behavior, and ethics in construction procurement.

Some writers suggest that there is a link between culture and organizational effectiveness. Druker and White (1996) cited that culture within an organization is reflected in the way that people perform tasks, set objectives and administers the necessary resources to achieve objectives. Barthorpe, et.al, (1999) drew the correlation between conflict and culture, stating that the cause of disputes is closely related to the culture of a society. Cultural misunderstandings are a major source of failure in their relationships. The potential for conflict is exacerbated when two different cultures are working together, for example, Western culture meets Eastern culture in joint-venture construction projects (Chan, 1997). Sweirczek (1994) cited that individualistic and low-context cultures, (i.e. western countries) tend to be confrontational and direct. High-context, collectivist cultures (i.e. East Asian countries), exhibit "face-saving", and indirect styles of conflict management. When these various cultural values come into contact, major difficulties emerge.

The concept of culture has become an important issue in analyzing procurement systems. Rowlinson and Root (1997) were surprised to find that the impact of contract conditions on performance was very limited. The project history and prior working relationships have the most significant impact on project culture. The view often expressed is that the conditions of contract are only necessary when a dispute arises but with good working relationships, this scenario can be avoided. Thus, development of a positive project (organization) culture, even before a contract commences, is the best means of ensuring a smooth-running project. This is true, especially for BR projects, where smooth contractual relationships among all parties are essential. The cultural values will affect the relationships, communications, and trust between the main contractor and subcontractors.

5.5.3.2 Relationships

The dynamic nature of the construction industry mandates a short-term contractual formation of various groups consisting of general contractors and a number of specialty subcontractors in joining forces to complete a project. This formation ends with the delivery of the subcontracted works and the payments made in full to the subcontractors.

The formation also gives parties an opportunity to develop a mutual relationship that can contribute to future collaboration. It is understood that the main contractor's organizational values, namely, the nature of relationships, should be developed with their subcontractors or suppliers. Maintaining a good relationship with the subcontractor or keeping a key supplier has also been found to be an important objective (Wangemann, 2000; Akintoye and Black, 1999).

However, in practice, Greed (1997) described the working environment in the construction industry as "a culture of intimidation" where there is an increasing emphasis on subcontracting and a decline in the use of direct labor. Greed (1997) observed that the whole industry seems to work through each level by putting pressure on the next one below. Nielsen (1996) noted that the relationships between supervisors and employees in the workplace have become counterproductive to achieving performance.

Suppliers or subcontractors should no longer be seen simply as the sellers of products (or service providers) but rather as partners in business, because only through this partnership can the main contractors achieve their BR objectives with the best quality and standards that will ensure the attainment of clients' satisfaction at the same time. A good long-term relationship will result by achieving client's satisfaction consistently. This should be the successful subcontractors' highest priority. Tan, et al (1998) suggested that working cooperatively with a supplier or subcontractor in procurement could move beyond mere cost reduction into the domain of efficient manufacturing. These circumstances often lead to a relationship somewhat akin to a partnership between a main contractor and a subcontractor. Thus, the main contractor – subcontractor relationship becomes an important determinant of subcontractor selection for a BR project.

5.5.3.3 Trust

Other variables to be considered for subcontractor selection in BR projects are trust and communications. Leenders and Fearon (2002) also noted that effective supply chain management rests on the twin pillars of trust and communications. Commonly, these considerations may be the last variable that affects the main contractor in decision-making. Swam, et al (2002) noted that trust and communications not only reduce the transaction costs, make possible the sharing of sensitive information, and permit joint projects of various kinds, but also provide the basis for expanding moral relations in business.

Trust relates to relationship and experience. Kadefors (2002) noted that a person would trust another person if it is in the other's interest to act in a way that is desirable to the first person; when they have confidence in each other, then the information is freely shared. Swam, et al. (2002) pointed out that trust is built through relationships, and the repetition of these events will impact future exchange relationships. Experience is considered to be the main driver of trust. Trust can also develop the employee's morale. Chang (1991) emphasized the morale of workers as a key factor in measuring construction productivity. The ability to handle human resources properly will be reflected directly in staff morale and team effectiveness. The employee's morale can decline due to material shortages, frequent foreman turnover, absenteeism, substandard employee facilities, and management-labor conflicts.

5.5.3.4 Communications

Communications is the key to a successful relationship. Management relies on clear communications and the ability to pass ideas and information through quickly and effectively between people with different technical skills and interests (Wangemann, 2000). The success of a project therefore depend on a great deal on the ability of the project parties to communicate with each other while performing their functions. Effective communications between the main contractor and subcontractors in the project helps to create enthusiasm when it is most needed.

Effective communications may occur in two ways: informal and formal. Informal communications are valuable in establishing good personal relationships, for the rapid and effective resolution of problems and for deciding courses of action. Formal communications are required to ratify a decision made informally, to record briefly the main reasons for this decision, and to communicate the relevant information to people who were not involved in making the decision.

In BR projects, to ensure efficiency in project control, procedures for rapid decision-making and communications is particularly required. Miscommunications often occur in a mixed culture organization because authority is not granted by the formal organizational chart. For instance, in an extreme form reflected by Liu and Fellows (1996), the problems of good communications between high-content and high-context expressions (for example English and Chinese), cultures might be the issue. Without sensitivity to the receiver(s) and care in producing and transmitting the message, it is likely that clarity will be poor and/or that offence may be taken. Consequently, project performance may suffer.

In order to eliminate issues, it must be established in the course of social interactions what is appropriate to the situation. Informal (face-to-face) communications is more efficient in communicating information among the parties than formal communications because it does not rely just on words, but also gestures, eye contact and other forms of "non verbal" communications. It also contributes to establishing the true meaning and intention of the parties (Davies and Haliel, 1998). The main contractor is therefore responsible for establishing good communications with all parties. The subcontractor's ability to communicate is also equally essential.

Based on the above discussions, similar cultures in developing a relationship are essential; good relations between the main contractor and the subcontractor are the cores of effective management. The approach to the selection of a subcontractor should take into account the fact that a subcontractor in the field of BR works is in quite a different situation from those in new-build contracts. It is suggested that in the case of BR works, the emphasis of a successful subcontractor is usually on securing repeat business from the main contractors. Consequently, there is a lack of a tendency on the part of the subcontractor to resort to litigation to resolve disputes. Subcontractors often put a higher priority on maintaining a harmonious relationship than on pursuing every possible claim, which might jeopardize this goal (Calvert, et al, 1995).

5.6 Subcontractor's Profiles (Input)

Data on subcontractor's profiles is essential for the evaluation of performance. Because the contract has not started, a service that will be provided cannot yet be evaluated. The main contractor can only judge the quality of the products/services of the subcontractors based on imperfect information until the project is finished. Hence, to judge the future quality of services provided by the subcontractors, a decision maker should be interested in assessing the subcontractor profiles with an assumption that good performance of the organization directly affects the quality of the organization's products. In practice, the decision-maker (i.e. the main contractor) can only judge the performance of the subcontractor through the characteristics and the past performance records of the subcontractor (Kashiwagi and Bayfield, 2002a).

Performance measurement is the process of determining how successful organizations or individuals have been in attaining their objectives (Kagioglou, et al, 2003; Evangelidisz, 1992). Several studies on performance measurement have identified factors that affect performance (Abdeen, 2002; Meyer, 2002; Clark, 2002). For instance, an organization's business performance would affect its stability and hence its capacity to complete a project.

Lebas and Euske (2002) noted that performance would not have the same meaning because this depends on whether the evaluator is inside or outside the organization. An internally defined model is likely to focus on construction of the results through actions. An externally defined model is more likely to focus on anticipating the possible action that the internal actors might select and thereby estimate the probability of certain future results that will be used in some other decision-making process.

In the present research, performance of the subcontractor is viewed from the outside. This takes the forms of viewing general indicators based on some preconceived and possibly statistically defined relations. The decision-maker is interested to forecast the performance based on evidence of performances. These performances may be divided into two categories, namely *current performance* and *past performance*.

5.6.1 Current Performance

Performance indicators, traditionally, have been based primarily on management accounting systems. These have resulted in most measures focusing on financial aspects, e.g. profits, sales, and productivity (Sanger, 1998; Ghalayini and Noble, 1996). Abidali and Harris (1995) suggested that both adverse financial and managerial indicators might be observed as the company moves towards insolvency.

Besides the financial perspective, the internal process of the firm is also an important indicator to measure the company's performance (Kagioglou, et al, 2001). The internal process can be identified by evaluating corporate strategy, the environment, resources, operations and productivity. Among these performance factors, productivity has been considered the primary indicator of performance. Since no process can produce the same exact results each time the activity is performed, it is important to establish the types of variability that can occur. The common causes of variability relate to personnel, equipment, material or manufacturing-related things (Leenders and Fearon, 1997). Snow and Alexander (1992) summarized seven factors that can influence productivity, namely background organization, quality of personnel, equipment, materials, standards, relevant experience, and physical environment.

In this present research, synthesizing the current performance indicators included four criteria. These are financial stability, subcontractor organization, personnel qualifications, and relevant experience. These are discussed below.

5.6.1.1 Financial Performance

The dimension of financial stability can be measured by four decision parameters: credit ratings, banking arrangements, bonding, and a financial balance sheet (profitability history). Evaluating the financial stability of companies require detailed information such as credit ratings, banking arrangements, financial statements, turnover history, and ratio analysis of accounts, etc (Crowe, et. al. 1999). These requirements, however, are not easy to fulfill in the BR subcontractor selection process because the time for preparing and evaluating the relevant documents is very limited in the early tender stages which is made worse by the fact that this information must come from references of third parties (e.g. banks).

In this present research, the appropriate attributes were determined to evaluate the financial health and the reputation of the subcontractor among the local banks, namely *bank references, profitability history*, and *current workload on hand (backlog).*

The financial stability indicator is a recent financial statement for the evaluation of a current situation or at least that of several months ago. It includes the approximate value of work in hand and the annual value of works completed (CIB, 1997). It also relates to the capability of subcontractors on how much work can be handled by them at any one time. This is an important criterion which indicates whether a subcontractor has the necessary financial resources to execute the works.

Another reason why financial stability is important is because in practice, the subcontractors' works are undertaken on credit, providing materials, goods, and services for a period of time before they are paid. Under the condition of contract, subcontractors are the most vulnerable in respect to claims. Normally, payments are due at not less than monthly periods. According to most standard conditions of contract, the main contractor will have 17 days from the due date within which to make payment (SIA, 1999). Subcontractors are therefore invariably financing the works in advance. In fact, subcontractors often suffer from cash-flow problems. When the subcontractor defaults on payments to the workforce and/or material suppliers, it leaves the main contractor to deal with the consequential difficulties (Druker and White, 1996).

5.6.1.2 Subcontractor's Organization

Adequacy of the organizational structure is another attribute used in the selection process. Organizational structure indicates the level of management commitment for different functions, such as quality control (Bubshait and Al-Gobali, 1996). The decision-making process and how decisions are communicated to different hierarchical levels of subcontractor personnel can also be inferred from the organizational structure. Solid organization equates smooth business (Calvert et al, 1995). Organization is the cornerstone of all successful businesses. Good organization is a strong part of professionalism. Without good organization, the best business idea will be fruitless.

In previous studies completed by others, some selection attributes were applied to measure the effectiveness of the organization but certain criteria such as attendance at meetings were not clarified. This attribute was not adopted in this present research because the performance of the subcontractor cannot be evaluated simply through attendance at meetings. There may be no meetings at the tender stage; the contract has not been started yet. If the meetings are meant for project clarification sessions, the absentees must be rejected since they would be unable to produce a quotation.

In this present research, criterion of subcontractor's organization includes *company's reputation, company's age* and *responsiveness*.

One of the attributes in evaluating a corporate business is image (i.e. assurance of quality management or good reputation). The company should be able to demonstrate a commitment to quality management but this can be difficult to evaluate. Quality assurance accreditation is one way in which this can be made evident. In this case, a subcontractor should be a member of a union or trade organization which promotes the quality of its members. For example, Singapore List of Trade Subcontractors (SLOTS) or association of building refurbishment contractors, help to promote a higher level of productivity and quality of subcontractors. The union monitors the company reputation; better trade subcontractors can be upgraded in accordance with their performance and track records under an incentive-oriented rating system (SCAL, 2003).

Woodson (1997) suggested that the age of the business is also a significant attribute to evaluate a subcontractor. If the subcontractor has been in business for a while, there is a better chance that his business will last. New businesses often fail, but businesses that have been around three to five years have a better chance of survival. Business owners who survived these early years have business experience and dedication.

Another attribute in evaluating a corporate business is responsiveness. The operation of a good organization can be seen through responsiveness. For instance, from the main contractor's point of view, one of the most critical aspects of a subcontractor is how easy the subcontractor can be reached. Contact persons and addresses are very important since BR works need quick responses. The unexpected usually occurs; the work program may need to be revised constantly and the subcontractor may need to be on site at short notice.

5.6.1.3 Personnel Qualifications

Previous studies completed by others distinguished personnel qualification into four attributes, namely geographical area experience, number of staff, technical competence, and work design experience. However, several attributes are inapplicable, such as the geographical region, for a tiny island like Singapore; this is because all subcontractors are local companies. Number of staff is also meaningless because workers will come on site with a subcontractor, either individually, or as part of a gang called "*kepala*" in Singapore.

Lahteenmaki, et al. (1998) found that human resource issues are supposed to have an impact on company performance. The ability of key personnel will affect the business performance. Guion (1997) noted that key personnel are the best evaluators in issues related to company performance. Consequently, evaluation of future business results is supposed to rest on long-term key personnel experience and competence to give a reliable picture of reality.

The technical competence of the organization is determined by the skills of the personnel, and the quality of personnel may be traced from the technical proposal that they produced. Hence, only the key personnel of the subcontractor should be evaluated. Baumol and Maddela (1990) identified changes in the quality of equipment, material or labor as critical factors of construction productivity. Quality changes in key personnel, materials, or equipment are often contributors to true labor productivity either decline or advancement.

The building construction process is characterized by the dependence of skilled craftsmanship for the interpretation of instructions and execution of work (Mohsini and Davidson, 1992). Managerial and technical capabilities are often considered under the manpower category. Abdeen (2002) also found indications that one of the factors that make any organization survive in the market is its ability to creatively use people management and motivation skills.

Therefore, a main contractor selects the subcontractors or suppliers based on the following requirements: (1) a subcontractor with a good track record of success with the customer; (2) a subcontractor with skills in an area that the main contractor is not; (3) a subcontractor with personnel resources to complement the main contractor's own staff; and (4) a subcontractor who can meet the customer's certification requirements.

In this present research, the criterion of personnel qualifications include only three attributes, namely *personnel qualification, related experience* and *technical ability*.

5.6.1.4 Relevant Experience

In most standard conditions of contract, it is stated clearly that the sub contractor is employed for his experience, character and capabilities. The basis for this principle is that the main contractor values the financial standing, technical capabilities and trustworthiness of the subcontractors. In the literature review, the attributes of relevant experience were difficult to trace because they included several criteria.

Relevant experience can indicate the firm's ability to successfully complete different construction projects. An empirical study showed that relevant experience is correlated with job performance (McDaniel, et al 1988). The experience is especially needed when difficult conditions occur, for example if abnormal construction is encountered or extremely rigid time limits are involved in a project, such as in a BR project environment.

The subcontractor's experience should be an important consideration. In BR subcontractor selection, the level of uncertainty regarding the existing building and services is high; it demands a quick response to unexpected situations as they emerge (Teo, 1991; Quah, 1989). Subcontracting companies' experience means the experience of the individuals inside the company. West and Allen (1997) explained that individuals are selected typically to work as part of a project team because they appeared to have the particular set of technical skills and experience that were deemed necessary for particular aspects of the job. Individual experience and skills are related to the period working in specific fields as well as individual talents.

The criterion of relevant experience includes type of past work and size of the work. Subcontractor's experience is the most significant attribute for evaluation, as similar projects undertaken in terms of type, size and complexities are reviewed carefully. Subcontractors who are familiar with the type of project may manage that kind of work more efficiently and thus may perform better. The level of satisfaction, time of completion and the percentage of subcontracted work are also considered. Egbu (1999a) suggested that a key consideration for any BR project is the selection of an experienced team, and the appointed person should have a good track record for refurbishment work. The relevant experiences are not only in type of projects but also size ($) of projects.

In this present research, the criterion of relevant experience include only two attributes, namely *similar type of project to the proposed work,* and *similar size ($) of projects to the proposed work*.

5.6.2 Past Performances

JDB (1997) suggested that companies which have the necessary skills, experience and adaptability, but do not have direct experience of work as the proposed project are not immediately rejected. Other factors have to be evaluated such as a good track record (past performance), or if they are highly qualified in other areas. This situation is also true in BR work where no projects are exactly alike; each project is different.

The quality assurance of companies can be examined from their past performance and previous experience on jobs of comparable nature. Ward, et al. (1991) noted that looking back on a completed project, no financial or early completion sticks in the mind but many other factors do. For example, the customers remember positive impressions created through harmony, goodwill and trust. Conversely, customers also remember negative impressions created through arguments, mistrust and conflicts. The main contractor's willingness in selecting subcontractors is likely to be strongly influenced by past performances or track records. Andrews (2000) cited that past contractual relationships give contractors information on the capabilities of a subcontractor to finish the works on time, budget, and produce high quality standards.

Previous studies also indicated that past performance or track record is an important indicator (Kashiwagi and Byfield, 2002a; Wangemann, 2000; Leenders and Fearon, 1997; Ward, et al. 1991). Past performance may be one of the factors that govern future performance. Kashiwagi and Byfield (2002b) predicted that performance of the present project can forecast 25 per cent of the performance in future projects.

5.6.2.1 References on Past Performance

Data of past performance may be based on the main contractor's own experience with the subcontractors, or through references of third parties. The indicators of past performances are similar to the indicators of current performances, such as quality of past work, safety records, legality of past contracts, quality of workmanship, skills of operators, financial performance, integrity, honesty, and reliability. They are different in data sources; if the current performances are obtained first-hand from subcontractors, the past performance information may be found from the information system of the decision maker or past clients (references) who had worked with the subcontractor before in past projects. In order to obtain information on past performance from the references, some questionnaires may be used to elicit this information, and some discussions may be required to test the suitability of proposed quotations for specific works.

Tam and Harris (1996) suggested that customer perspective is an important indicator of the subcontractor's ability in working on the project. Evaluating the subcontractor through these references is an effective method to screen the performance of firms because non-performing subcontractors may be unable to get references, especially from previously dissatisfied clients.

The main contractor may not need to elicit the attributes of the subcontractor's past performances because these can be obtained from the references. The number of references can be obtained by the subcontractors indicating whether they were good in their past performance (Kashiwagi and Byfield, 2002a). The past performance of a subcontractor is evaluated through many different references on many different jobs. However, unlike previous studies, this present research did not apply the minimum reference score approach. Within the minimum score (e.g. minimum 2 references) approach, there was no reward for the candidates who obtained more than 2 references. This approach therefore seems unfair because it tends to decrease the quality of performance, and could frustrate the candidates. The candidates who have more references should get additional scores.

Based on the discussion of the subcontractor's profiles, it can be summarized that the company profile of a subcontractor can be judged based on the firm's organization, quality of personnel, financial stability, relevant experience, and past performance through references. However, past performance is difficult to measure objectively. Nevertheless although some indicators are qualitative in nature, the intelligent system can eliminate the subjectivity of the measurement.

The following sub-sections discuss both the project specifications (output) as a product of the decision of an organizational objective and the subcontractor proposal (input).

5.7 Project Specifications

The objectives of a main contractor organization will affect the ways in which decisions are made. The aim of the main contractor is to select the most qualified subcontractor that meets the project objectives and whose price is competitive. The main contractor judges the performance of the subcontractor's organization based on the decision maker's objectives, information gathered from subcontractors' quotations and other sources. The objectives are incorporated in the project document specifications; meanwhile the information of subcontractor quotations is obtained from the subcontractor proposal.

In the buyer-seller process, once the product specifications have been finalized, the specification requirements are considered set. A seller's responsibility is to deliver products that satisfactorily conform to quality to meet specification requirements. However, unlike the buyer-seller relationship, in the relationship for BR subcontractor selection, there is no real product that can be evaluated in advance. As the main product of the building industry is normally purchased before it is designed or built, the usual methods of evaluating and selecting “off the shelf” products cannot be applied (Holt, 1995; Mohsini and Davidson, 1992).

Furthermore, BR projects differ slightly from new-build projects; the existing building condition will typically influence the refurbishment proposal. Specific procedures have to be implemented concerning problems that deal peculiarly with an existing building, such as interaction between old buildings, temporary works, existing services, and new construction that will affect construction methods, planning, and programming throughout most of the construction period, as well as the interaction with neighboring buildings, processes, activities or people (CIRIA, 1994). These conditions will affect the project specifications that describe the requirements.

In general, the project specifications would include price specifications, planning, project duration (planning), and technical and managerial qualities. The project specifications of BR projects as well as new-build projects may be similar. However, the features of new-build and BR projects are quite different; for example, the risks and level of uncertainties are higher in BR than in new-build projects. The need for clarity and precision of specifications is important, but the scope of BR works is imprecisely defined at the outset of the design stage (Gilleard and Lee, 1999). These features will drive the decision-maker to handle BR projects in different ways. This should be reflected accordingly in the project specifications.

Although the specifications of BR projects can be complex, these should be developed precisely. Wangemenn (2000), however, warned that the terms and conditions should be minimized because additional requirements could lead to additional contract price, which means that the more the requirements, terms, and conditions that the main contractor has in the subcontract, the higher the contract price is likely to be.

There are two approaches to writing specifications; namely the prescriptive and performance-based approaches. The conventional specification is a prescriptive approach that defines requirements in static terms (e.g. floor areas, construction budget, regulatory requirements, etc.). The numbers specified are taken for granted and are often not questioned for their relevance. On the other hand, currently, there is a tendency to move toward a performance-based approach (Aronoff and Kaplan, 1995). The basic concept of the performance-based approach is not to prescribe a solution but rather to demonstrate that the proposed design meets defined objectives. This approach may result in alternative designs that are more flexible, rational, and innovative as well as cost effective. It focuses on performance targets rather than products or elements, and it clearly describes what is wanted without specifying how. In this case, the performance-based specification is more appropriate than the prescriptive specification for BR works.

5.7.1 Project's Specification vs. Subcontractor's Proposal

In other previous studies, the evaluation of the proposal was excluded because the model was used for the pre-qualification stage when the proposal has not been submitted yet. The significance of this present model (the SSDSS) is that all the tender stages proceed simultaneously in one stage.

For evaluation, a subcontractor submits a proposal that should comply with the project specifications; how far the firm can fulfill the performance specifications for the works. The main contractor will consider how robust the subcontractor's proposal is in the delivery of both financial and operational goals. The proposal relates to the quotation price, and the managerial and technical offer which can be seen as the ways in which the subcontractor will manage the project risks (Kashiwagi and Byfield, 2002a). The proposal is the subcontractor's product (output) that complies with the project specifications and objectives of the main contractor.

A common approach in evaluating the subcontractor's product on the extent of the services is cost, time, and quality (Kagioglou et al, 2001; Rowlinson, 1999). A project may be regarded as successful when the building is delivered at the right time, at the appropriate price and quality standard; it also provides the client with a high level of satisfaction (Love et al, 1998). Sanvido (1991) mentioned that in evaluating the project criteria, the performance would depend on the evaluator's point of view. The main contractor's criteria for evaluating the performance of the subcontractor's proposal include: profit or under budget (saving for the main contractor); meeting schedule; quality specifications met or exceeded; good safety; and client satisfaction.

5.7.1.1 Cost - Price

Cost and price are two different things; it depends on the point of view adopted. From the main contractor's point of view, the main costs are related to the price which a subcontractor quotes. According to conventional economics literature, price is equal to cost plus profit (Welch and Welch, 1992). The cost can in turn be categorized into direct costs (i.e. comprising of variable, fixed, and semi variable costs) and indirect costs (overheads). Direct costs are specifically traceable or caused by a specific project of production or operation, while indirect costs are costs that are associated with or caused by two or more operating activities jointly, but are not traceable to each of them individually (Mann, 1992).

Price

Several forms of price analysis have been proposed. However, there were no ideal price formulas that can be used to form a positive judgment concerning the right price of which profit is one component (Dobler and Burt, 1996). Several studies also found that a strong relationship between the price level in the building industry and the level of competitiveness in the industry follows the supply and demand relationship (Ming, et al. 1996).

In marketing theory, Erridge (1995) noted that product and price have a close relationship. However, construction contract bidding differs from product pricing when viewed in decision-making terms. The contractor/subcontractor relationship, for example, is more complicated than the usual buyer/seller situation in that the contractor and subcontractor have to make decisions in two stages over time and in uncertain conditions. There are, however, certain basic concepts of pricing on which professionals have agreed. One objective of sound purchasing is to achieve good supplier relations. This objective implies that the price must be high enough to keep the supplier in business (Dzever, et al., 2001).

Furthermore, the price must also include a profit that is sufficiently high enough to encourage the supplier to accept the business in the first place, and in motivating the firm to deliver the materials or services on time (Dobler and Burt, 1996). Tam and Harris (1996) indicated that if the subcontractor knows at the outset of the project that a profit can be made, a more cooperative attitude often results. However, on the contrary, the company may seek every opportunity to claim and risk upsetting the main contractor. What profit does it take to get these two desired results? On what basis should it be calculated?

Profit

Dobler and Burt (1996) argued that there is no single answer to the question: what is a fair profit? In a capitalistic society, generally, profit is implied to mean the reward over costs that a firm receives for its efficiency and the degree of risks it assumes. A fair profit in society cannot be determined as a fixed percentage figure; rather it is a flexible figure that should be higher for the more efficient producer than it is for the less efficient one. Low cost producers can price lower than their competitors, while simultaneously enjoying a higher profit. Consequently, one of the main contractor's greatest challenges is to constantly seek out the efficient, low-cost producer.

Attractive terms of payment and discounts can often be taken on materials and subcontractors' quotations are sometimes considered as an extra source of profits. It seems that profit should provide three basic incentives: (1) inducing the subcontractor to take the jobs at a reasonable price (win-win game); (2) inducing the subcontractor to perform as efficiently as possible, to deliver on time; and (3) providing all reasonable services associated with the order.

In practice, the profit margin is added to the direct costs for a particular project with: the volume of work in hand, the orders anticipated, market condition, and the inherent challenges in the works. The senior management will then decide what should be added to allow for profit from the returns on capital and the risks that are inherent in the works as a percentage factor. This may produce a tender sum that is considered too high to win the contract. The company must then decide on what sum it is willing to reduce the tender sum to in order to obtain the contract. When the contractor has little work in hand, there is obviously greater pressure on the management to secure a contract by submitting the lowest tender. The estimated direct costs will be reduced to as low a figure as possible and the allowance for profits will be kept to the minimum.

Contract price

Like all buyers and sellers anywhere, a main contractor also wants the best value for money. In the conventional approach, price is the first consideration that most contractors would make in selecting a subcontractor. Price has a direct effect upon the anticipated profitability of a project and can determine the profits returned to the main contractor. This emphasizes the importance of subcontractor's prices in the selection process, but the selection should not be undertaken on price alone because it may be inaccurate and comprises hidden costs (Andrews, 2000). Price pressure through the low-cost route may force subcontractors to increase the volume but the low margin may bring higher risks and lower the level of quality.

On the other hand, from the main contractor's point of view, a subcontractor may consider high price as a means for safe business that may implicate a surplus. Price, actually, relates directly to the project characteristics. However, the decision to bid is not only based on the project characteristics or bill of quantities but also heavily on the habit of the main contractor in deciding on the setting of a quotation for subcontracted works. Shash (1998) found the following indications:

1. A main contractor with a good reputation would receive a lower quotation than others who did not. It seems that subcontractors appreciate a low profit margin from well-organized works, by giving them an opportunity to manage their resources properly and to satisfy their various contractual commitments.
2. A subcontractor would reward a general contractor who paid promptly with a low quotation. On the other hand, if a general contractor has a reputation for late payments, the subcontractor will submit a high quotation to cover interest costs and the possibility of no payment.
3. A subcontractor understands that the growth and prosperity of its business can depend on the amount of work that it may secure in future projects released by the main contractor.
4. A subcontractor considers the future relationship seriously when giving a quotation for the work. From this perspective, subcontractor assesses the possibilities of future work to be awarded by the contractor and adjust its bids correspondently. In other words, if the possibilities of future work are high, subcontractors will lower their bid price, and vice versa.

In addition to these considerations, characteristics of a BR project should be considered. Refurbishment cost is likely to escalate at short notice; estimators in BR work often have to make decisions on the basis of incomplete and imprecise information during the tender preparation stage. In many cases, detailed drawings and specifications for the work that will be performed are not a prerequisite to appointment or even commencement (CIRIA, 1994). Estimation of the cost should therefore include realistic contingencies for specific areas of uncertainty, and in early estimation, this may be a major allowance. These considerations will affect the decision in selecting the subcontractors' quotation price.

The evaluation of subcontractors' quotations is mostly based on accuracy, consistency of price estimation, discount rates and terms of payment. A subcontractor would be selected because of its ability in providing a realistic quotation price and cost control. Previous studies (Okoroh and Torrance, 1999) also included "receipt of quotation on time" as a selection attribute. However, this attribute would not be adopted in this present research because late quotation may reflect low performance by the subcontractor and should therefore be rejected. "Terms of payment and discount" are two essential factors that should be included but do not currently exist in previous studies.

5.7.1.2 Project Duration (Planning)

Planning is the mover of the project and must be based on clearly defined objectives. With proper planning, adequate resources would be made available at the right moment, adequate time is then allowed for each stage of the process, and all the various component activities would start at the appropriate time (Gould and Joyce, 2003). Planning techniques can range from a simple bar chart to computerized network analysis.

Harris and McCaffer (2001) suggested that planning techniques should be based on the following important principles:

1. It should provide information in a readily understandable form; it should be realistic.
2. It should be flexible, and should be possible to alter certain elements without disrupting the entire plan.
3. It should serve as a basis to control and monitor progress.
4. It should be comprehensive, and should cover the stages from briefing to commissioning.

The most important task in the planning process is the preparation of a realistic time schedule. A basic time schedule should be worked out at a very early stage and should serve as a framework where all key activities can be indicated. The main contractor needs to evaluate the ability of a subcontractor in terms of construction time, or how long the work can be completed. Delivery date is related to project duration. Project characteristics, such as construction costs, gross floor area, project complexity, quality level, management style, etc. can significantly influence the construction duration (Chan and Kumaraswamy, 1999, 1997 and 1995). Studies undertaken specifically for construction time performance found that time performance is also significantly influenced by the managerial performance of construction management teams (Walker and Shen, 2002).

In a BR project, work often cannot be accurately predetermined in terms of duration. Plans of work and schedules must be realistic and must be shown to those who work toward them. For example, in some occupied BR business centers, a time window would need to be created to allow for power shut down in the area to be refurbished. The work timetable of the occupants and the neighbors becomes essential information for the planning of BR works. A high degree of pre-planning is clearly essential for BR subcontractors; provisions will need to be made for fallback actions in preserving the integrity of the time window. Planning should include: forecasts of resource requirements of people, materials and equipment; analyses for their most efficient use; and a forecast of milestones against which progress can be measured.

5.7.1.3 Technical and Managerial Quality

Quality is defined as the totality of attributes, characteristics of a facility, product, process, component, service, or workmanship that bear on its ability to satisfy a given need: fitness for purpose. It is usually referenced to and measured by the degree of conformance to a predetermined standard of performance (Sanvido, et al, 1992). It is common to rely on the quality assurance of the subcontractor or supplier rather than the traditional approach of the purchaser inspecting the work (JDB, 1997).

However, as mentioned earlier in subcontractor selection, there is no product quality to be evaluated. The main contractor is concerned with determining and ensuring that the subcontractor is able to meet the quality specifications of the works. The capability refers to the ability of the subcontractor to consistently meet the project quality that relates to capability to meet managerial, technical (material and equipment), and financial specifications. The technical solutions posted by the subcontractor will be considered to ensure that they are feasible in offering the main contractor a service, which will satisfy its requirements. Issues such as the use of innovation both to enhance the service provided and to reduce the costs involved will be considered in this area.

The nature of refurbishment works lends itself to a variety of areas that create difficulties in writing the project specifications (Egbu, 1999a; Ismail, et al, 1999; Gilleard and Lee, 1999). The basic objective of cost, time and quality, which occurs in all projects, is often supplemented in BR projects by major objectives such as minimal disruption to the operations of the building, safety, and housekeeping programs. For instance, some buildings were still occupied when they were refurbished and needed special handling (Marosszeky, 1991), including:

1. Controlling dust and vibrations, especially in carrying out refurbishment works in occupied premises such as shopping centers or hospitals can be a major issue. The subcontractor needs to reduce the impact of noise and vibration to occupants and yet have minimal effect on the regular progress of the refurbishment operations.
2. Securing refurbishment sites, improving quality and safety issues will increasingly become more important. Refurbishment works often involve alterations to the structure or partial demolition with important implications for shoring and other temporary works.
3. Special material technology is needed when marrying new materials with old materials - dealing with the interface between old and new technology and combining of old technologies with new ones.

Therefore, special technical and managerial skills are needed in a BR project. A subcontractor must be selected because of his managerial and technical capabilities to perform the work needed by the main contractor. The technical capabilities of a subcontractor include the ability of the subcontractor to meet the site requirements of BR projects, the level of experience and the ability to interpret and use the contract documents effectively.

The subcontractor’s proposal should include appropriate shop drawings, construction methods, time schedules, project quality plans, and health-safety and house keeping programs. The appropriate shop drawings submission schedules should include the major pieces of equipment which the shop drawings indicate and the anticipated date when each drawing will be submitted; the subcontractors should also include information on escalation for wages, materials, and equipment.

The last attribute (health-safety) is one of the most important issues that people in BR works have to contend with. The fragmented nature of projects and the high number of subcontractors may magnify the problem generated by a mobile, often self-employed workforce, many of whom lack the necessary training. Submitting a proper proposal is evidence of the technical and managerial ability of the subcontractor.

Based on the discussion of the project specifications, it can be summarized that the quality of the subcontractor's proposal can be evaluated based on his ability to manage or minimize the project risks through complying with cost, time, and quality objectives of the project specifications.

The discussions above also indicate that in decision analysis, costs and quotation price should not be used as the only factors in BR subcontractor selection. Besides price, there are other sets of criteria, such as planning, quality, subcontractor's background, etc. that should be considered.

5.8 Decision Strategy (Output)

The decision in selecting subcontractors should always be based on a reasonable set of criteria. As mentioned earlier, this present research argued that the subcontractor should not be selected based on the lowest price alone. There is a better combination of selection criterion, apart from price, which the main contractor should always consider in selecting subcontractors for BR projects.

The process of evaluating a subcontractor is essentially about the decision-making processes that will occur within the overall procurement strategy. The decision process of selecting subcontractors would depend upon the main contractor's characteristics and decision-making strategy. The strategy would focus equally on the main contractor's needs, project characteristics, and on the expected subcontractor's performance.

The knowledge gaps revealed that the selection of general subcontractors is carry out mostly through conventional tender in one-stage approach. However, this is not a suitable tender procedure for BR subcontractors (see Chapter 3). In selecting a contractor and supplier, there is an acceptable principle for competitive tender, which may be relevant to subcontractor selection. The aim of tendering is to be able to identify a minimum number of comparable, competent, suitable organizations willing and able to tender from whom compliant tenders will be received, so that good value for money can be achieved while containing the costs of the tendering process (Russel, 1992; Vokurka, 1996).

In procurement practices, subcontractors may be selected through a competitive one-stage, two-stage or negotiation approach.

5.8.1 One-stage approach

Traditionally, in the conventional one-stage tender, price was the only consideration in selecting a subcontractor and making a contract (Humpreys, et al., 2003; PCIB, 2002; Leenders and Fearon, 2002; Dzever, et. al., 2001; Andrew, 2000; CIB, 1997; Vokurka, et. al., 1996; Erridge, 1995). However, this present research argues that in selecting subcontractors for BR projects, the conventional tender system is inappropriate. The subcontractors' price will remain a consideration, but not necessarily the most significant, and also not the only factor in the overall decision. The decision to select subcontractors for certain works should always be based on a reasonable set of criteria.

The use of the conventional form of procurement, based on the lowest price, can be used if the contractors are very familiar with the contractual arrangements and its implications (Cox and Townsend, 1998; Dobler and Burt, 1996). By its nature, the conventional approach presumes that the design phase is nearly complete before the contractor starts work; therefore, quantities and prices are worked out on the basis of the design. However, the nature of refurbishment works has a high level of uncertainties and a possible lack of information on the conditions of the existing building is frequently encountered, so much so that a conventional contract could be founded on false assumptions.

If the conventional system is applied successfully in refurbishment works, it seems that a high level of investigation of the existing building conditions should precede the detailed design, and a certain element of flexibility needs to be introduced to allow quick reactions to the discovery of new problems. In fact, building diagnostics can be a difficult task (AIA, 1986).

Obviously, the above discussion indicates that in general, the conventional one-stage approach is likely to be inappropriate for refurbishment works. The conventional approach is inefficient for refurbishment projects and fails to cope with, or to foresee, the additional strain that could be put on relationships between the various parties involved in a BR project, and its inability to allow the early involvement of the subcontractor is a serious disadvantage.

5.8.2 Negotiation and two-stage approaches

Other procurement strategies are negotiation and two-stage approaches. Negotiation is one of the most important parts of professional purchasing (Cox and Townsend, 1998; Dobler and Burt, 1996). Dobler and Burt (1996) suggested that negotiation is the appropriate method of procurement when competitive bidding is impractical. Negotiation must be utilized in its broadest context in the decision making process. The purpose of negotiation is to discuss factors in the procurement situation that may affect what is considered a reasonable price.

The negotiation approach should provide a good working relationship between the project team, main contractor and the subcontractor (Liu and Fellows, 1999). Calvert, et al (1995) suggested that when builders are selected for negotiated contracts by reputation, i.e. recommendation or repeat order by a satisfied client, they have every incentive to please the client and preserve their good name.

The term two-stage tendering essentially describes the procedure where a subcontractor is selected in one operation and the contract sum is agreed in the second operation. The first and second steps of the two-stage approach are called subcontractor "qualification" strategy and "tender assessment" respectively and the whole process of identifying the appointed subcontractor is called subcontractor "selection". The first step that processes a set of criteria is needed to identify subcontractors who meet the minimum quality requirements (e.g. general skills and competence) to carry out a given type and size of work (CIB, 1997).

Tender assessment is the part of the selection process that covers preparation and evaluation of formal written offers from a limited number of subcontractors. The tender assessment on price can be initiated only after a list of comparable quality subcontractors is produced from the pre-qualification stage. Otherwise, the straightforward selection based on price is based on the principal assumption that all subcontractors are comparable in quality.

Besides the advantages, however, these approaches have limitations; the two-stage tender process will require more time for processing bids than the one-stage approach. The negotiation seems a non-formal process; there is no standard process and it's time consuming to arrive at a decision.

5.8.3 Appropriate selection approach

Based on these discussions, the combination and modification of the two-stage pre-qualification and negotiation approach seems to be appropriate for selecting a subcontractor for a BR project. These approaches introduce an element of competition in the selection of subcontractors and allow a more cooperative relationship to develop between the main contractor's team and the selected subcontractor with the possibility of having subcontractor's inputs to the design process and collaborative considerations of buildability, temporary works, access, and problems with continued occupancy.

These approaches may allow the subcontractor to be engaged at an early stage. There are many arguments that can be made for the inclusion of a subcontractor at an early stage, due to the potential impact of early inputs in the design, buildability and lifecycle costs of a project (Cox and Townsend, 1998). CIRIA (1994) also suggested that on account of the subcontractors' specialized knowledge and skills, it will often be advantageous to engage the service of a specialist works contractor or subcontractor at an early stage so that they can contribute to the design. Since a subcontractor will be naturally reluctant to give advice until he has a contractual appointment, this will have a bearing on the selection of an appropriate contract strategy.

BR projects have a number of problems which stem from their characteristics of uncertainty and change, together with the issues that arise from occupation and discovery. In these circumstances, any formal contractual framework will only work effectively if the parties enter into it in a constructive spirit and negotiate their differences in a fair-minded way. The confrontational and legalistic approach sometimes adopted on new-build projects with various degrees of success has no place in a BR project. Calvert, et al (1995) suggested that co-operation and goodwill are a much better formula than a bond.

For this present research, the combination of negotiation and a two-stage tender approach was adapted, but the processes of the tender were conducted and evaluated continuously in the one-step process. In practice, to carry out this approach manually is a very complex and time-consuming process. However, advancement of the computer systems through the SSDSS can help to eliminate these problems.

5.9 Logical Causal Model

In order to understand the relationships of the hierarchy of clearly identified criteria, they need to be mapped in a logical causal model. A causal model that links actions to result in the future can come in various forms.

Among these criteria, the most complex relationships are the driving factors that can affect performance. The evaluation criteria are used as a predictor of the subcontractor's future performance. The performance measurement means all processes done today will lead to measuring the value outcome tomorrow. To create something in the future, a causal model is necessary so that the process through which the performance (future results) will be created can be identified. Lebas and Euske (2002) introduced a causal model that is portrayed as a tree to illustrate how an organization goes through the process of creating performance. The analogy to a tree helps to capture the process complexity and characteristics of growth and change. More information concerning this concept can be found in Lebas and Euske (2002).

Figure 5.2 illustrates an example of the three generic stages of a causal model: (1) Outcomes (often reduced to outputs and results), (2) Processes, and (3) Foundation. This figure summarizes description of criteria relationships and also show linkage between the criteria with the six factors influencing success of BR project (section 5.4).

In Figure 5.2, outcomes, results, or outputs are consequences of the product attributes that constitute the fruits of the tree. These attributes are the elements of the product that the main contractor (customer) values. They include price, availability and quality of services. The customer's values can be grouped into economical, technical, and specific objectives (see Figure 5.3).

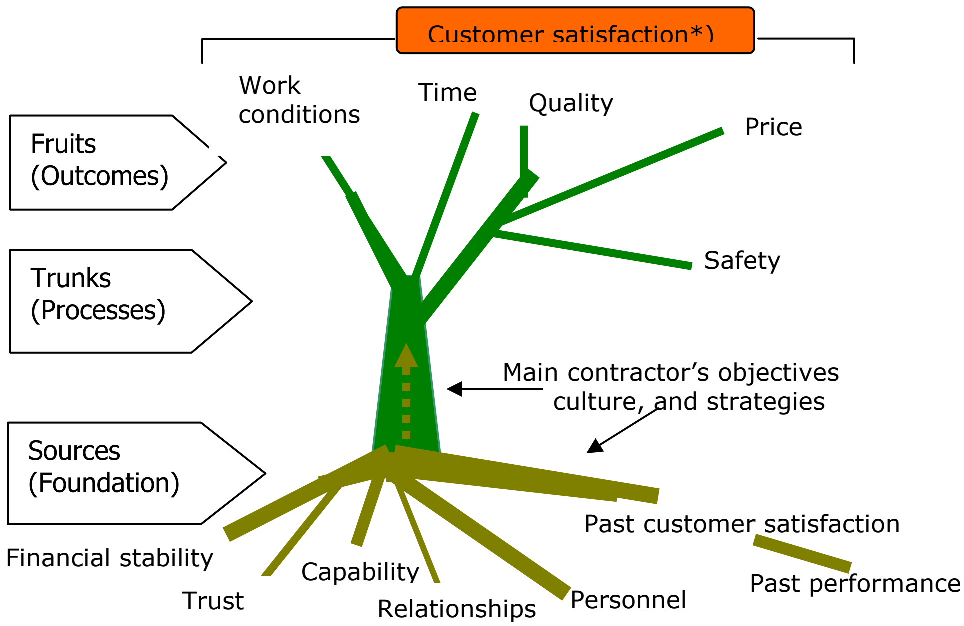


Figure 5.2 Performance tree diagram

*) The factors influencing success of BR project could be satisfied when the economical, technical, and specific objectives are obtained.

The attributes are not only the basis for customer (main contractor) satisfaction, but also the stakeholder satisfaction in general. As mentioned in Section 5.2, six factors influencing success of BR projects are client's involvements, collaborative approach, client's representative, authority and communication, building diagnostics, and construction team. These factors could be satisfied when the economical, technical, and specific objectives are also obtained.

The attributes are the result of the business processes. These constitute the trunk of the performance tree. Subcontractors have to be monitored so that they deliver what the main contractors want within the constraints of the strategic intent of the organization, e.g. general, projects, or social objectives. These organizational objectives constitute the fertilizer for the performance tree.

Continuing the tree analogy, the quality of the processes would be the richness of the sap and its effective movement through the trunk and the branches. Furthermore, the quality of the processes rests in part on the nutrients (fertilizer) in the soil. Such elements would include the competence and awareness of the main contractor's reputation and strategies, e.g. maintenance policy for existing structures of negotiation, partnerships between both the main contractor and subcontractor, and the objectives of the organization. This illustration is consistent with the fact that the results of an organization can be multifaceted in nature.

The discussions above do not only illustrate the logical relationships of the hierarchical criteria, but also justify that price is not the only factor to be considered for BR subcontractor selection. Price is the outcome of the process which can be influenced by many other criteria. A set of criteria other than price alone should be considered carefully.

5.10 Structuring Hierarchy of Factors

Based on the above discussions, a hierarchy of factors, criteria, and attributes can be constructed. The highest level of the tree is labeled "factor", the intermediate level of the tree is labeled "criterion", while the lowest level is called "attribute". The hierarchy tree for the SSDSS is shown in Figure 5.3.

In order to arrive at a decision, data must be gathered for each subcontractor. The data for attributes should be fulfilled. The main contractor has to collect the information from each subcontractor that provides an in-depth look at how subcontractors conduct their business and perform in actual jobsite conditions (Dulung and Low, 2005).

Based on the background knowledge, a list of indicators was identified that presents the characteristics of a project, a subcontractor, and the main contractor. Besides the data on attributes, the general information relating to the subcontractor and project identifications are also needed to relate to the project's purpose. The minimum amount of general information should be collected, namely, name, address, contact person, and legal status of the companies (Hatush and Skitmore, 1997).

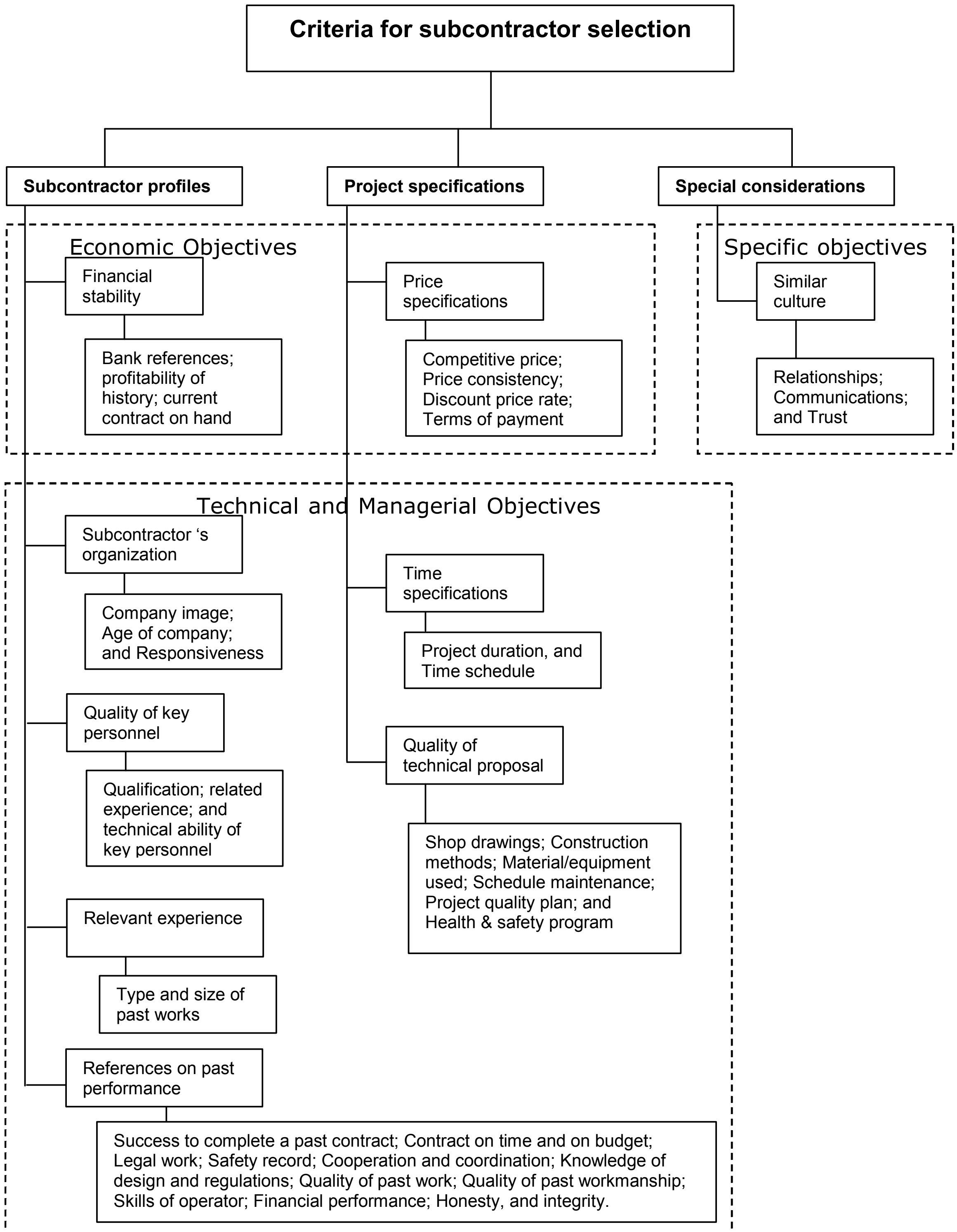


Figure 5.3 Hierarchy of criteria and attributes for the SSDSS

A list of factors (F) are presented below, followed by the criteria (C), attributes (A), and questions (Q):

F1. PROJECT SPECIFIATIONS

- C1. General information
  - Project identification
    - Q1. What is the project name?
    - Q2. What is the project number?
    - Q3. What is the subcontractor's code?
    - Q4. What is the subcontractor's work type?
- C2. Price specifications
  - A1. Competitive price
    - Q5. How much is the quotation price?
  - A2. Discount price
    - Q6. Does the subcontractor offer discount price rate?
  - A3. Price consistency
    - Q7. Is the price rate in price analysis consistent?
  - A4. Terms of payment
    - Q8. Does the subcontractor propose terms of payment?
    - Q9. Does the subcontractor request advance contract deposit?
    - Q10. Is the payment based on work progress?
    - Q11. Is the cost to be paid after the work is completed?
- C3. Time specifications
  - A5. Project duration
    - Q12. How long is the project duration for completion?
  - A6. Time schedule
    - Q13. Is the duration of work proposed comparable to the main contractor's program?
    - Q14. Is the duration of work proposed shorter than the main contractor's program?

Q15. Did the subcontractor submit an appropriate time schedule?

A7. Schedule of maintenance

Q16. Does the subcontractor offer appropriate schedule maintenance in accordance with the specifications and conditions of the main contract?

C4. Quality specifications

A8. Shop drawings

Q17. Does the subcontractor submit appropriate shop drawings in accordance with the specifications and drawings of the main contract?

A9. Construction methods

Q18. Does the subcontractor submit appropriate construction methods in accordance with the main contractor's plan?

A10. Materials and equipments used

Q19. Does the subcontractor offer appropriate materials/equipments in accordance with the specifications and conditions of the main contract?

A11. Project Quality Plans

Q20. Does the subcontractor provide project quality plans?

A12. Housekeeping programs and Safety policy

Q21. Does the subcontractor offer health, safety, and housekeeping programs?

F2. SUBCONTRACTOR'S PROFILE

C5. General information about the subcontractor's organization

Subcontractor's identifications

Q22. What is the subcontractor's name?

Q23. What is the address of the subcontractor?

Q24. Who is the contact person in the subcontractor's firm?

C6. Subcontractor's organization

A13. Company image

- Q25. Did the subcontractor join the subcontractor trade association?

- A14. Age of the company
  - Q26. How long has the subcontractor's firm been trading under the same company name within the construction sector?
- A15. Responsiveness
  - Q27. Is the subcontractor easy to contact?
  - Q28. Is the subcontractor quick to respond when receiving a request?

C7. Relevant experience

- A16. Type of past work
  - Q29. Did the subcontractor provide details of subcontracting jobs completed within the past 5 years?
  - Q30. How many refurbishment works have been completed?
  - Q31. How many new building works have been completed?
- A17. Size of the past work
  - Q32. Did the subcontractor experience a similar size ($) project to the proposed work within the past 5 years?
  - Q33. Is the proposed work of size ($) most often undertaken by the subcontractor’s company?

C8. Financial stability

- A18. Bank references
  - Q34. How long has the subcontractor’s firm been with the same bank?
  - Q35. What was the rating given by the bank referee regarding the company’s financial performance?
- A19. Profitability history
  - Q36. Has the company shown profitability over the last 2 years?
  - Q37. Return on sales?
  - Q38. Return on assets?

A20. Current and projected work load

Q39. How many projects is the subcontractor currently carrying out?

C9. Personnel qualifications

A21. Qualification of key personnel

Q40. What percentage (%) of the subcontractor's key personnel hold a construction related qualification? (e.g. Degrees, Diplomas, Certificates).

Q41. What percentage (%) of the subcontractor's key personnel hold a construction related certificate? E.g. government or other recognized institution’s certificates.

A22. Experience of key personnel

Q42. Are the key personnel of the subcontractor’s experienced working in building refurbishment works before?

Q43. How many projects have been completed by them?

A23. Technical abilities

Q44. Do the key personnel of the subcontractor’s have the technical ability to interpret and use contract documents?

C10. Past performance

A24. Number of references

Q45. How many references does the subcontractor have?

A25. Failure to complete a contract

Q46. Did the subcontractor fail to complete an entire contract before?

A26. Contract on time

Q47. Did the subcontractor complete the contracts by the completion dates?

Q48. Was the delay entirely due to the subcontractor's fault?

Q49. Only partly due to the subcontractor's fault?

A27. Contract on budget

Q50. Was the contract completed on budget?

Q51. What approximate percentage of the cost overrun was attributable to the subcontractor making claims? …%

A28. Legality of contract

Q52. Has the subcontractor ever been engaged in illegal or fraudulent activities before?

A29. Safety records

Q53. Did the company has zero accident on any site under its control within the last 5 year?

A30. Cooperation and coordination

Q54. What was the rating given by a previous main contractor who employed the subcontractor, regarding the ability of its key personnel in terms of cooperation and coordination?

A31. Knowledge of design and regulations

Q55. What was the rating given by a previous main contractor who employed the subcontractor regarding the knowledge of design and regulations that are relevant to the building refurbishment works?

A32. Quality of past works

Q56. What was the rating given by a previous main contractor who employed the subcontractor regarding the quality of finished work?

A33. Quality of workmanship in general

Q57. What was the rating given by a previous main contractor who employed the subcontractor regarding the quality of workmanship? (In general)

A34. Quality of operators

Q58. What was the rating given by a previous main contractor who employed the subcontractor regarding the skills of operators using equipment?

A35. Financial performance (Past)

Q59. What was the rating given by a previous main contractor who employed the subcontractor regarding the financial stability of the subcontractor?

A36. Honesty and Integrity

Q60. What was the rating given by a previous main contractor who employed the subcontractor regarding the honesty/integrity of the subcontractor?

F3. SPECIAL CONSIDERATION

C11. Qualitative aspects

A37. Culture

Q61. What rating would you give to the similarity of the culture of your company with the subcontractor?

A38. Relationships

Q62. What rating would you give to the subcontractor regarding the relationship of your company with the subcontractor?

Q63. What rating would you give to the subcontractor regarding the relationship of your site staff with the subcontractor's site personnel?

A39. Trust

Q64. What rating would you give to the subcontractor regarding his trustfulness?

A40. Communications

Q65. What would be the rating given by you regarding the ability of the subcontractor in communications?

Based on the above discussions, it can be summarized that in making decisions for BR subcontractor selection, main contractors should formulate criteria and its relative weight of emphasis of each criterion should be given. Their decisions are influenced by their main objectives (i.e. general, project, and specific objectives), the project specifics and subcontractor's profiles. On the other hand, the subcontractors may place a quotation for work that is not only influenced by the project characteristics but also by the main contractor's characteristics.

Mapping factors, obviously, signify the logical relationships of the criteria, and also justify that a quotation price should not be the only consideration. Choice of the subcontractor should be made on a value for money basis rather than automatically accepting the lowest bid. The ultimate aim should be to identify the best subcontractor and not the lowest bidder. This should include a good relationship and historical experience between the main contractor and the subcontractor, and many other interrelated factors (Hughes, et al, 1997). It is essential that the subcontractor, no less than its operatives, seeks a fair engagement that is fairly and consistently administered. As it has been frequently noted, money will not buy good working relations, but there must be a genuine agreement about what is being paid for if such relations are developed (CIRIA, 1994).

Although the lowest tender should be accepted, the definition of "lowest tender" needs some qualification. It should be the lowest tender from a financially sound company that has the competence and experience in the subject of the tender. In the case of building refurbishment projects, it should be possible to select a sound subcontractor that has the competence and experience (Egbu, 1997; CIRIA 1994).

Besides the proposal and the company's profile, the subcontractor appointed to undertake the work should be considered on the basis of both previous experience and future relationships with the main contractor. The past and future relationships will affect the subcontractor in deciding the price for the subcontract work and shape a smooth contractual relationship between the main contractor and the subcontractor. These factors are complex and interrelated in the decision-making process. This process of judgment is quite difficult to predetermine and may be performed through cumbersome negotiations between the decision maker's team and the short listed subcontractor. By capturing this process in the KBES decision tool, it can provide valuable guidance for the main contractor to make decisions consistently and accurately.

Chapter 6
FINDING AND ANALYSIS OF INTERVIEWS

6.1 Introduction

As stated in the research strategy (see Chapter 4), the research was carried out through three fieldworks: first, capturing knowledge from literature and several domain experts; second, identifying the relative importance of the criteria; and third, applying and validating the model. The purposes of the first and second fieldworks were to capture knowledge, and to identify significant factors that main contractors should consider in selecting the best subcontractors for BR projects in Singapore. These fieldworks were carried out through both interview and postal questionnaire methods.

Since the knowledge acquisition exercise provided a comprehensive elucidation of the findings, the analysis will be divided into two chapters (Chapter 6 and 7). This chapter presents the results of the interviews. Chapter 7 presents the results of the questionnaire survey of BR contractors.

6.2 Interviews

Based on the literature review, it was found that there are hardly any publications on the selection of subcontractors for BR works; specifically where the main contractors in Singapore evaluate the performance of subcontractors. Even for general construction projects in Singapore, there is no consensus yet on a common set of evaluation criteria for subcontractor selection (Yeap, 2000).

In order to capture the knowledge of the domain problems, industry interaction (fieldworks), which involved meetings with the domain experts (DEs), was carried out. The entire fieldwork involved 48 DEs. There were 6 DEs involved for the first fieldwork, 37 DEs for the second fieldwork, and 5 DEs for the last fieldwork.

6.2.1 Domain Experts Arrangement

In the first fieldwork, the process of knowledge acquisition was conducted through three stages: the first stage was to prepare the interview and to contact the DEs; the second stage was to collect the knowledge of BR subcontractor selection by interviewing 6 DEs; and the third stage was to analyze, transform, and reformulate the knowledge.

Both structured and unstructured interviews were adopted in consultation with the DEs. The purpose of the interviews was to allow the knowledge engineer to obtain deep-seated rules of the selection tasks. Before the structured interview was carried out, the unstructured interview was applied in the initial step of the meeting to explore the knowledge of the subcontractor selection process for a BR project.

The DEs were selected based on the domain experts' characteristics as Prerau (1990) suggested that the quality of DEs might be considered through their educational level, work experience, communication skills, cooperation availability, computer background, and willingness to cooperate in the KBS development. The quality of the DEs is critical for the success of KBS implementation (Yoon and Guimaraes, 1995; Prerau, et al, 1990), because they provide a wealth of knowledge and expertise on the subcontractor selection process.

There is no consensus how many DEs should be interviewed in knowledge acquisition (Turban and Aronson, 2001). In previous studies, for instance, Ling (1998) interviewed 8 experts and Russell (1988) interviewed 4 experts. The quality of the knowledge base does not depend on the number of DEs but on the quality of DEs and the process of knowledge acquisition (Prerau, 1990).

The 6 qualified DEs were selected from senior staff positions in companies such as directors, project manager and contract managers. They have all had more than 7 years of construction experience, and had expertise particularly in subcontractor selection for BR projects. In addition, the respondents have Bachelor degrees in engineering; and four of them hold masters degrees in project/construction management. Through these backgrounds, the DEs should be able to formulate insights into the area that result in heuristics, which form the core of the KBS.

In this initial study, the statistical validity was not a crucial issue. The initial 6 DEs was not a critical consideration because the result of this present research did not depend solely on these interviews; the result of this fieldwork is a complement to the other three knowledge acquisition stages (literature review, questionnaires survey, and the third fieldwork).

The 6 respondents were initially the result of selection based on the "laddering" technique where the 6 DEs were categorized into two task groups, namely primary and secondary DEs. They were interviewed in two steps. In the initial step, four DEs were interviewed, one expert as primary DE and three DEs as secondary DEs. The primary DE was selected based on his expertise, experience, educational background, communication skills, and his willingness to commit to the substantial amount of time and effort needed for his role in the SSDSS development. The primary DE was interviewed intensively to gain insight into the deep-seated rules of the subcontractor selection tasks. After the primary DE was interviewed, his expertise needed to be reviewed and refined.

In the second step, 3 secondary DEs were interviewed individually. The aim of these interviews was to check the admissibility of the primary knowledge. Having interviewed the 3 secondary DEs, another new secondary expert (DE-E) was added to the interview. This interview aimed again to check the acceptability of the knowledge captured. However, in this interview, the DE-E expressed similar concepts of knowledge with the former DEs; no new knowledge (rules, concepts, and criteria) was articulated. This indicated that most of the knowledge was covered. Up to this step, 5 DEs had been interviewed. To confirm this indication, another new secondary DEs (DE-F) was interviewed, but similar results were also found; no new knowledge emerged. Therefore, in this stage, 6 DEs were interviewed, and it was assumed that the 6 DEs were sufficient to formulate the heuristic knowledge for the SSDSS. Beeston (1983) suggested that when the research result was found to be satisfactory and no longer interesting, there is no point in stretching the respondents further.

6.2.2 Meeting with the Domain Experts

The DEs were visited regularly to formulate the heuristics, and to gather the facts in more detail (e.g. list of factors driven, and other issues related to building refurbishment) and the process of know-how (knowledge rules) in selecting subcontractors.

Besides face-to-face meetings, discussions via telephone were also conducted to clarify the interview results. Because the DEs' work schedules were very tight, they avoided meeting in their offices. The advantage of these non-office venues was that it made the meeting atmosphere more relaxed. In the office environment, the meetings may often be interrupted, e.g. when answering telephones, visitors, or other duties.

The discussions were carried out in a convenient atmosphere since the author knew the DEs personally. The relaxed atmosphere was a very important aspect to enable the DEs to express their views and opinions freely. Each interview ranged between 80 and 120 minutes; 30 minutes for the structured interview technique and the rest of the time for unstructured interviews. The unstructured interviews allowed the respondents to introduce whatever information they felt was relevant to the topic identified from the literature review. Table 6.1 lists the background of the respondents, time schedules for interviews, and contact methods.

Table 6.1 List of personnel contacted and time schedules of contacts

Domain expert codes and Contacted Dates	Years of experience	Designations and Type of Company	Contact Methods
DE-A 30 July 2003 1 August 2003 10 August 2003 20 September 2003 25 September 2003	15 years	1) Project Manager 2) Master of CM General Contractors	E-mail, Telephone, Face-to-face
DE-B 12 August 2003 19 August 2003	10 years	1) Director and 2) Project Manager 3) Master of PM. Interior BR contractor and General contractor	E-mail, Telephone, Face-to-face
DE-C 12 August 2003 20 August 2003	7 years	1) Project Manager 2) Master of PM General Contractor	E-mail, Telephone, Face-to-face
DE-D 12 August 2003 13 August 2003	11 years	1) Project Manager 2) Master of CM General Contractor	E-mail, Telephone, Face-to-face
DE-E 22 August 2003 23 August 2003	20 year	Managing Director General Contractor	E-mail, Telephone, Face-to-face
DE-F 22 August 2003 24 August 2003	15 years	Site Manager Building Interior Contractor	E-mail, Telephone, Face-to-face

In order to interview effectively and to save time, the purpose and needs of the research were communicated to the DEs before the meeting through either: (1) telephone conversations, or (2) e-mail correspondences (they were sent a list of questions). This involved providing the DEs with the purpose of the knowledge acquisition session and overview of the session's goal and agenda. In this way, a good rapport was created with the DEs.

6.2.2.1 Meeting with Primary DE

The first meeting was done through interviewing the primary DE on 1st August 2003. The respondent was a senior project manager who had 15 years of experience in the construction industry, and 70% of his experience was involved with the selection of subcontractors in BR projects. He also had basic IT skills and held a masters degree in construction management.

Table 6.2 The Structured Interview

1. An introduction and light conversation for "breaking the ice". It includes getting information about the position of the interviewee in his/her firm, activities, and involvement with subcontractor selection.
2. In selecting subcontractors, do you apply one-step tender, two-step tender, or negotiation?
3. Does your company provide special guidelines for selecting subcontractors?
4. What are the criteria that are considered when selecting subcontractors?
5. Which of those criteria considered are more important than others? Could you rank these criteria in order?
6. I have summarized some criteria for subcontractor selection from the literature review (see a criteria list). Do you agree with these criteria?
7. If you agree with these criteria, do you have any idea how to evaluate these criteria?
8. Do you think evaluating these criteria is relevant?
9. Do you think the methods used currently for bid analysis are able to identify the most suitable and favorable subcontractor?
10. Could you explain the chronology of the subcontractor selection process? You may draw flowcharts to illustrate the process.
11. What type of problems, if any, have you experienced during the project execution period caused by the subcontractor not being able to carry out the job?
12. Do you have any other comments related to the subcontractor selection process?

Thank you very much for your cooperation.

After a short introduction, the conversation shifted to a discussion about the research project. A detailed description of the works of KBS and his experience on BR works was discussed in the meeting. Since the objectives of the interview and the research had been communicated in advance, the primary DE show-cased two tender documents to illustrate the analysis of his former projects. These documents helped the discussion to flow. In this meeting, a list of questions was also formulated for guiding the subsequent meetings with the secondary DEs. The list of questions developed is shown in Table 6.2.

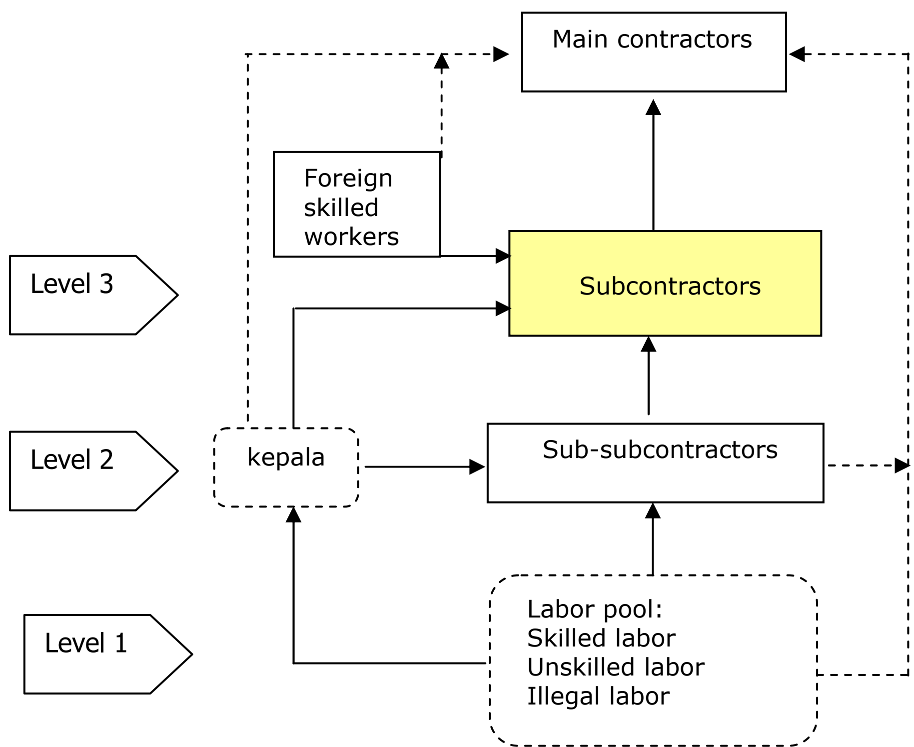


Figure 6.1 Typical subcontractor arrangements in Singapore

The second interview with the primary DE was carried out on 10 August 2003, 10 days after the first meeting. Based on the literature review and previous discussion had at the second meeting, a flow chart that depicts the general situation of the sub-contracting system in Singapore was develop. This is shown in Figure 6.1.

The second interview was to develop a pilot KBS for subcontractor selection and to insure that the system used logical and correct guidelines. In-depth discussions were carried out on the flowchart. In the meeting, the primary DE commented on the flowchart, and the rules were discussed and further refined.

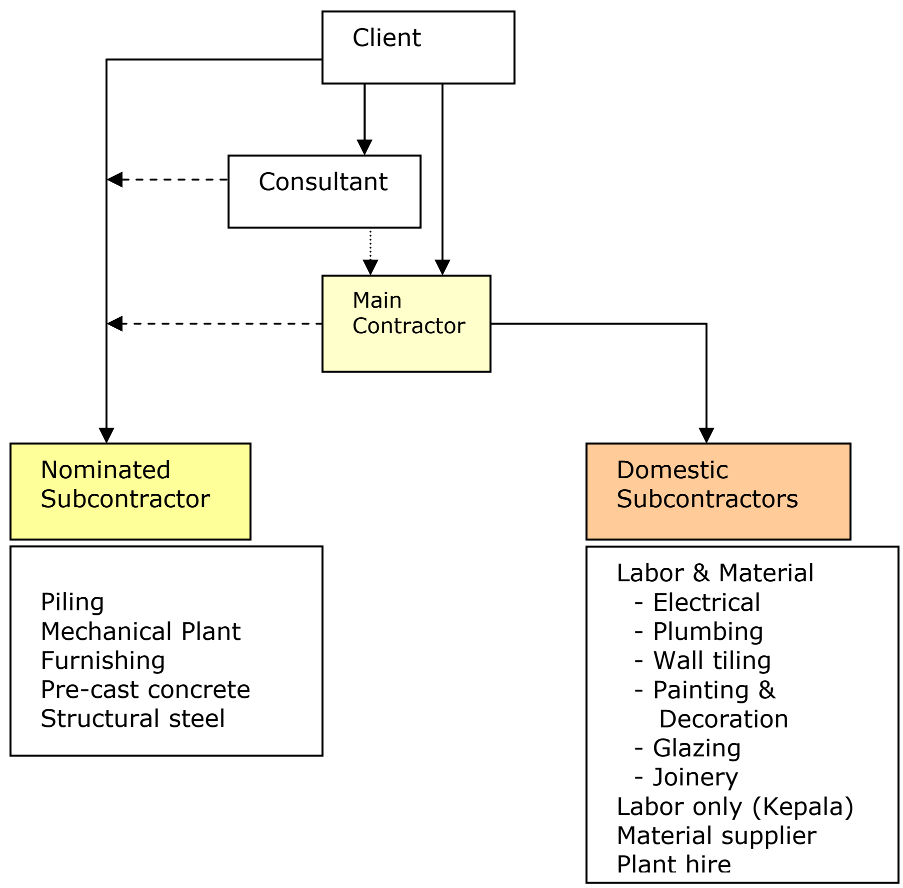


Figure 6.2 Typical current site organizations in BR project

The facts that were depicted in the flowchart in Figure 6.1 were concerned with the lower level of relationship, unclear identifications, responsibilities, and organization.

Level 1: workers' skills were generally unidentified; the welfare and safety of workers suffered from this because work gangs were disorganized and ad hoc in nature.
Level 2: lack of commitment to the sub-subcontractor; skill and quality is inconsistent due to their fluidity; some skilled workers emerged as *kepalas*; they were mostly illegal set-ups and paid little or no taxes and levies.
Level 3: this is less fluid than the lower levels; agreements made with the main contractor were not easily enforceable.

At this meeting, the primary DE showed the documents of a current project, namely for a hotel renovation project. The documents described the contract between the main contractor and the subcontractors, the scope and specifications of works, schedule of the project, drawings and other flowcharts. The detailed flowchart of the site organization that was used in the current project was printed in the project documents. He sketched the flowchart of the current site organization for this BR project as shown in Figure 6.2.

These meetings yielded many rules and some information for further developent of the initial concept of KBS for subcontractor selection. All the interview responses were found to fall into one of the following three categories:

1. What information was considered for selecting subcontractors?
2. How was the information used to assess the four criteria?
3. What strategies were employed to evaluate the criteria?

After the second meeting with the primary DE, the secondary DEs were contacted for interview appointments.

6.2.2.2 Meeting with the Secondary DEs

In the initial meetings with the secondary experts, three secondary DEs were interviewed. Their positions included one director (DE-B) and two project managers (DE-C and DE-D) of contractors' firms. Each DE was interviewed individually at a different time and place. The structured interview was carried out based on the structured questionnaire that had been developed with the primary expert in the first meeting.

A summary of the transcripts from previous meetings with the primary DE was brought to the meetings with the secondary DEs for review and refinement. The three secondary DEs observed and agreed with the summary. They made a suggestion on the flowchart in that the main contractor often recruited the foreign skilled labor not only through the subcontractors, but also directly.

The DE-A, B, C, and D agreed to utilize the "negotiation" approach in the selection of subcontractors. On the other hand, the DE-E and F preferred to utilize the "one-stage" tender approach in that they believed it was an easy and simple method. The DE-C noted that the authority that made the final decision on which subcontractor to select, usually based it on the estimated subcontract price. For instance, the project manager in the site office would decide directly a subcontract package with less than S$100.000, while the senior manager or the directors of the company would decide larger contracts. The DEs acknowledged that they do not have written guidelines for subcontractor selection. The DE-A, B, and C, however, explained that their companies have an information system to record the track-records of the subcontractors who worked with them before. They mentioned that their directors often asked them to select subcontractors based on the relationships between the management and subcontractors.

Most of the DEs utilized 4 to 8 criteria, and explained why the subcontractors were selected or rejected. They also concurred that the universal criteria based on the literature reviewed were acceptable, but they expressed difficulties in measuring these criteria simultaneously because of time pressure. Only DE-A can explain how these criteria can be evaluated but he argued that these criteria might not be quantifiable through manual calculations because of time constraint. All the DEs demonstrated a keen interest in this research project.

Table 6.3 shows the DEs and the evaluation criteria that they usually applied when selecting BR subcontractors. Besides the many similarities, they also have different opinions about the hierarchies of the criteria, as tabulated in Table 6.3. However, all DEs agreed that the weighting criteria could be dynamic; it depends on the project characteristics and economic situation. For example, when an economic crisis hits the construction industry, the most important criterion may be switched to the lowest priced quotation.

Table 6.3 Criteria used and agreed by domain experts

No	Criteria used and agreed by domain experts	Used by Domain experts
1	Relationship with main contractor	A, B, C, D, E, F
2	Reputation or track record	A, B, C, E, F
3	Experience working with similar works	A, C, D, E, F
4	Technical proposal	A, B, C, E, F
5	Quality of workmanship	A, B, C, D
6	Financial strength	A, B, F
7	Quotation price	A, C, D, E, F
8	Time to submit quotation	A, E
9	Work Duration	Agreed
10	Managerial ability	Agreed
11	Geographical office	Agreed
12	Number of current contract works	Agreed
13	Health, safety and housekeeping program	Agreed
A = Primary DE B, C, D, E and F = The secondary DEs		

The 6 DEs' judgments were extracted and described below:

Domain expert A stated that: the relationship between subcontractors and the main contractor was the most important factor, followed by the criteria of reputation, experience, technical proposal, quality of workmanship, financial stability, quotation price, and time needed to submit quotation. DE-A preferred to utilize the negotiation approach in selecting subcontractors.

Domain expert B stated that: the relationship between subcontractors and the main contractor was the most important factor, followed by the criteria of reputation, financial stability, technical proposal, and quality of workmanship. DE-B preferred to utilize the negotiation approach in selecting subcontractors.

Domain expert C stated that: the relationship between subcontractors and the main contractor was the most important factor, followed by the criteria of reputation, experience, technical proposal, quality of workmanship, and quotation price. DE-C preferred to utilize the negotiation approach in selecting subcontractors.

Domain expert D stated that: the relationship between subcontractors with the main contractor was the most important factor, followed by the criteria of experience, quality of workmanship, and quotation price. DE-D preferred to utilize the negotiation approach in selecting subcontractors.

After interviewing the first four DEs, it can be assumed that the knowledge was covered comprehensively. To verify that the completeness of the knowledge was captured, two additional secondary DEs (called DE-E and DE-F) were also interviewed separately as follow:

Domain expert E stated that: the reputation of subcontractors was the most important factor, followed by the criteria of quotation price, time needed to submit quotation, relationship between main contractor and subcontractor, experience, and technical proposal. DE-E preferred to utilize the competitive tender approach in selecting subcontractors.

Domain expert F stated that**:** the quotation price of the subcontractors was the most important factor, followed by the criteria of financial stability, relationship between main contractor and subcontractor, experience, and the technical proposal. DE-F preferred to utilize the competitive tender approach in selecting subcontractors.

However, they also expressed the same comparable opinions with the former DEs; there was no new knowledge found, and they proposed fewer criteria than the other DEs. Since the additional two DEs did not express new knowledge, this appears to indicate that the comprehensive knowledge was captured.

As shown in Table 6.4, eight main criteria were agreed upon by the DEs. These were included in their decisions for the selection of subcontractors. However, every DE has different opinions on the importance of the eight criteria which were presented in the DE columns of Table 6.4. In these columns, the smaller the numbers, the more important the criteria would be. Furthermore, the DEs disagreed in their tender strategies as to whether the competitive or negotiation methods should be applied. The notation "C" symbolizes the competitive method and "N" for negotiation.

Table 6.4 Knowledge captured from the domain experts

No	Criteria used by domain experts and their indices	Domain Experts					
		DE-A	DE-B	DE-C	DE-D	DE-E	DE-F
1	Relationships with main contractor	1	1	1	1	4	3
2	Reputation/ track record	2	2	2		1	
3	Experience with similar works	3		3	2	5	4
4	Technical proposal	4	4	4		6	5
5	Quality of workmanship	5	5	5	3		
6	Financial stability	6	3				2
7	Quotation price	7		6	4	2	1
8	Time to submit quotation	8				3	
9	Competition (C) or negotiation (N)	N	N	N	N	C	C
1 to 7 = the weighting criteria (1 = the highest priority and 7 = the lowest priority) C & N = tender strategies (C= Competition and N = Negotiation)							

These meetings helped to confirm that it was possible to construct a KBS prototype for subcontractor selection in BR projects.

6.2.2.3 Regular Consultations with the Primary DE

The interval between the last meetings with the secondary DEs and the first regular consultation with the primary DE took nearly a month. This was because the work needed to develop even a small prototype of the KBS, coding the transcripts and drawing the program flowchart was time consuming and tedious.

Table 6.5 Example of excerpt of line-by-line transcription

Knowledge Acquisition: # 05 Domain Expert: E Session Type: Face-to-face Interview		Date: 23 August 2003
Line	**Transcript**	**Rules/ Comments**
001 002 003	KE: In selecting subcontractors, do you apply one-step or two- step tender?	Focus on rules
004 005 006 007	DE: We always use one-step tendering because it is quite simple, it also needs less time than other.	Rule: one-step Reason: simple, less time
008 009 010 011	KE: What criteria do you use in bid analysis and evaluation?	Focus on concept and rules
012 013 014 015 016 017 018 019 020 021 022 023	DE: Well…there are no standard criteria for the subcontractor selection. The first criteria considered are the track record then ……. quotation price, the lowest price is the more favorable. Our firm always asking to make more profit to the company. We consider also other criteria such as how long he can finish the works, friendship, past experience, his proposal, and time to submit their quotation. Submission time is very important because the time to select subcontractor is very limited. We are also pressured by the client to prepare the main contract quotation.	Concepts: reputation, quotation price, duration, friendship (relationship), experience, technical proposal, submission time. Rule: Reputation, lowest price
024 025 026 027	KE: Based on the literature review, there are more criteria usually used in subcontractor selection like these…are you agreeable with these criteria?	Focus on concepts
028 029	DE: Yes, I agree for complement of the price, but how to evaluate those criteria? We are difficult to measure them, and we do not have time for such calculations. Etc.	Concepts: financial, workmanship, technical and managerial ability.

Table 6.6 Examples of knowledge rules obtained from the interviews

Strategies:	View the quotation price first, then the subcontractors' performances
Concepts:	Quotation price: 1 2 3 4 5 Work Duration: 1 2 3 4 5 Relationship with our company: 1 2 3 4 5 Time to submit quotation: 1 2 3 4 5 Technical proposal: 1 2 3 4 5 Experience working with the subcontractors: 1 2 3 4 5 Quality of workmanship: 1 2 3 4 5 Managerial ability: 1 2 3 4 5 Financial strength: 1 2 3 4 5 Geographical office: 1 2 3 4 5 Number of current contract works: 1 2 3 4 5 Safety program: 1 2 3 4 5
Facts:	Price: 1 = Lowest = 10%<est. 5 = Highest = 10%> est. Work Duration: 1 = Lowest = 10%<est. 5 = Highest = 10%> est. Relationship: 1 = well known staff. 5= Highest = Unknown Etc.
Rules:	Did the candidate submit the price? IF the price = something <1, 2, 3, 4, 5> THEN the price is the lowest AND the subcontractor qualified Did the candidate state the duration? IF the duration = something <1, 2, 3, 4, 5> THEN the duration is poor AND the subcontractor disqualified Continue? IF yes then go to the next OR Stop.
Heuristics:	The subcontractor submits low price and good relationship. The lowest quotation price is favorable, and then checks in order the duration, relationship, proposal, managerial, technical, workmanship etc. Then sum up the scores. The higher the scores, the better the performance of the subcontractors.

The coding was initiated by evaluating the recorded interviews and then transferring these into a transcript. Table 6.5 shows an example of a transcript (excerpt of the interviews). After that, the transcript was analyzed and transferred into knowledge rules as shown in Table 6.6.

After the knowledge rules were formulated, the rules were stored in knowledge base. Writing a computer program with conventional programming language is flexible but time consuming. During this time, the primary DE was always consulted via telephone for clarification whenever necessary. Four weeks were spent writing, debugging and revising the prototype software.

In the early stage, the Graphical User Interface (GUI) system was also constructed. The GUI should be designed early and developed in parallel with the development of the KBS (see Chapter 3). The primary DE was excited to participate in simulating the KBS prototype results, and he gave valuable suggestions on the GUI performance of the prototype software.

6.2.2.4 The Selection Process

The DEs provided valuable knowledge of the BR subcontractor selection process. The DEs' judgments (knowledge) regarding the process of subcontractor selection, especially on how to obtain and evaluate the subcontractor quotations were extracted and described below.

The DEs expressed that the following most common procedures were used in the selection of BR subcontractors. The process may differ for different situations, but the primary steps are similar. Obtaining subcontractor quotations consisted of two steps: subcontractor's enquires and receiving the quotations. In this case, the subcontractor is assumed to be delivering the laborers and materials.

Subcontractor's Enquires

In issuing an enquiry contract with a subcontractor, the main contractor should ensure that the following details are explicitly described and are agreed in writing. These should preferably form part of the quotation and part of the contract that will be agreed upon between the main contractor and the sub contractor when the works commence.

The components of the quotation to be checked should include the following:

1. The sub-contract program should be stated in a reasonably detailed format, giving a realistic work sequence and a schedule program.
2. The contract stage at which the service is required and the subcontractor's commitments on either side of this date should be stated so that necessary changes in the schedule can be made as smoothly as possible.
3. The subcontractor's responsibilities relating to other high-quality work should be stated.
4. The quotation covers the actual materials stated in the drawings.
5. The materials meet the standards described in the specifications.
6. The quantity is appropriate to the total quantities that will be required in the works.
7. The delivery period and program meet the time required for incorporation into the works.
8. The discount rate (where applicable) is not less than the normal market rate.
9. The trading conditions and terms of payment are acceptable.
10. The time limit that may be applied to the acceptance of the supplier's offer is acceptable.
11. Whether the material is offered on a firm price basis or at prices that prevail at the date of delivery.
12. The arrangements relating to the supply of equipment, access ways, storage facilities, etc. must be agreed upon.
13. Where the responsibility lies for the provision of water, power and any other services must be made clear.
14. Specific instructions from the client regarding materials that will be used or adopted for the works must be given.
15. Facilities for inspection by the main contractor's representatives must be provided before the beginning of the contract.
16. Responsibility for informing the appropriate body when work has to be inspected at various stages must be determined.

17. Control information must be provided regularly by the subcontractor on site.
18. Site safety and industrial relation requirements must be followed.

The above information is primarily obtained by the estimator from the main contract documents and the construction program. Appropriate sections of the conditions of contract and specifications are usually copied directly from the main contract documents and forwarded to the subcontractor with copies of the drawings. A detailed abstract from the contract program may be necessary to ensure that the subcontractor is fully aware of the period he is required on site, the production levels needed and the interaction with other subcontractors. As the subcontractors' enquiries are sent out as early as possible, this will, in the first instance, be the outline or preliminary construction program. As the construction program becomes fully developed, a more detailed program can be forwarded to the subcontractors who are preparing their quotations. Standard letters and subcontractor enquiry forms are used to speed up the dissemination of information and to ensure that no basic contractual details are omitted.

Receiving Quotations

On receipt of the subcontractors' quotations, the main contractor is required to check that all the items have been priced correctly in accordance with the units of measurement required. The selection of the subcontract price that is to be included in the estimation value is not necessarily a question of finding the cheapest price. Consideration about the subcontractor and any qualifications that may have accompanied the quotation should also be given. However, the time available for these selection tasks is very limited.

A diagram representing the whole process for the tender of main contracts and subcontracts is presented in Figure 6.3. Although the flowchart presents a simplification of the whole tender process, it clearly shows the time pressure in the decision-making process. Because of this pressure, the main contractor faces many difficulties in having to evaluate many decision criteria manually, and consequently, he often makes decisions inconsistently and inaccurately.

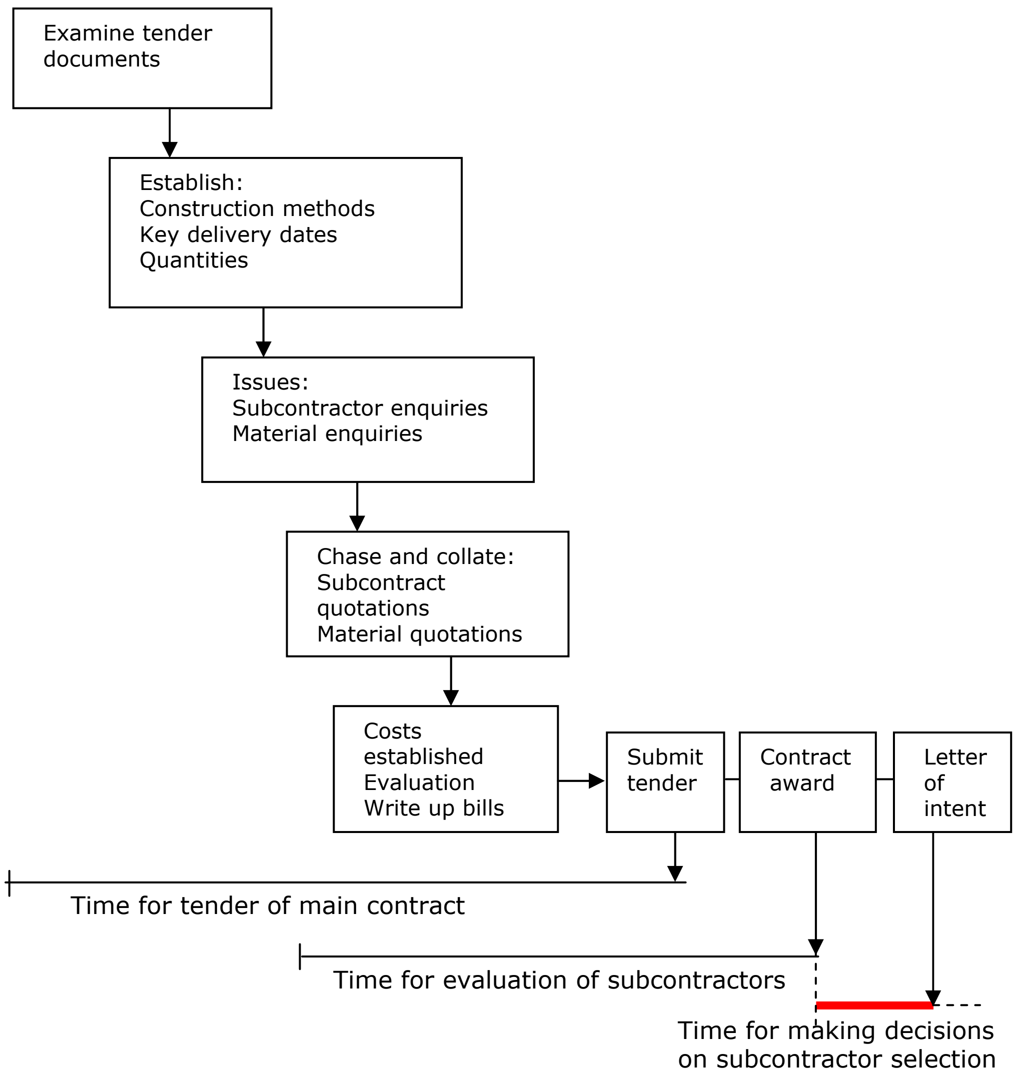


Figure 6.3 A simplified flowchart of the whole tender process

Most contractors established themselves through undertaking the type of work they normally subcontract; this allows them to rationalize some of the financial risks. However, the absence of a direct financial risk in subcontract works is not total security because of the indirect risks of losses caused by delays and disruptions to the main works if the subcontractors default. For this reason, the effective control of subcontract operations is important and this control begins with the selection of the subcontractors themselves.

The survey results showed the attributes for subcontractor selection that the respondents preferred. They preferred to utilize as many as these attributes as possible, and qualitative factors contributed to most of the weights of these attributes. They expressed difficulties to consider these criteria/attributes simultaneously because of time consuming. These factors were difficult to measure without an appropriate automation tool, namely the KBS.

Chapter 7
FINDINGS AND ANALYSIS ON QUESTIONNAIRE RESULTS

7.1 Introduction

This chapter forms the second part of the knowledge acquisition stage. It presents the results of the questionnaires' survey of BR contractors. The purpose of this fieldwork is to check for the admissibility of criteria that main contractors should consider when deciding on which subcontractors to select for BR projects.

Since more than one domain expert (DE) participated, some disagreements in the weighting criteria may occur. Turban and Aronson (2001) mentioned that aggregating knowledge from several DEs is a difficult task. Most knowledge engineers agreed that if knowledge acquisition with a single expert can be described as a bottleneck, then acquisition from multiple experts has the potential to become an even more arduous task (McGraw and Briggs, 1989).

Based on the previous stage of knowledge acquisition (the literature review and DEs interviews) on the existing practices of BR-subcontractors, it was revealed that the existence of various criteria were as agreed in previous studies and by the DEs but there was no consensus as yet on a common set and weighting of criteria for BR subcontractor selection. The weighting of the selection criteria was derived from the questionnaire survey. The primary objective of the questionnaire was to examine the criteria identified and their relative importance.

7.2 Questionnaire Results

This section presents results of the survey questionnaire. The first step in processing the data was to edit the data to ensure its completeness, consistency and reliability (Vaus, 2002; Levine, et al, 1999). After the responses were edited, the data was coded so that it could be classified and processed readily by the computer. This code was also used to preserve the confidentiality of the data sources. Due to the complexity of data calculations and analysis, the data was recorded in a personal computer and analyzed by using the SPSS statistical software package (SPSS Version 11.00).

7.2.1 Response Rates

Based on various sources of contractors (Office Estate Development, National University of Singapore (OED-NUS), Ministry of Education, Singapore Polytechnic, and Singapore Contractors Association Ltd. (SCAL) contractor's directory), 135 contractors were identified as potential respondents. According to these sources, these contractors have the experience in handling BR projects.

The first questionnaire was sent on 3 October 2003 and the respondents were requested to respond by 31 October 2003. However, at the end of October, the source from OED-NUS provided more names of contractors who had engaged in renovation projects in the NUS Campus. Hence, another 16 questionnaires were sent on 1 November 2003 and the contractors were requested to respond by 17 November 2003. In anticipation of delays, a one-week extension was given to the respondents to reply. From 8 October to 24 November 2003, 47 responses were received from the contractors. Table 7.1 shows the details of the responses.

Table 7.1 Contractors' responses

Description	Number	Percentage
Survey forms sent on 3 October and 1 November 2003	135	100%
Survey forms returned by 24 November 2003	47	35%
Usable responses	41	87%
Unusable responses	6	13%

The overall response rate, at 35%, was quite acceptable when compared with other surveys in the AEC field. Six responses were unusable because four firms responded that they could not participate in the survey because of slow business. The other two contractors explained that they could not participate because they had just moved to a new office. The unusable responses may be related to the situation in the construction industry in Singapore that was affected adversely by the economic downturn in the Asian region.

7.2.2 Reliability of Survey Results

The data analysis started by analyzing the characteristics of the data to check for the reliability of the survey results.

7.2.2.1 Company Size

The respondents were general building contractors. The respondents represented all of the financial classifications in the Building and Construction Authority's (BCA) registry of contractors (A1, A2, B1, B2, C1, C2, and C3). For the statistical analysis, the respondents were grouped into small companies for C1, C2, and C3; medium companies for B1 and B2; and large companies for A1 and A2. Figure 7.1 indicate the company size (based on the financial classification).

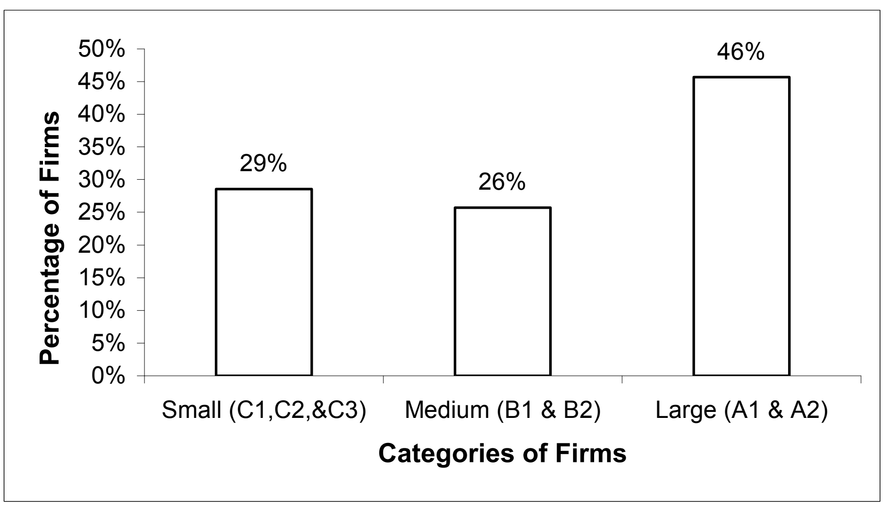


Figure 7.1 Size of the respondents

The responses received from large and medium-sized contractors were 46% and 26% respectively. Small-sized firms represented 29% of the total number of firms that participated in the questionnaire survey. Hence, the respondents represented a significant proportion of the contractors in the BCA contractor registry.

7.2.2.2 Position of Respondents

More than half of the respondents who participated in the survey held senior positions in their firms. Figure 7.2 shows the respondents' positions in all the firms that participated in the survey. 54% of the respondents were directors; 29%, 3%, and 14% of the respondents were project managers, site managers and estimators respectively.

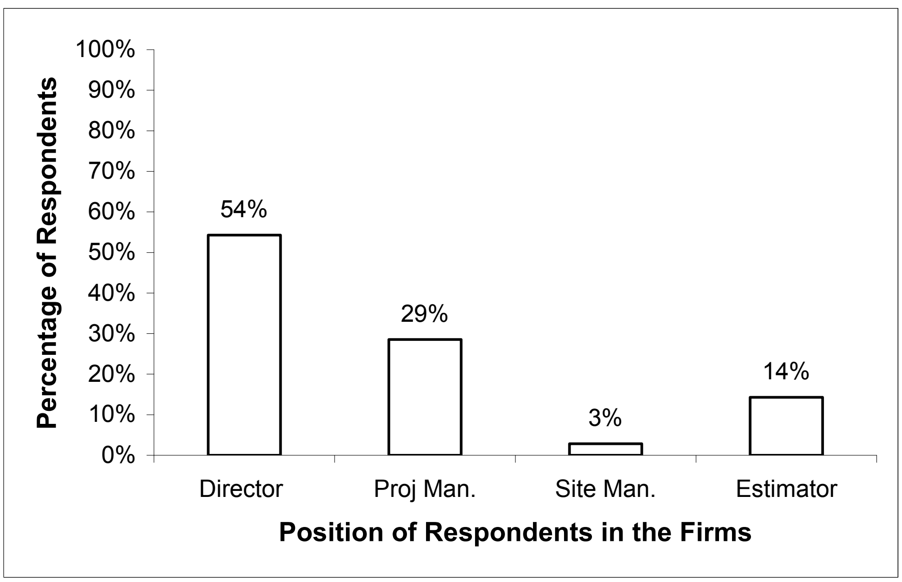


Figure 7.2 Position of respondents in the firms

7.2.2.3 Years of Experience in Refurbishment Works

More than 70% of the respondents have more than 10 years of experience in BR works. Twenty-three percent of the respondents have between 5-10 years of experience in BR works, and only about 6% of the respondents have less than 5 years of experience in BR works. Figure 7.3 indicates the percent of respondents and the number of years of experience they have in handling BR works.

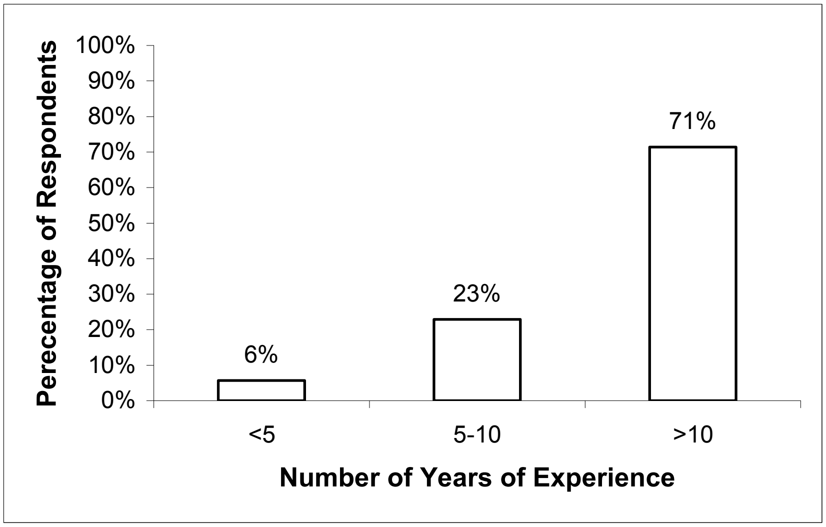


Figure 7.3 Number of years of experience in BR works

The seniority and background experience of the respondents would help to make the survey dependable, and the views expressed by the respondents were therefore significant.

7.2.3 Comments and Additional Attributes

Most of the respondents did not fill in the open question to provide additional attributes that they may consider when selecting BR subcontractors. Only 5 respondents provided comments on the questionnaires. The comments mostly stressed that the most important factors for subcontractor selection were the track records and reputation of the subcontractors (Dulung and Low, 2005). One of the respondents expected the subcontractors to offer a low price. Most of them commented that prompt service was important.

7.3 Statistical Analysis

According to statistical conventions, the data analysis would consist of descriptive and inferential statistics. Descriptive statistics are used to describe variability of the data, such as mean, range, mode, standard deviation and variance. The data is interpreted further through inferential statistics to infer from a smaller group of data (sample) to provide a forecast for a possibly larger group (population).

Before discussing the influencing variables, it is important to present the findings of current decision-making practices used by main contractors in selecting subcontractors for BR works. The results showed that almost all the respondents (89%) have a pool of subcontractors from which the firms regularly select to carry out the subcontracting works. Figure 7.4 shows the methods used by the respondents to select the BR subcontractors. However, the interviews indicated that although they maintained the pool, they also considered new subcontractors from time to time in order to keep up with the competition.

More than half the respondents replied that they have a written policy which serves as guidance in the subcontractor selection process. However, 86% of the respondents answered that they did not employ a specific computer tool to support data processing for the selection of subcontractors. Furthermore, 71% of the respondents utilized group decision-making based on informal discussions, experience and intuition. These findings indicated that the decisions made for the selection of subcontractors were mainly evaluated manually and with inputs from more than one decision-maker. Since most of them did not utilize a special decision support system, they tended to make decisions through unstructured and unsystematic ways, and consequently, the decisions made may be ineffective and inconsistent.

From the selection of importance scores (1 to 5), most of the respondents considered all criteria to be important. However, exact ranking of the weighting criteria and the statistical analyses were needed to check and calculate the mean important rating of the decision criteria. Statistical analyses were also needed to test the research hypotheses.

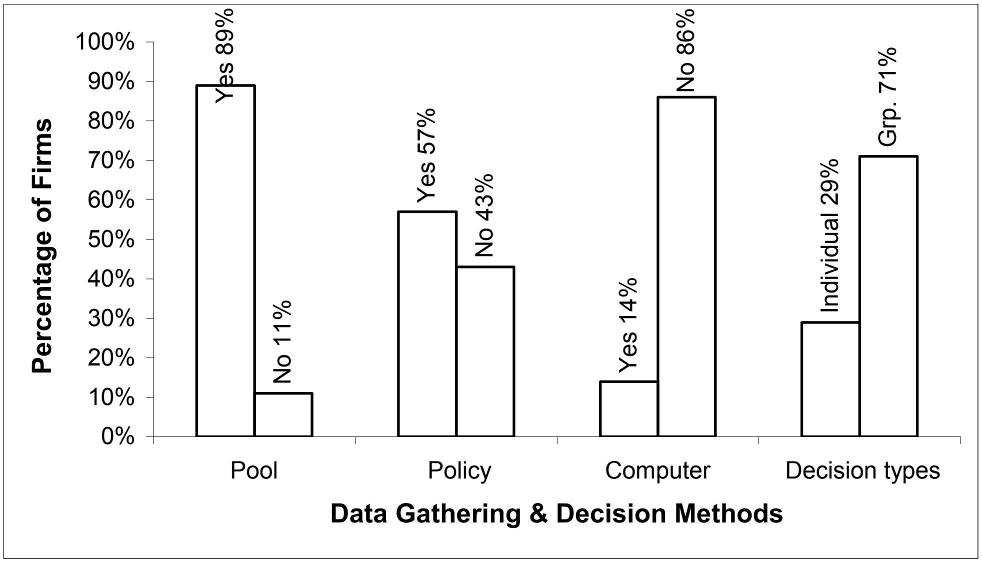


Figure 7.4 Methods used for decision-making

7.3.1 Testing the Hypotheses

After calculating the mean importance ratings, the important attributes according to the BR contractors' inputs were assessed. Statistical tests of the mean were carried out to check whether the population would consider the attributes to be important or otherwise. This test aims to test the research hypotheses.

As mention in Chapter 2, this present research is based on the general hypothesis that:

There is a combination of criteria, apart from price, which main contractors should consider when selecting subcontractors for BR projects.

This general hypothesis is elaborated in three main hypotheses as follows:

H1. Main contractors select subcontractors for BR projects based on the project specifications.

H2. Main contractors select subcontractors for BR projects based on the subcontractor's profile.

H3. Main contractors select subcontractors for BR projects based on their special considerations.

From the table of critical values of ***t***-distribution, for degrees of freedom = 40 (41-1), and the level of significance for a one-tailed test at 0.05, the t value was 1.684. This meant that if the calculated ***t*** value was larger than 1.684, the null hypothesis, which the attribute was unimportant, was rejected and the alternative hypothesis was accepted. The ***t*** values of the statistical tests of the main ratings by BR contractors were calculated using Equation A1.7. (Appendix 1).

7.3.1.1 Hypothesis 1: Main contractors select subcontractors for BR projects based on the project specifications

The results of the survey of BR contractors relating to the attributes identified under the project specifications factor are shown in Table 7.2.

Table 7.2 Respondents' survey results relating to Project Specifications

Criteria and Attributes	Number of responses					a_h	*s*	*t* value
	#1	#2	#3	#4	#5			
(H1.1) Main contractors select subcontractors for BR projects based on the price specifications								
(H1.1.1) Main contractors select subcontractors for BR projects based on the competitiveness of the price	0	2	7	13	19	4.20	0.90	8.50
(H1.1.2) Main contractors select subcontractors for BR projects based on the discount price rate	0	3	15	10	13	3.80	0.98	5.26
(H1.1.3) Main contractors select subcontractors for BR projects based on the price rate consistency	0	0	10	20	11	4.02	0.72	9.06
(H1.1.4) Main contractors select subcontractors for BR projects based on the terms of payment	0	1	7	23	10	4.02	0.72	9.06
(H1.2) Main contractors select subcontractors for BR projects based on the time factors								
(H1.2.1) Main contractors select subcontractors for BR projects based on the project duration	2	2	11	17	9	3.71	1.03	4.39

(H1.2.2) Main contractors select subcontractors for BR projects based on the appropriate schedule of construction	1	0	5	21	14	4.14	0.83	8.91
(H1.2.3) Main contractors select subcontractors for BR projects based on the appropriate schedule of construction	0	2	10	21	8	3.86	0.79	6.9
(H1.3) Main contractors select subcontractors for BR projects based on the technical proposal								
(H1.3.1) Main contractors select subcontractors for BR projects based on the shop drawings	0	0	7	19	15	4.20	0.71	10.71
(H1.3.2) Main contractors select subcontractors for BR projects based on the construction methods	0	0	9	20	12	4.09	0.72	9.53
(H1.3.3) Main contractors select subcontractors for BR projects based on the materials/equipment used	0	0	8	23	10	4.06	0.67	10.04
(H1.3.4) Main contractors select subcontractors for BR projects based on the project quality plans	0	1	16	14	10	3.80	0.84	6.11
(H1.3.5) Main contractors select subcontractors for BR projects based on the appropriate health, safety and house keeping programs	0	0	15	17	9	3.86	0.76	7.19

Hypothesis H1.1: price specifications

Four attributes were identified under price specifications as follow:

1. Competitiveness of the price
2. Discount price rate
3. Price rate consistency
4. Terms of payment

As shown in Table 7.2, the t-tests of the means showed that BR contractors considered the four attributes as important for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:

H1.1.1: Main contractors select subcontractors for BR projects based on the competitiveness of the price.
H1.1.2: Main contractors select subcontractors for BR projects based on the discount price rate.
H1.1.3: Main contractors select subcontractors for BR projects based on the price rate consistency.
H1.1.4: Main contractors select subcontractors for BR projects based on the terms of payment.

These findings were consistent with the common reasons cited by main contractors in conventional procurement where the lowest price was often the most dominant criterion (Kumaraswamy and Walker, 1999; Hatush and Skitmore, 1997). In order to minimize production costs, an organization needs to ensure that the resources used to produce the output were obtained from the lowest possible prices. By choosing the lowest price, the main contractors are expecting to maximize profit because the quotation price will become part of the main contract price, which will in turn affect the latter's competitiveness.

Hypothesis H1.2: time specifications

Three attributes were identified under the criterion of time specifications as follow:

1. Project duration
2. Maintenance schedule
3. Construction time schedule

As shown in Table 7.2, the t-tests of the means showed that BR contractors considered the three attributes as important for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:
H1.2.1: Main contractors select subcontractors for BR projects based on the project duration.

H1.2.2: Main contractors select subcontractors for BR projects based on the maintenance schedule.
H1.2.3: Main contractors select subcontractors for BR projects based on the construction time schedule.

Hypothesis H1.3: quality of technical proposal

Five attributes were identified under the criterion of the quality of technical proposal as follow:

1. Shop drawings
2. Construction methods
3. Materials/equipment used
4. Project quality plans
5. Appropriate health, safety and house keeping programs

As shown in Table 7.2, the t-tests of the means showed that BR contractors considered the five attributes as important for subcontractor selection. It can therefore be concluded that the following may be supported:
H1.3.1: Main contractors select subcontractors for BR projects based on the shop drawings.
H1.3.2: Main contractors select subcontractors for BR projects based on the construction methods.
H1.3.3: Main contractors select subcontractors for BR projects based on the materials/equipment used.
H1.3.4: Main contractors select subcontractors for BR projects based on the project quality plans.
H1.3.5: Main contractors select subcontractors for BR projects based on the appropriate health, safety and house keeping programs.

The quality of a proposal that includes time specifications is important criteria because the main contractor will consider how robust a subcontractor's proposal is in its delivery. The proposal is related to the quotation price, managerial and technical offers, and often reflects the way subcontractors manage the project risks (Kashiwagi and Byfield, 2002a).

A common approach for evaluating the subcontractor's product and service offerings is based on cost, time and quality (Kagioglou et al, 2001; Rowlinson, 1999). A project may be regarded as successful when the building is delivered at the right time, at an appropriate price and quality standard. It should also provide the client with a high level of satisfaction (Love et al, 1998).

7.3.1.2 Hypothesis 2: subcontractor's profile

The results of the survey of BR contractors relating to the attributes identified under the subcontractors' profile factor are shown in Table 7.3.

Table 7.3 Respondents' survey results relating to Subcontractors' Profile

Criteria and Attributes	Number of responses					a_h	*s*	*t* *value*
	#1	#2	#3	#4	#5			
(H2.1) Main contractors select subcontractors for BR projects based on the organization characteristics								
(H2.1.1) Main contractors select subcontractors for BR projects based on the reputation	0	2	14	19	6	3.71	0.78	5.79
(H2.1.2) Main contractors select subcontractors for BR projects based on the age of the company	0	4	20	13	4	3.40	0.81	3.30
(H2.1.3) Main contractors select subcontractors for BR projects based on their responsiveness	0	0	5	18	18	4.31	0.69	12.28
(H2.2) Main contractors select subcontractors for BR projects based on their personnel qualifications								
(H2.2.1) Main contractors select subcontractors for BR projects based on their related certificates	1	5	26	9	0	3.06	0.67	0.47
(H2.2.2) Main contractors select subcontractors for BR projects based on their related experience	0	0	9	25	7	3.94	0.63	9.66
(H2.2.3) Main contractors select subcontractors for BR projects based on their technical ability	0	0	6	25	10	4.09	0.62	11.25

H2.3 Main contractors select subcontractors for BR projects based on their financial performance								
(H2.3.1) Main contractors select subcontractors for BR projects based on their bank references	2	0	21	12	6	3.49	0.93	3.38
(H2.3.2) Main contractors select subcontractors for BR projects based on their profitability history	1	2	29	7	2	3.17	0.70	1.55
(H2.3.3) Main contractors select subcontractors for BR projects based on their workload	0	0	8	24	9	4.02	0.65	10.07
H2.4 Main contractors select subcontractors for BR projects based on their relevant experience								
(H2.4.1) Main contractors select subcontractors for BR projects based on the type of their past works	0	1	12	19	9	3.88	0.78	7.20
(H2.4.2) Main contractors select subcontractors for BR projects based on the size ($) of their past works	0	4	16	16	5	3.54	0.84	4.09
(H2.5) Main contractors select subcontractors for BR projects based on the references to their past performance								
(H2.5.1) Main contractors select subcontractors for BR projects based on their number of references	0	0	0	6	35	4.87	0.36	33.17
(H2.5.2) Main contractors select subcontractors for BR projects based on their completed past contracts	0	0	5	20	16	4.20	0.93	8.25
(H2.5.3) Main contractors select subcontractors for BR projects based on their contracts completed on time	0	0	3	22	16	4.31	0.61	13.83
(H2.5.4) Main contractors select subcontractors for BR projects based on their contracts completed on budget	0	0	6	25	10	4.08	0.62	11.25
(H2.5.5) Main contractors select subcontractors for BR projects based on the legality of their past works	0	2	6	17	16	4.14	0.85	8.60
(H2.5.6) Main contractors select subcontractors for BR projects based on their health, safety and house keeping programs	0	1	10	19	11	3.97	0.79	7.91
(H2.5.7) Main contractors select subcontractors for BR projects based on their closed cooperation and coordination	0	0	2	18	21	4.46	0.60	15.73

(H2.5.8) Main contractors select subcontractors for BR projects based on their knowledge of design and regulations	0	0	5	24	12	4.17	0.63	11.93
(H2.5.9) Main contractors select subcontractors for BR projects based on the quality of their past works	0	0	10	17	14	4.09	0.77	9.15
(H2.5.10) Main contractors select subcontractors for BR projects based on the quality of their past workmanship	0	1	9	18	13	4.06	0.80	8.35
(H2.5.11) Main contractors select subcontractors for BR projects based on the skills of their operators	0	2	6	24	9	3.97	0.76	8.24
(H2.5.12) Main contractors select subcontractors for BR projects based on their past financial performance	0	1	18	19	3	3.60	0.67	5.60
(H2.5.13) Main contractors select subcontractors for BR projects based on their honesty and integrity	0	0	6	25	10	4.09	0.62	11.25

Hypothesis H2.1: organization characteristics

Three attributes were identified under the criterion of organization characteristics as follow:

1. Company reputation
2. Company age
3. Responsiveness

As shown in Table 7.3, the t-tests of the means showed that BR contractors considered the three attributes as important for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:

H2.1.1: Main contractors select subcontractors for BR projects based on the company's reputation.

H2.1.2: Main contractors select subcontractors for BR projects based on the age of the company.

H2.1.3: Main contractors select subcontractors for BR projects based on their responsiveness.

Hypothesis H2.2: personnel qualifications

Three attributes were identified under the criterion of personnel qualifications as follow:

1. Related degrees or certificates
2. Relevant experience
3. Technical abilities

As shown in Table 7.3, the t-tests of the means showed that BR contractors considered two attributes (relevant experience and technical ability) as important and a "related degree" as an unimportant attribute for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:

H2.2.2: Main contractors select subcontractors for BR projects based on their related experience.

H2.2.3: Main contractors select subcontractors for BR projects based on their technical abilities.

The hypothesis "H2.2.1: Main contractors select subcontractors for BR projects based on their related certificates" was rejected as it was considered to be an unimportant attribute.

Hypothesis H2.3: financial performance

Three attributes were identified under the criterion of financial performance as follow:

1. Bank references
2. Profitability history
3. Current workload

As shown in Table 7.3, the t-tests of the means showed that BR contractors considered two attributes (bank references and current workload) as important and one attribute (profitability history) as unimportant for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:

H2.3.1: Main contractors select subcontractors for BR projects based on their bank references.
H2.3.3: Main contractors select subcontractors for BR projects based on their current workload.
The hypothesis "H2.3.2: Main contractors select subcontractors for BR projects based on their profitability history" was rejected as it was considered to be an unimportant attribute.

Hypothesis H2.4: relevant experience

Two attributes were identified under the criterion of relevant experience as follow:

1. Similar type of projects to the proposed work
2. Similar size ($) of projects to the proposed work

As shown in Table 7.3, the t-tests of the means showed that BR contractors considered the two attributes as important for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:
H3.4.1 Main contractors select subcontractors for BR projects based on the type of their past works.
H3.4.2 Main contractors select subcontractors for BR projects based on the size ($) of their past works.

Hypothesis H2.5: past performance

Thirteen attributes were identified under the criterion of past performance as follow:

1. Number of references
2. Always completing past contracts
3. Completing past contracts on time
4. Completing past contracts on the original budget
5. Never engaged in illegal and fraudulent activities before
6. No fatal accident on any site under its control in the last 3 years

7. Showing close cooperation and coordination
8. Showing good knowledge of design and regulations
9. Producing good quality in past works
10. Employing high quality workmanship in past projects
11. Employing highly skilled operators in past projects
12. Showing stable financial performance
13. Showing integrity/honesty

As shown in Table 7.3, the t-tests of the means showed that BR contractors considered the thirteen attributes as important for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:

H2.5.1: Main contractors select subcontractors for BR projects based on their number of references.

H2.5.2 Main contractors select subcontractors for BR projects based on their completed past contracts.

H2.5.3 Main contractors select subcontractors for BR projects based on their contracts completed on time.

H2.5.4 Main contractors select subcontractors for BR projects based on their contracts completed on budget.

H2.5.5 Main contractors select subcontractors for BR projects based on the legality of their past works.

H2.5.6 Main contractors select subcontractors for BR projects based on their health, safety and house keeping programs.

H2.5.7 Main contractors select subcontractors for BR projects based on their closed cooperation and coordination.

H2.5.8 Main contractors select subcontractors for BR projects based on their knowledge of design and regulations.

H2.5.9 Main contractors select subcontractors for BR projects based on the quality of their past works.

H2.5.10 Main contractors select subcontractors for BR projects based on the quality of their past workmanship.

H2.5.11 Main contractors select subcontractors for BR projects based on the skills of their operators.

H2.5.12 Main contractors select subcontractors for BR projects based on their past financial performance.

H2.5.13 Main contractors select subcontractors for BR projects based on their honesty and integrity.

The above findings are consistent with the view that data on subcontractors' profiles are essential for performing an evaluation (Kashiwagi and Bayfield, 2002a). Because the contract has not started, the service that will be provided cannot be evaluated yet. In practice, the decision-maker (main contractor) can only judge the performance of the subcontractor candidates through the characteristics and the past performance of the subcontractors (Kashiwagi and Bayfield, 2002a). Performance measurement means the process of determining how successful organizations or individuals have been in attaining their objectives (Kagioglou, et al, 2003; Evangelidisz, 1992).

7.3.1.3 Hypothesis 3: special considerations

The special consideration factor is qualitative aspects. The results of the survey of BR contractors relating to the attributes identified under special considerations are shown in Table 7.4.

Table 7.4 Respondents' survey results relating to Special Considerations

Criteria and Attributes	Number of responses					a_h	s	t value
	#5	#4	#3	#2	#1			
(H3.1) Main contractors select subcontractors for BR projects based on their qualitative aspects								
(H3.1.1) Main contractors select subcontractors for BR projects based on their similar culture	0	2	14	17	8	3.74	0.83	5.83
(H3.1.2) Main contractors select subcontractors for BR projects based on their relationships	1	5	14	14	7	3.51	1.00	3.27
(H3.1.3) Main contractors select subcontractors for BR projects based on their trust.	0	0	7	19	15	4.20	0.71	10.71
(H3.1.4) Main contractors select subcontractors for BR projects based on their communication abilities	0	0	13	22	6	3.83	0.67	7.96

Hypothesis H3.1: qualitative aspects

Four attributes were identified under the criterion of qualitative aspects as follow:

1. Similar culture
2. Relationships
3. Trust
4. Communications

As shown in Table 7.4, the t-tests of the means showed that BR contractors considered the four attributes to be important for subcontractor selection. It can therefore be concluded that the following hypotheses may be supported:

H3.1.1: Main contractors select subcontractors for BR projects based on their similar culture.

H3.1.2: Main contractors select subcontractors for BR projects based on their relationships.

H3.1.3: Main contractors select subcontractors for BR projects based on their trust.

H3.1.4: Main contractors select subcontractors for BR projects based on their communication abilities.

The above findings were consistent with experts' views that some of the decisions could be based on subjective (qualitative) rather than objective criteria. Some previous studies of selection criteria have also included qualitative factors that arose because of the increasing importance of economic globalization (Walker, et al, 2003; Rahman, et al, 2002; Dzever et al, 2001; Barthorpe et al, 1999; Liu and Fellows, 1999; Rowlinson, 1999). Swam, et al (2002) also noted that trust and communication attributes not only reduce the transaction costs, make possible the sharing of sensitive information, and permit joint projects of various kinds, but also provide a basis for expanding on moral relations in business.

7.3.2 Mean of the importance ratings

In order to calculate the mean of the importance ratings, the following mathematical equation was adopted:

$$a_h = \frac{1(n_1) + 2(n_2) + 3(n_3) + 4(n_4) + 5(n_5)}{(n_1 + n_2 + n_3 + n_4 + n_5)} \quad \text{..............(7.1).}$$

where:

h : is the attribute reference,

a_h : is the mean importance rating of attribute h, and

n_1, n_2, n_3, n_4, and n_5 are the number of respondents who indicated on the five-point Likert scale, the level of importance as 1, 2, 3, 4 and 5 respectively for attribute h, where 1 represent "very unimportant", 2 for "unimportant", 3 for "good to have", 4 for "important", and 5 for "very important".

The results of the mean importance rating using Equation 7.1 are tabulated in Table 7.5. The overall rankings of the criteria in Table 7.5 were based on the calculations of the attributes without first considering their hierarchy of criteria and factors.

As shown in Table 7.5 the 10 most important attributes (out of 39) chosen by the respondents were:

1. Number of references
2. Showing close cooperation and coordination
3. Completing past contracts on time
4. Responsiveness
5. Subcontractors can be trusted
6. Always completing past contracts
7. Appropriate shop drawings
8. Competitive price
9. Showing good knowledge of design and regulations
10. Never engaged in illegal and fraudulent activities before

Table 7.5 Attributes ranked by mean importance ratings

Code and Attributes	Mean importance rating	Overall Rank
2.5.1 Number of references	4.86750	1
2.5.6 Showing close cooperation and coordination	4.45714	2
2.5.2 Completing past contracts on time	4.31429	3*
2.1.3 Responsiveness	4.31429	3*
1.1.1 Competitive price	4.20000	5.5*
3.1.3 Trust	4.20000	5.5*
2.5.1 Always completing past contracts	4.20000	5.5*
1.3.1 Appropriate shop drawings	4.20000	5.5*
2.5.7 Showing good knowledge of design and regulations	4.17143	9
2.5.4 Never engaged in illegal and fraudulent activities before	4.14286	10
1.2.2 Appropriate time schedule	4.14285	11
2.5.8 Producing good quality in past works	4.08573	12
2.5.3 Completing past contracts on original budget	4.08571	13.5*
2.5.12 Showing integrity/honesty	4.08571	13.5*
2.2.2 Technical abilities	4.08571	13.5*
1.3.2 Appropriate construction methods	4.08571	13.5*
2.5.9 Employing high quality workmanship in past projects	4.05714	17.5*
1.3.3 Materials and equipment used	4.05714	17.5*
2.3.3 Enough workforce	4.02857	19.5*
1.1.4 Terms of payment	4.02857	19.5*
1.1.3 Price rates consistency	4.02857	19.5*
2.5.5 No fatal accident on any site under its control in the last 3 years	3.97143	22
2.5.10 Employing highly skilled operators in past projects	3.96346	23

Code and Attributes	Mean importance rating	Overall Rank
2.2.3 Relevant experience in building construction	3.94286	24
2.4.1 Similar type of projects to the proposed work	3.88571	25
1.3.6 Appropriate health, safety and house keeping programs	3.85714	26
1.3.4 Appropriate schedule of maintenance	3.84285	27
3.1.4 Communications	3.82857	28
1.3.5 Project quality plans (PQP)	3.80000	29.5*
1.1.2 Discount price rates	3.80000	29.5*
3.1.1 Similar culture	3.74286	31
2.1.1 Company reputation	3.71429	32
1.2.1 Project duration	3.70588	33
2.5.11 Showing stable financial performance	3.60000	34
2.4.2 Similar size ($) of projects to the proposed work	3.54286	35
3.1.2 Relationships	3.51429	36
2.3.1 Bank references	3.48571	37
2.1.2 Company age	3.40000	38
2.3.2 Profitability history	3.17143	39
2.2.1 Related degree or certificates	3.05714	40

* Joint ranking.

Among the 10 most important attributes, the factor of the subcontractor profiles dominated the important attributes. Even the top three ranks (1 to 3) were related to this factor. The results indicated that the main contractor considered number of references and showing close cooperation and coordination as the two most important criteria for subcontractor selection. It also showed that the main contractors preferred to select BR subcontractors based on their track records of past performance. The findings synthesized well with Kumaraswamy and Matthews' (2000) study in that the main contractors considered the ability of a subcontractor to respond quickly to them as a critical factor for selecting the subcontractor. In this research, the subcontractor's responsiveness was considered an important factor (joint 3rd ranking out of 40 attributes) in Table 7.5.

The lowest ranking was "related degree or certificates" factor. This findings were consistent with the result of testing hypotheses that "main contractors select subcontractors for BR projects based on their related certificates" was rejected as it was considered to be an unimportant attribute. Therefore, only 39 attributes were included in the model.

7.3.3 Weighting Criteria

Besides the rankings of important attributes, it is also necessary to calculate the weighting importance of the associated criteria and factors. In this calculation, the means of criteria and factors were calculated based on the mean importance rating. The technique applied for the calculation of the weighting criteria was the multi-criteria decision making technique, which was discussed earlier in Chapter 4 (Research Methodology). The following equations were applied:

1. To calculate the weight of an attribute (W_h)

$$W_h = \frac{a_h}{\sum_{h=1}^{m} a_h} \qquad \text{.................................(7.2).}$$

where:

h is the attribute reference, and there are m number of attributes under one criterion

W_h is the weight of attribute h

a_h is the mean importance rating of attribute h obtained from Equation 7.1.

2. To calculate the weight of a criterion (W_j)

$$W_j = \frac{a_j}{\sum_{j=1}^{n} a_j} \qquad \text{...................................(7.3).}$$

where:

$$a_j = \frac{\sum_{h=1}^{m} a_h}{m} \qquad \text{.......................................(7.4).}$$

j is the criterion reference, and there are n number of attributes under one criterion

W_j is the weight of criterion j

a_j is the mean importance rating of criterion j

a_h is the mean importance rating of attribute h obtained from Equation 7.1

h is the attribute reference, and there are m number of attributes under one criteria.

3. To calculate the weight of a factor (W_k)

$$W_k = \frac{a_j}{\sum_{k=1}^{p} a_k} \qquad \text{..............................(7.5).}$$

where:

$$a_k = \frac{\sum_{j=1}^{n} a_j}{n} \qquad \text{..............................(7.6).}$$

k is the factor reference

W_k is the weight of factor k

a_k is the mean importance rating of factor k

a_j is the mean importance rating of criterion j, obtained from Equation 7.4

j is the label for criterion, and there are n number of criteria under one factor.

From the results of applying Equations 7.2 to 7.6 to the data obtained from the survey results, the result for the weight of the important attributes, criteria and factors are shown in Table 7.6.

Table 7.6 Weight, Criteria and Factors

No.	FACTORS, Criteria and Attributes	Mean importance rating	Attribute weight	Criterion weight	Factor weight
1.	**PROJECT SPECIFICATIONS**	***3.9721***			***0.3491***
1.1.	Price factors	*4.0143*		***0.3369***	
1.1.1.	Competitive price	4.2000	0.2616		
1.1.2.	Discount price rates	3.8000	0.2367		
1.1.3.	Price rates consistency	4.0286	0.2509		
1.1.4.	Terms of payment	4.0286	0.2509		
	Sub- total mean ratings of attributes	*16.0571*			
1.2.	Time factors	*3.9020*		***0.3274***	
1.2.1	Project duration	3.7059	0.3166		
1.2.2.	Appropriate time schedule	4.1429	0.3539		
1.2.3.	Appropriate schedule of maintenance	3.8571	0.3295		
	Sub- total mean ratings of attributes	*11.7059*			
1.3.	Quality of technical proposal	*4.0000*		***0.3357***	
1.3.1.	Appropriate shop drawings	4.2000	0.2100		
1.3.2.	Appropriate construction methods	4.0857	0.2043		
1.3.3.	Materials and equipment used	4.0571	0.2029		
1.3.4.	Project quality plans (PQP)	3.8000	0.1900		
1.3.5.	Appropriate health, safety and house keeping programs	3.8571	0.1929		
	Sub- total mean ratings of attributes	*20.0000*			
	Sub- total mean ratings of criteria	***11.9162***			
2.	**SUBCONTRACTOR'S PROFILES**	***3.5833***			***0.3150***
2.1.	Organization characteristics	*3.8095*		***0.2126***	
2.1.1.	Company reputation	3.7143	0.3250		
2.1.2.	Company age	3.4000	0.2975		
2.1.3.	Responsiveness	4.3143	0.3775		
	Sub- total mean ratings of attributes	*11.4286*			
2.2.	Personnel qualifications	*2.6762*		***0.1494***	
2.2.1.	Relevant experience in building construction	3.9429	0.4911		
2.2.2.	Technical abilities	4.0857	0.5089		
	Sub- total mean ratings of attributes	*8.0286*			
2.3.	Financial performance	*3.5619*		***0.1988***	
2.3.1.	Bank references	3.4857	0.3262		
2.3.2	Profitability history	3.1714	0.2968		
2.3.3.	Current workload	4.0286	0.3770		
	Sub- total mean ratings of attributes	*10.6857*			
2.4.	Relevant experience	*3.7143*		***0.2073***	
2.4.1.	Similar type of projects to the proposed work	3.8857	0.5231		
2.4.2.	Similar size ($) of projects to the proposed work	3.5429	0.4769		
	Sub- total mean ratings of attributes	*7.4286*			

No.	Fators, Criteria, and Attributes	Mean importance rating	Attribute weight	Criterion weight	Factor weight
2.5.	Past performance *(third parties for references)*	***4.1546***		***0.2319***	
2.5.2.1	Number of references	4.8675	0.0901		
2.5.2.2.	Always completing past contracts	4.2000	0.0778		
2.5.2.3.	Completing past contracts on time	4.3143	0.0799		
2.5.2.4	Completing past contracts on original budget	4.0857	0.0756		
2.5.2.5.	Never engaged in illegal and fraudulent activities before	4.1429	0.0767		
2.5.2.6.	No fatal accident on any site under its control in the last 3 years	3.9714	0.0735		
2.5.2.7.	Showing close cooperation and coordination	4.4571	0.0825		
2.5.2.8.	Showing good knowledge of design and regulations	4.1714	0.0772		
2.5.2.9.	Producing good quality in past works	4.0857	0.0756		
2.5.2.10.	Employing high quality workmanship in past projects	4.0571	0.0751		
2.5.2.11.	Employing highly skilled operators in past projects	3.9714	0.0735		
2.5.2.12.	Showing stable financial performance	3.6000	0.0667		
2.5.2.13.	Showing integrity/honesty	4.0857	0.0756		
	Sub- total mean ratings of attributes	*54.0104*			
	Sub- total mean ratings of criteria	***17.9165***			
3.	**SPECIAL CONSIDERATIONS**	***3.8214***			***0.3359***
3.1.	Qualitative aspects	*3.8214*		***1.0000***	
3.1.1.	Similar culture	3.7429	0.2449		
3.1.2.	Relationships	3.5143	0.2299		
3.1.3.	Trust	4.2000	0.2748		
3.1.4.	Communication	3.8286	0.2505		
	Sub- total mean ratings of attributes	*15.2857*			
	Sub- total mean ratings of criteria	***3.8214***			
	Sub- total mean ratings of factors	**11.3768**			

Chapter 8
MODEL DEVELOPMENT, APPLICATION AND VALIDATION

8.1 Introduction

This Chapter presents the development, application, and validation of the subcontractor selection decision support system (SSDSS) for subcontractor selection in BR works. The first part introduces the analysis and synthesis of the SSDSS. In order to develop an appropriate system for the evaluation and selection of the potential subcontractor, the SSDSS was developed. The intent was to model the evaluation and selection decision process based on inputs from professional's expertise. The model's knowledge base was developed through interactions with contractors who served as the domain experts (DEs). Its development was also supplemented by methodologies garnered from the literature review.

The second and third parts of this chapter present the full application and validation of the SSDSS. A hypothetical but realistic selection scenario relating to the award of a contract to the subcontractor was applied to explain the model. The simulation exercise considered all the attributes, including the quotation price factor. The results from the application of the SSDSS developed were also used in the validation stage.

The development of the model is discussed in Section 8.2 where the decision diagram is introduced. The major components of the SSDSS are discussed in Section 8.2, and details of the consultation process are given in Section 8.3. The validation of the system is covered in Section 8.4.

8.2 Model Development

Before describing the SSDSS in detail, the decision-making process of the system must be defined.

8.2.1 Decision-making process of the system

The decision-making process of the system consists of a decision diagram and a decision process. These are described below.

The evaluation and selection of a potential subcontractor is a multi-step process, which includes a request for sourcing, evaluation of the firm's performance, including its financial stability and past performance, and lastly, evaluation of the technical proposal and quotation price. This evaluation is processed automatically in information generator diagram as shown in Figure 8.1.

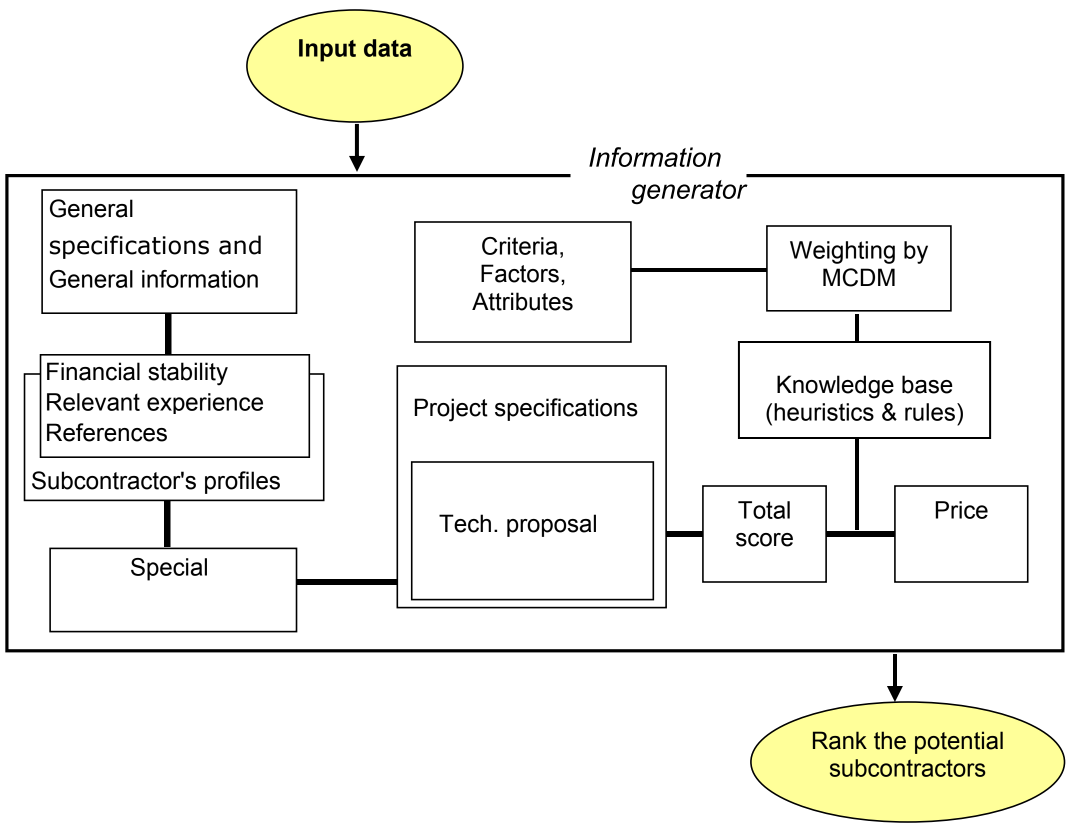


Figure 8.1 Information generator diagram

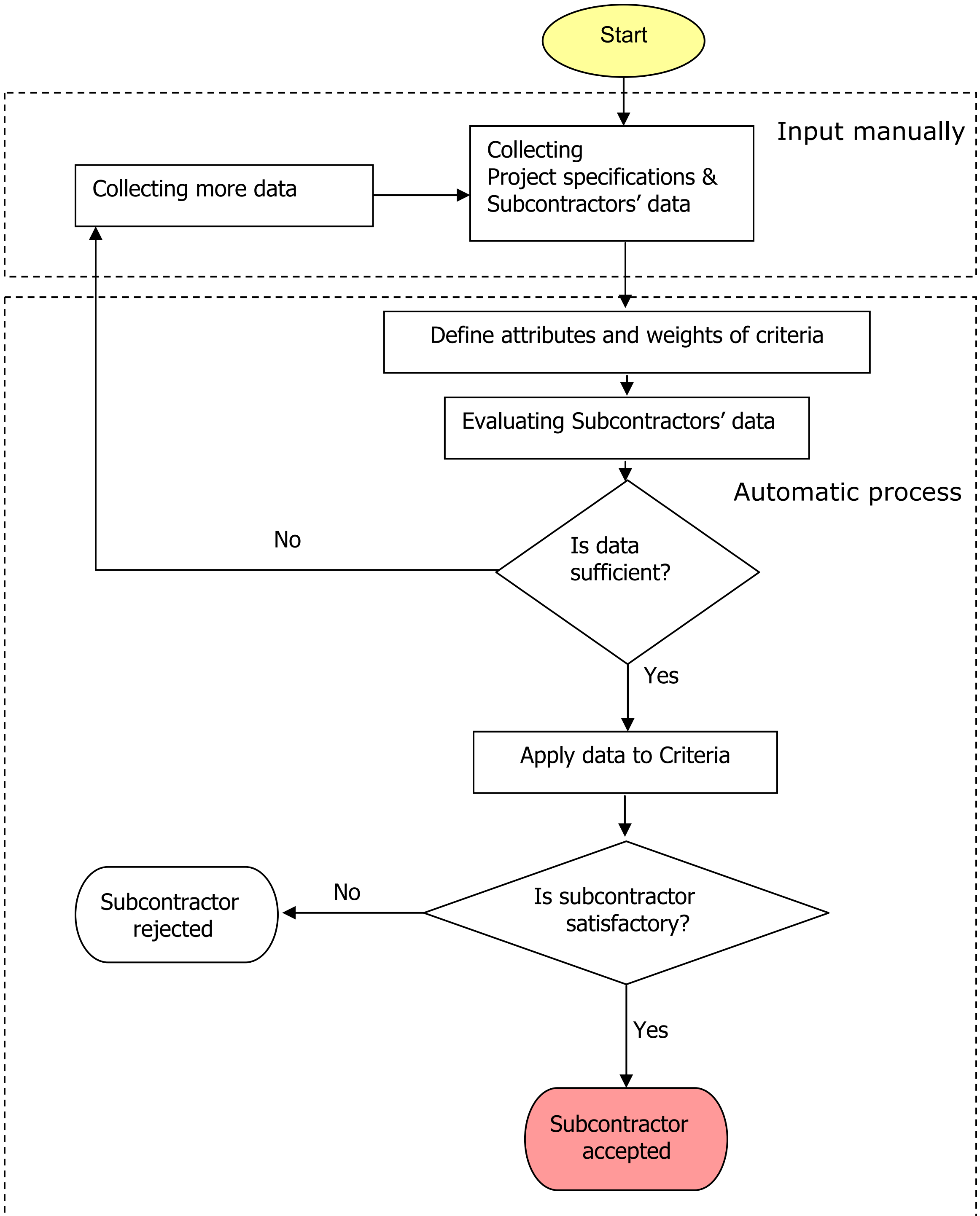


Figure 8.2 Evaluation process

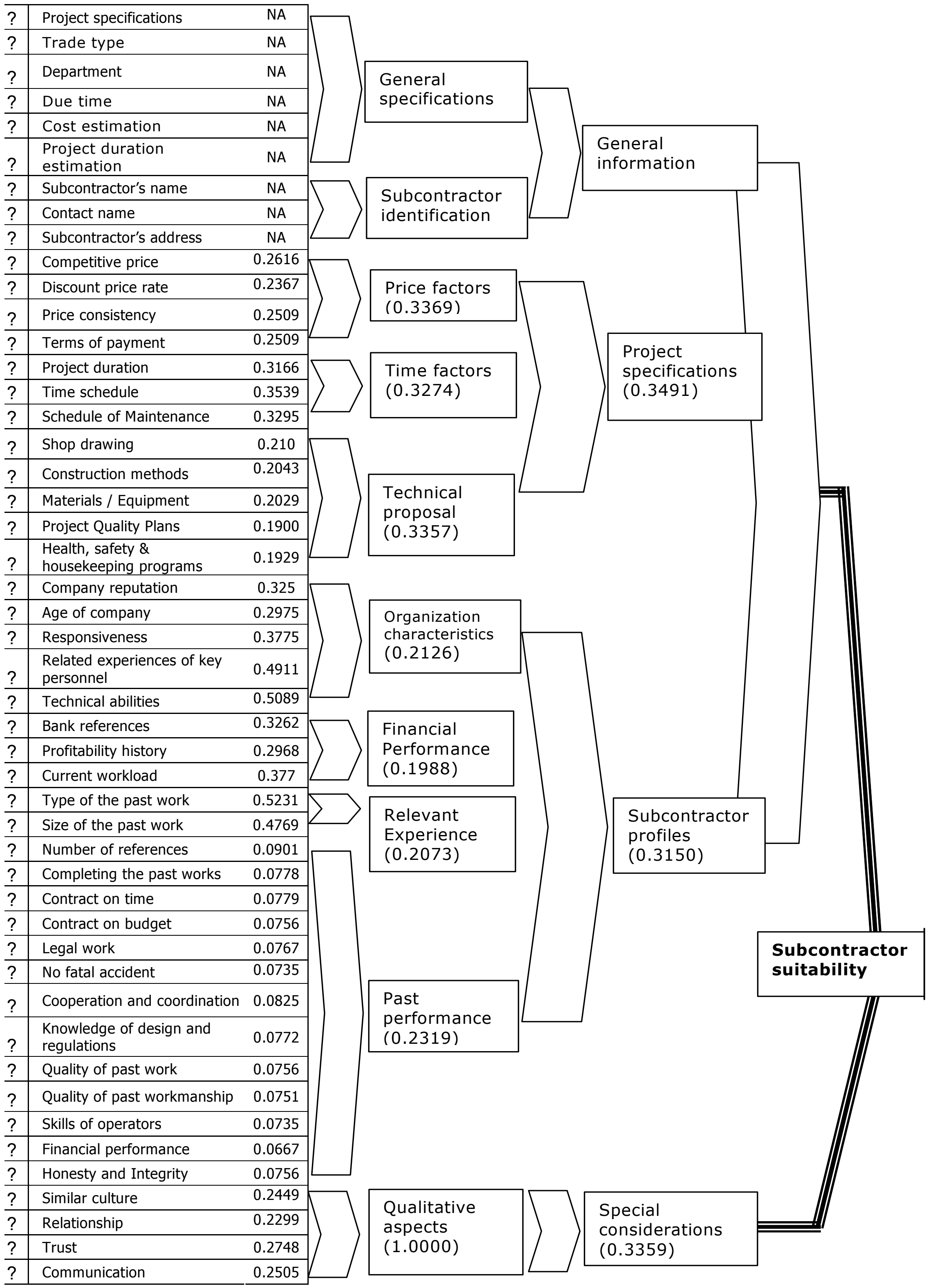


Figure 8.3 Diagram of Hierarchy tree for SSDSS

The evaluation process goes through two stages, one manually and the other automatically as shown in Figure 8.2. The first of these is a manual process, the user needs: (1) to input the project specifications and subcontractor's data, and (2) to decide on the types of attributes and the weights of the criteria. After these steps, the data is processed automatically. The first decision at this point is to review if the data is sufficient to process the selection process. If not then the process will go back to collect more data; otherwise the process continues to the next step, and applies the data to the factors, criteria and attributes.

At this point, the information generator module is consulted. In this case, the information generator module is called the subcontractor selection decision support system (SSDSS). Figure 8.3. shows the hierarchy tree for SSDSS diagram, the influencing attributes, and their contribution on the final decision for the evaluation and selection of a potential subcontractor. In order to calculate the weighting criteria, procedures/concept and rules are needed. The descriptive questions asked regarding each attribute and the concept and rules are as shown in Table 8.1.

Table 8.1 Decision attributes

Questions for Attributes	Concepts & Rules
1. What is the project name?	INPUT : the project's names
2. What is the subcontract number?	INPUT : the project code
3. What is the subcontract work type?	INPUT : work type
4. Who is division and section in charge?	INPUT : division & section's name
5. When will the work start?	INPUT : date
6. How much is the cost estimation?	INPUT : the cost estimation
7. How long is the estimated project duration?	INPUT : the estimation of the project duration
8. How much is the quotation price?	INPUT : the price figure $

Questions for Attributes	Concepts & Rules	
9. What is the ranking of the quotation price submitted for this work inline with other bidders?	AUTO :	Apply the comparison rules i=(1,2,3,4,5,6,..n)/$
10. Does the subcontractor obtain one of the three top scores?	YES-NO	If YES=1, NO=0, go next
11. Does the subcontractor offer a discount price rate?	YES-NO	If YES=call for clarification, NO=0, go next
12. Is the price rate in price analysis consistent?	YES-NO	If YES=1, NO=0; go next
13. Does the subcontractor propose terms of payment?	YES-NO	If YES go to 14, NO call for clarification
14. Does the subcontractor request an advanced contract deposit?	YES-NO	If YES=0.5, go next NO=0 go to 17
15. Is the payment based on work progress?	YES-NO	If YES=0.5, go to 17, NO=0, go next
16. Is the cost paid after work is completed?	YES-NO	If YES=0.5, NO=0, go next
17. How long is the duration of a work?	INPUT : the project duration	
18. Is the duration of work proposed comparable to the main contractor's program?	YES-NO	If YES=1, NO=0, go next
19. Is the duration of work proposed shorter than the main contractor's program?	YES-NO	If YES=apply comparison rules, NO=0, go next
20. Does the subcontractor submit an appropriate time schedule in accordance with the main contractor's program?	YES-NO	If YES=1, NO=0 go next
21. Does the subcontractor submit appropriate shop drawings in accordance with the specifications and drawings of the main contract?	YES-NO	If YES=1, NO=0 go next
22. Does the subcontractor submit appropriate construction methods in accordance with the main contractor's plan?	YES-NO	If YES=1, NO=0 go next
23. Does the subcontractor offer appropriate materials in accordance with the specifications and conditions of the main contract?	YES-NO	If YES=0.5, NO=0 go next
24. Does the subcontractor offer appropriate equipment in accordance with the specifications and conditions of the main contract?	YES-NO	If YES=0.5, NO=0 go next
25. Does the subcontractor offer appropriate schedule maintenance in accordance with the specifications and conditions of the main contract?	YES-NO	If YES=1, NO=0 go next
26. Does the subcontractor provide a project quality plan?	YES-NO	If YES=1, NO=0 go next
27. Does the subcontractor offer health, safety and housekeeping programs?	YES-NO	If YES=1, NO=0 go next
28. What is the subcontractor's name?	INPUT : the subcontractor's name	
29. What is the address of the subcontractor?	INPUT : subcontractor's address	
30. Who is the contact person in the subcontractor's firm?	INPUT : contact name	
31. Did the subcontractor join the subcontractor organization?	YES-NO	If YES go next, NO go to 35
32. If yes, Singapore List of Trade Subcontractor (SLOTS)	YES-NO	If YES=0.4 go next, NO=0 go 35
33. Or Refurbishment Association	YES-NO	If YES=0.4 go next, NO=0 go 35
34. Or other performance certificates from recognized institutions (e.g. BCA, HDB, SCAL)	YES-NO	If YES=0.2, NO=0 go next

Questions for Attributes	Concepts & Rules	
35. How long has the subcontractor's firm been trading under the same company name within the construction sector?	INPUT : company's age & Apply the comparison rule	
36. Is the subcontractor easy to contact? (e.g. when the subcontractor is called, no answering machine in receiving incoming calls)	YES-NO	If YES=0.5, NO=0 go next
37. Is the subcontractor quick to respond when receiving requests and instructions from the main contractor?	YES-NO	If YES=0.5, NO=0 go next
38. If yes, how long = ……..hours	INPUT : the responsiveness (hours) & Apply the comparison rule	
39. What percentage (A%) of the subcontractor's key personnel has good technical ability?	INPUT	A% * 0.5, go next
40. Has the key personnel of the subcontractor experienced working in building refurbishment work before?	YES-NO	If YES=0.5, NO=0 go next
41. How many projects have been completed?	INPUT figure then apply the comparison rule * 0.5	
42. Does the key personnel of the subcontractor have the technical ability to interpret and use contract documents?	YES-NO	If YES=1, NO=0 go next
43. Has the subcontractor's firm been with the same bank for minimum 2 years?	YES-NO	If YES=0.5, NO=0 go next
44. What was the rating given by the Bank referee regarding the company's financial performance?	Rating	Poor – Exc. i=(1-5)… i/5 * 0.5, go next
45. Has the subcontractor's firm shown profitability over the last 2 years?	YES -NO	If YES go next, NO go to 49
46. Return on sales	INPUT/AUTO	Apply comparison rule * 0.5, go next
47. Return on assets	INPUT/AUTO	Apply comparison rule * 0.5, go next
48. Is the subcontractor currently working for other main contractors?	YES-NO	If YES=1, NO=0 go next
49. Is the subcontractor currently working for other (two or more) main contractors?	YES-NO	If YES=0.5, NO=0 go next
50. Did the subcontractor provide details of subcontracting jobs completed within the past 3 years?	YES-NO	If YES go next, NO=0 go to 54
51. How many refurbishment works have been completed?	INPUT	If YES=0.7, NO=0 go next
52. How many new build works have been completed?	INPUT	If YES=0.3, NO=0 go next
53. Did the subcontractor experience a similar size ($) project to the proposed work within the past 3 years? (More or less 20%)	YES-NO	If YES=0.5, NO=0 go next
54. Is the proposed work of size ($) most often undertaken by the subcontractor company?	YES-NO	If YES=0.5, NO=0 go next
55. How many references does the subcontractor have?	INPUT then apply comparison rule * 0.8, go next	
56. What was the average rating given by references regarding past performance (overall)?	INPUT then apply comparison rule * 0.2, go next	
57. Has the subcontractor completed an entire contract before?	YES-NO	If YES=1, go to 60, NO go next
58. If no, was the failure reasonable?	YES-NO	If YES=0.5, go to 60, NO=0 go next
59. Did the subcontractor complete the past contract by the completion date?	YES-NO	If YES=1, go to 63, NO go next

Questions for Attributes	Concepts & Rules	
60. If no, entirely due to the subcontractor's fault	YES-NO	If YES=0, go to 63, NO go next
61. Or only partly due to the subcontractor's fault	YES-NO	If YES=0.5, go to 63, NO=0 go next
62. Did the subcontractor complete the past contract by the original budget?	YES-NO	If YES=1, NO=0 go next
63. Has the subcontractor been engaged in illegal and fraudulent activities before?	YES-NO	If YES=1, NO=0 go next
64. What was the rating given by a previous main contractor who employed the subcontractor regarding his health, safety and housekeeping program?	Rating	If YES=1, NO=0 go next
65. What was the rating given by a previous main contractor who employed the subcontractor regarding the ability of key personnel in cooperation and coordination?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
66. What was the rating given by a previous main contractor who employed the subcontractor regarding the knowledge of design and regulations that are relevant to the building refurbishment works?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
67. What was the rating given by a previous main contractor who employed the subcontractor regarding the quality of finished work?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
68. What was the rating given by a previous main contractor who employed the subcontractor regarding the quality of workmanship?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
69. What was the rating given by a previous main contractor who employed the subcontractor regarding the skills of operator using equipment?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
70. What was the rating given by a previous main contractor who employed the subcontractor regarding the financial stability of the subcontractor?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
71. What was the rating given by a previous main contractor who employed the subcontractor regarding his integrity?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
72. What rating would you give to the similarity of the culture of your company with the subcontractor?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
73. What rating would you give to the subcontractor regarding relationship of your company with the subcontractor?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
74. What rating would you give to the subcontractor regarding relationship of your site staffs with the subcontractor's site personnel?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
75. What rating would you give to the subcontractor regarding his trustworthiness?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
76. What rating would you give to the subcontractor regarding his ability in communications?	Rating	Poor – Exc. i=(1-5)… i/5 * 1, go next
Setting the score of criteria	AUTO	If of the 3 important criteria obtains less than 50% of the score the subcontractor is rejected. Aggregating scores by MCDM equation.. STOP

Each of the attributes shown in Table 8.1 was evaluated in terms of "input and automatic evaluation", "rating", or "yes-no" by the DEs. The concept "input and automatic evaluation" means the user needs to input data before the system can process the data automatically. The concept of "rating" means the user needs to decide on the importance or the rating performance of particular attributes before the system can calculate the mean weighting attributes automatically. The comparison rules means the rating of the subcontractor are compared each other. The system provides the alternative ratings from 1 to 5 that represent values of extremely unimportant to extremely important or poor to excellent. The "yes-no" question is a type of Boolean rule, whether yes, or otherwise no.

These evaluations may be based on information supplied by the subcontractors and the third parties, such as information on financial stability from banks, and information of past performance from a former main contractor who had employed the subcontractor before.

The intelligent system used the "rule based reasoning" (RBR) where the specialized domain knowledge is represented as a set of IF *<precondition(s)>* THEN *<conclusion(s)>* rule format. Examples of representative "IF-THEN" rules are shown below:

Rule number: PS/PF/01

IF (1) the subcontractor obtains 3 top scores

(2) the price out of range

THEN (1) call for clarification

Rule number: PS/PF/02

IF (1) the subcontractor offers the discount price rate

THEN (1) score=1 otherwise=0

Rule number: PS/PF/03

IF (1) the subcontractor proposes terms of payment

THEN (1) Go next step otherwise=call for clarifications

IF (1) payment after the project is completed

THEN (1) score=1 otherwise Go next step
IF (1) payment based on work progress
THEN (1) score=0.5 otherwise G next step
IF (1) the subcontractor requests advanced contract deposit
THEN (1) score=0 otherwise=0.5

The examples shown above are all for the price criterion. The first example, rule PS/PF/01, states that if a subcontractor obtains 3 top scores, but his quotation price is out of estimation range, then clarifications are called for. Rule PS/PF/02 states that if the subcontractor offers a discount price rate, then he gets a score=1; if not, then no score. Rule PS/PF/03 states that (1) if the subcontractor proposes the terms of payment, then the process continues to the next step (does the subcontractor request an advanced contract deposit?), otherwise call him for clarification; (2) if the payment is made after the project is completed, then he gets a score=1, if not then continue on to the next step; (3) if the payment is based on the progress, then he gets a score=0.5, if not then continue on to the next step; (4) if the subcontractor requests an advanced contract payment deposit, then he gets no score, if not then he gets a score=0.5. Further descriptions of the decision attributes used as part of the rules are given in Table 8.1.

These attributes are then evaluated in terms of project specifications, subcontractor's profiles, special considerations, and general factors. These factors are evaluated in terms of their scores, ratings, and then multiplied by the weights of attributes, criteria, and factors. These factors are then combined to provide an overall evaluation of the subcontractor's suitability.

8.2.2 Architecture of the System

The major characteristics of the SSDSS are:

1. Contains a knowledge base about the decision support system for BR subcontractor selection. The knowledge based systems (KBS) is easier to modify, allowing a programmer or user to modify segments of the

program relatively easily because the expert knowledge and the procedure mechanism are separate. The KBS allows users without much programming experience to read and even to write or to maintain the rule-base and the weighting criteria.

2. Contains an inference engine, or inference reasoning capability, which in some ways mimics the way a human decision maker thinks.
3. Has a facility to explain the guidance or reasoning process, so that the user can see why and how the subcontractors are selected or rejected.
4. Contains symbolic programming and reasoning capability.
5. IF-THEN rules are a principle of RBR which stored in the knowledge base.
6. Since IF-THEN rules are not embedded in the source code, the knowledge base is more readily understandable and maintained by non-technical users.

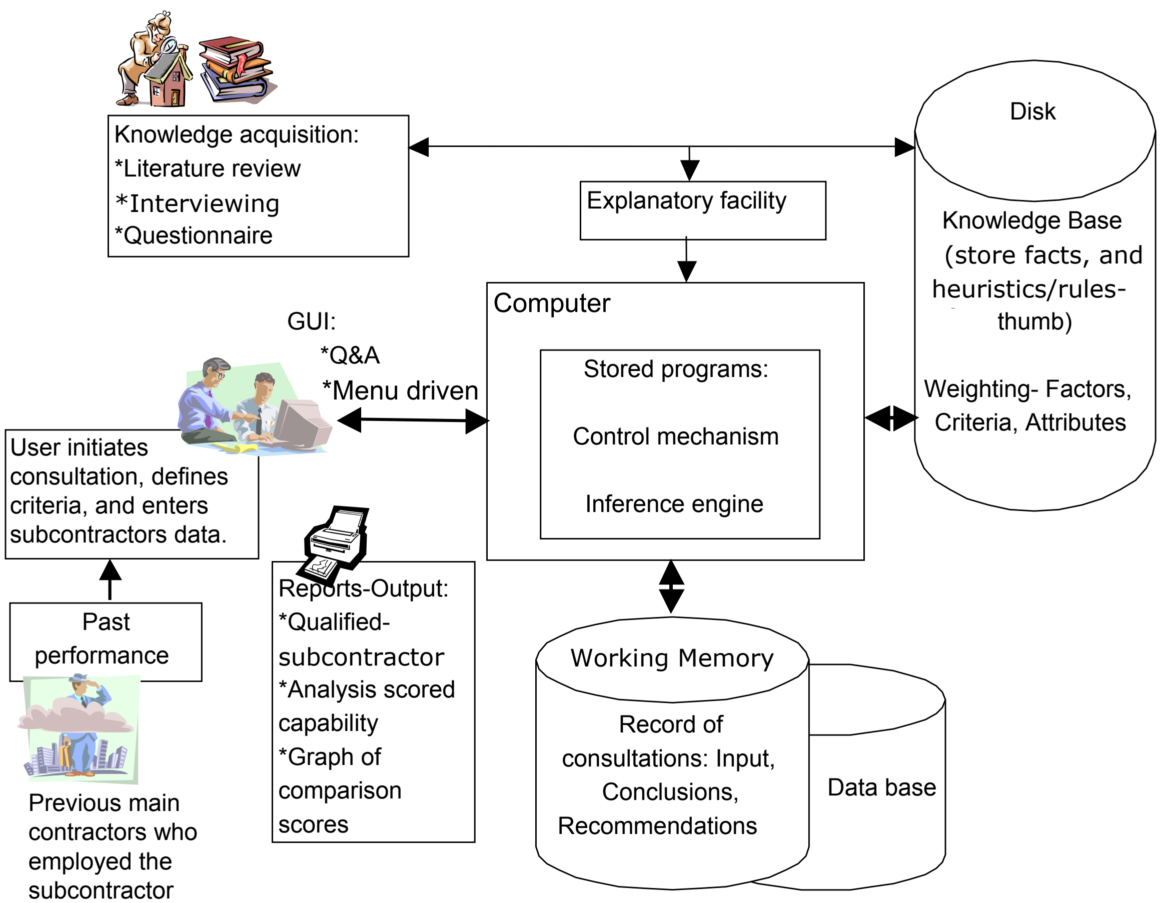


Figure 8.4. The architecture of the SSDSS

The general architecture of the SSDSS is shown in Figure 8.4. The system has the following components: (1) the knowledge subsystem, (2) the working memory subsystem, (3) the knowledge representation and inference engine subsystem, (4) the knowledge acquisition facility subsystem, (5) aggregating the scores, (6) the explanatory facility subsystem, (7) the graphical user interface (GUI), and (8) the computer hardware and control mechanism.

8.2.2.1 Knowledge Base Subsystem (KBS)

The KBS is the component of the SSDSS that contains all the information associated with the BR subcontractor selection system. This information ties together facts, rules, and heuristics that were obtained from the DEs and literature. The knowledge is stored as "IF, THEN" rules in the knowledge base.

8.2.2.2 Working Memory Subsystem

The working memory subsystem is the component of the SSDSS that contains all the information about the problem currently being solved. Its content changes dynamically and includes information that defines the parameters of the specific problem and information derived by the system at any stage of the solution process.

8.2.2.3 Knowledge Representation and Inference Engine Subsystem

Once knowledge is acquired, it must be organized in an application knowledge base or for later use. It can be organized in several different configurations to facilitate fast inference (or reasoning) from the knowledge.

The representational stage plays a central role in the field of artificial intelligence (AI). It concerns the search for models of knowledge that enable systems to behave intelligently. Knowledge representation is defined as a combination of data structures and interpreting procedures that, if represented and used adequately in a program, will lead to knowledgeable and intelligent behavior.

The "intelligence" of the system, which is the mechanism that combines this knowledge and information to make decisions, is called the inference engine. The inference engine performs the task of deciding how and when the rules are to be applied to solve the problem of evaluating a potential subcontractor. The structure of the inference engine is independent of the knowledge base.

Once knowledge representation in the knowledge base is completed, or is at least at a sufficiently high level of accuracy, it is ready to be used. A computer program is needed to access the knowledge for making inferences. This program contains an algorithm that controls a reasoning process and is usually called the *inference mechanism* or the control program. It controls the reasoning process of the system and uses the knowledge base to modify and expand the context to solve a specific problem. Inference rules differ from knowledge rules. Inference rules are procedural rules. They contain rules about rules, which advise on how to solve a problem given that certain facts are known. On the other hand, knowledge rules are declarative rules, which state all the facts and relationships about a problem. Inference rules become part of the inference engine, while the knowledge rules are stored in the knowledge base.

8.2.2.4 Knowledge Acquisition Subsystem

The knowledge acquisition subsystem is the accumulation, transfer and transformation of problem solving expertise from various knowledge sources, e.g. experts or literatures, to a computer program for constructing or expanding the knowledge base (the knowledge acquisition stage has been completed and discussed in Chapters 3, 5 and 6).

8.2.2.5 Aggregating the Scores

The total score of each subcontractor is computed by multiplying the rating of a subcontractor for an attribute by the importance weight assigned to the attribute and then summing up the products over all the attributes. The application of this approach to the program is represented by the following equation:

$$A_{i(WSM-score)} = \sum_{j=1}^{n} a_{ij} w_j \quad \text{......................(8.1).}$$

where:

$A_{i\,(WSM\text{-}score)}$	: is the *i-th wsm* score of alternative.
n	: is the number of decision criteria
a_{ij}	: is the actual value of the *i-th* alternative in terms of the *j-th* criterion
w_j	: is the weight of importance of the *j-th* criterion

This approach has been discussed earlier in Chapter 2, and Chapter 7 (Section 7.3.3. Weighting Criteria).

In application, Equation 8.1 was adjusted to take into consideration the three-level hierarchy “factor”, “criteria”, and “attribute”. Equation 8.2 is the mathematical expression for the subcontractor model:

Aggregating score = Score (P)+Score (S)+Score (Sp)…….(8.2).

where:

Score (P)	: is the aggregate score of attributes under “project specifications” factor
Score (S)	: is the aggregate score of attributes under “subcontractor’s profile” factor
Score (Sp)	: is the aggregate score of attributes under “special consideration” factor

The detail formula for Score (P), Score (S), and Score (Sp) are given:

Score (P) = $$w_1[w_{11}(\sum_{a=1}^{4} w_{11a}a_{11a}) + w_{12}(\sum_{b=1}^{3} w_{12b}a_{12b} + w_{13}(\sum_{c=1}^{5} w_{13c}a_{13c})]$$

…………… (8.3).

Where:

Score (P) is the aggregate score of attributes under "project specifications" factor

W_1 is the weight of project specification factor (see Equation 7.5)

W_{11}, W_{12}, and W_{13} are the weights of the "price factors", "time factors", and "technical proposal" criteria respectively.

W_{11a}, W_{12b}, and W_{13c} are the weights of the attributes under the "price factors", "time factors", and "technical proposal" criteria respectively.

a_{11a}, a_{12b}, and a_{13c} are the ratings given to subcontractor for the attributes under the "price factors", "time factors", and "technical proposal" criteria respectively.

Score (S) = $$w_2[w_{21}(\sum_{d=1}^{5} w_{21d} a_{21d}) + w_{22}(\sum_{e=1}^{3} w_{22e} a_{22e} + w_{23}(\sum_{f=1}^{2} w_{23f} a_{23f})$$

$$+ w_{24}(\sum_{g=1}^{13} w_{24g} a_{24g})]$$ ………… (8.4).

Where:

Score (S) is the aggregate score of attributes under "Subcontractor's profiles" factor

W_2 is the weight of subcontractor's profiles factor (see Equation 7.5)

W_{21}, W_{22}, and W_{23} are the weights of the "organization characteristics", "financial performance", "relevant experience", and "past performance" criteria respectively.

W_{21d}, W_{22e}, W_{23f}, W_{24g} are the weights of the attributes under the "organization characteristics", "financial performance", "relevant experience", and "past performance" criteria respectively.

a_{21d}, a_{22e}, a_{23f}, a_{24g} are the ratings given to the subcontractor for the attributes under the "organization characteristics", "financial performance", "relevant experience", and "past performance" criteria respectively.

Score (Sp) = $w_3[w_{31}(\sum_{h=1}^{4} w_{31h}a_{31h})]$ .... (8.5).

Where:

Score (Sp) is the aggregate score of attributes under "special considerations" factor

W_3 is the weight of special consideration factor (see Equation 7.5)

W_{31} is the weight of the "qualitative aspects" criteria.

W_{31h} is the weight of the attributes under the "qualitative aspects" criteria.

a_{31h} is the ratings given to subcontractor for the attributes under the "qualitative aspects" criteria.

8.2.2.6 Explanatory Facility Subsystem

The explanatory facility subsystem's function is to explain the reasoning processes. Based on the instruction imputed, the inference mechanism selects the appropriate rules from the knowledge base to execute the order process. A SSDSS is capable of explaining this reasoning process; for example, it is capable of showing how it used the rules and the information provided by the user.

8.2.2.7 Graphical User Interface (GUI) Subsystem

The GUI subsystem covers all aspects of communications between a user and the SSDSS. It is essential in allowing users to operate the system in a simple and easily followed manner, using whatever control items and methodologies that are required. The communication process is designed to be as user-friendly as possible. All the possible questions and levels of rating of the different alternatives are shown to the user as a "scroll bar" or "combo box" for their selection.

8.2.2.8 Hardware and Control Mechanism

The SSDSS was developed on an IBM personal computer (PC). The expert system shell was developed using the high-level language compiler "Microsoft Visual Basic ™" and database "Microsoft Access 2000™" (see Chapter 4 for the justification in using this software). The shell essentially dictates how knowledge is to be represented. The shell is a forward chaining inference engine that uses “IF, THEN” rules to represent the expert’s knowledge.

The hardware/ software requirements that are necessary to execute the program are:
- IBM PC or 100% compatible desktop personal computer or notebook
- Microsoft Windows 98/2000/XP
- Pentium @ 200MHz or equivalent or better
- Memory with minimum 64 MB of RAM for minimum 16 bits.

8.2.3 Data Processing

The user responds to a series of questions to provide inputs to the SSDSS for the various attributes. These user inputs are then used by the decision rules of the SSDSS to determine the three broader factor evaluations and ultimately the overall subcontractor suitability.

The SSDSS uses various levels of attributes to determine broader factor evaluations of project specifications, subcontractor’s profiles and special considerations. These factors are then combined to provide an overall evaluation as to the subcontractor’s suitability. A flowchart of the software is shown in Figure 8.5, with some of its subroutines. Each subroutine performs a specific function in the overall analysis process. There are two environments in the SSDSS, namely development and consultation environments. The development environment consists of four main processes (subroutines), namely input data (INPUT subroutine); determination of decision factors, criteria and questions (DF subroutine); determination of weighting criteria (WC subroutine); and determination of scoring rules (STAT subroutine). The last subroutine determines the scoring rules (SORTX subroutine), which is basically the consultation environment, and the other subroutines are part of the development environment.

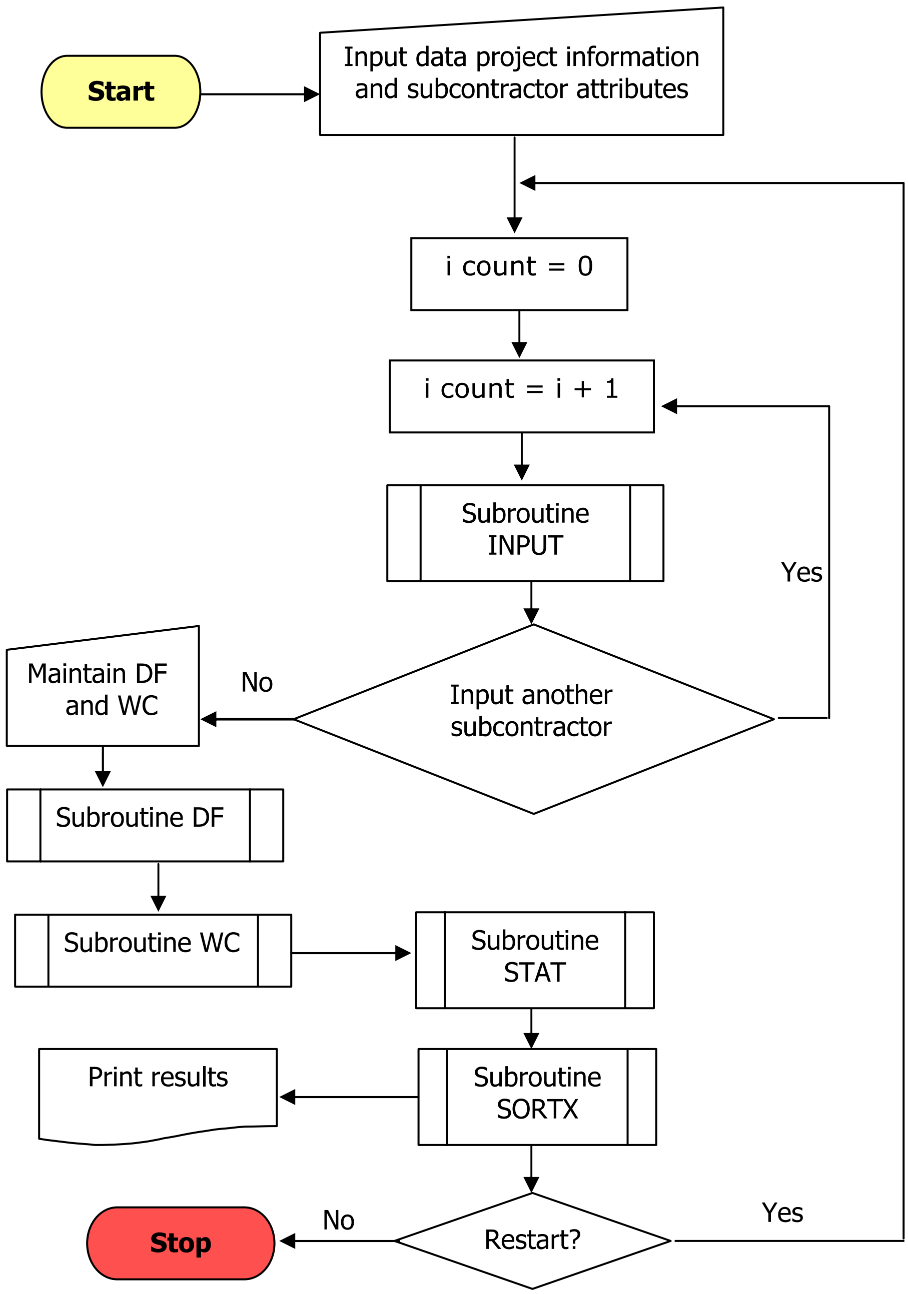


Figure 8.5 Flowchart of the data processes

8.2.3.1 DF Subroutine

The first process is the determination of decision factor (DF) or the DF subroutine. This presents the decision factors, criteria, attributes and question alternatives available, reads the user selection, then provides the necessary queries to the user based on the selected alternatives.

The alternatives include:

1. Accept the system-specified DFs, including criteria and attributes based on the program supplied factor analysis results. The software supplied by default 3 factors, 9 criteria and 39 attributes. The user can modify the set-up default easily through selecting the response choice via the "combo box" facility in the GUI.
2. Modify the software default or program-supplied DFs, including the following possibilities:
   - Modify/delete DFs,
   - Add additional DFs to an existing system-specified DF,
   - Create and add additional DFs to the system.
3. The user can create his own selection decision system, including the determination of DFs. Each setting will be saved with a specific name so that it can be used in the next exercises.

Once the DFs have been specified, the parameter weightings of subcontractor selection are performed.

8.2.3.2 WC Subroutine

The second process is the weighting criteria (WC) subroutine that addressed the weighting of the DFs requested by the user. The user has two options:

1. System specified weights based on the software supplied factor analysis results (based on the surveys of this research).
2. User specified weights: these allow the user to input the perceived importance on a scale from 1 to 5 for each attribute.

If the user wants to exclude the DF from the analysis, a zero would be inputted for the weight. The system allows the user to input the desired weights and then view the normalized weights. A facility has been provided which permits the normalized weights to be modified by re-entering the perceived importance, again on a scale from 0 to 1. The user can continue to modify his input values until he is satisfied with the normalized weights given to each decision parameter.

8.2.3.3 INPUT Subroutine

The third process is the INPUT subroutine that queries the user input. Once the appropriate queries and input are made by the user, the program proceeds to the next step, namely the input of data. There are two groups of inputs, namely the project‘s and the subcontractors’ data. The former data is the specifications of the project. The other data required is the user input on the name of the subcontractor and scores of each DF.

The system then proceeds with queries for each of the three broader factor evaluations of project specifications (proposal), subcontractor profiles including past performance, and special considerations. The type of factor is shown at the top of each screen as a reminder. The consultation process is user-friendly in that each question provides the possible response choices on a scale from 1 to 5 where 1 = “poor” and 5 = “excellent” (e.g. poor, unsatisfactory, satisfactory, very good, excellent). This avoids the problem of a user having to remember the proper responses for a particular attribute rating.

The system does not proceed through every possible attribute, but only those queries that require a rating for that attribute. If a factor can be evaluated automatically by the system without asking about a particular attribute, the user will not be queried regarding the unnecessary information. When an evaluation is made for each factor, that factor and rating is shown on the screen with a note on the bottom of the screen to “press any key to evaluate the next factor”.

8.2.3.4 STAT Subroutine

The next process is the STAT subroutine that calculates the statistics for all the input DF data and aggregates the weighted scores for all the subcontractor candidates. The statistics calculated for the DF scores and the aggregate weighted scores. In this process, Equation 8.1, and 8.2 are applied.

8.2.3.5 SORTX Subroutine

The last process is the SORTX subroutine that ranks and orders the aggregate weighted scores from the largest to the smallest that are obtained from the INPUTS subroutine. The aggregate weighting score is then calculated using Equation 8.1. This process is continued until the list of subcontractor candidates has been exhausted. These aggregate weighted scores are then printed onto the screen for further analysis by the user. When the DFs are evaluated, the final screen shows a summary of the ratings of each of the three factors plus the final overall evaluation (favorable, average, or unfavorable) of that subcontractor for that work type.

The screen shows the subcontractor name, type of subcontract work and final evaluation at the top of the screen. The screen also shows not only the statistical analysis of the scores, but also displays a graph for comparing the scores. This graph is an important instrument to show the pattern of the scores and factors of each potential subcontractor, and compare it with the ideal pattern of the score factor. Finally, the system asks the user if there is another potential subcontractor to evaluate.

8.2.3.6 Other Facilities

The other features of the system are review, view and help facilities. The review facility has been provided to review previous subcontractor candidates. The benefit of this facility is that it provides the user with the ability to display previous inputs prior to assigning a score to the subcontractor candidate who is being analyzed.

The hierarchy of weighted scores can be viewed on the monitor. The user then has the option to view the input data of a specific subcontractor candidate by inputting the subcontractor candidate. Along with the score of each DF for the subcontractor candidate, the mean of each DF is also provided.

8.3 Application of the System

This section gives a working example of the selection model. The hypothetical but realistic subcontractors 1, 2,…n are prefixed by SCr_1, SCr_2,...SCr_n, which were evaluated using the SSDSS developed. For the purpose of this example, a refurbishment of a six-storey office building with a gross floor area 2,300m^2 is assumed. The main contractor needs to subcontract part of the project namely façade work, which is estimated at $10 million. The main contractor (user) short-listed five subcontractors, and found that three of the subcontractors can fulfill all the essential attributes.

The 5 subcontractors are called Subcontractor SCr1; SCr2; SCr3; SCr4; and SCr5. Subcontractor SCr1 has an excellent reputation in undertaking facade works. Subcontractor SCr2 specializes in refurbishment works while subcontractor SCr3 specializes in high-rise building projects. SCr4 has an excellent record in healthy, safety and house keeping programs. SCr5 has never failed in the previous works.

Subcontractors SCr1, SCr2, SCr3, SCr4 and SCr5 have practiced in the construction industry for 12, 7, 10, 5 and 15 years respectively. Subcontractor SCr2 gathered most of its experience in refurbishment projects. Subcontractor SCr3 has undertaken two refurbishment projects while subcontractor SCr1 does not have experience in BR projects. Subcontractor SCr2 has earlier worked with the main contractor on 5 projects. Subcontractor SCr2 enjoyed a very good relationship with the main contractor when they worked together on the 5 projects. Other data has been inputted to the program.

A consultation begins with a welcome to the SSDSS and is followed by a brief explanation of the system and how it operates. Figure 8.6 is an example of the user/system screen. The completed user's guide of the program is presented in Appendix 3.

The following steps are described for the consultation.

Figure 8.6 Welcome screen

8.3.1 First Step

Initially the user needs to input the general information of the project and the criteria used. The user also has an option to use the criteria and their weights, which have been pre-defined (default set-up) in the program, or to modify them. In this simulation, the user was assumed to use the default set-up.

Three factors, 9 criteria, and 39 attributes for BR subcontractor selection have been pre-defined in the system. These aspects include their weights, which were derived from the survey results of this research (see Figure 8.7).

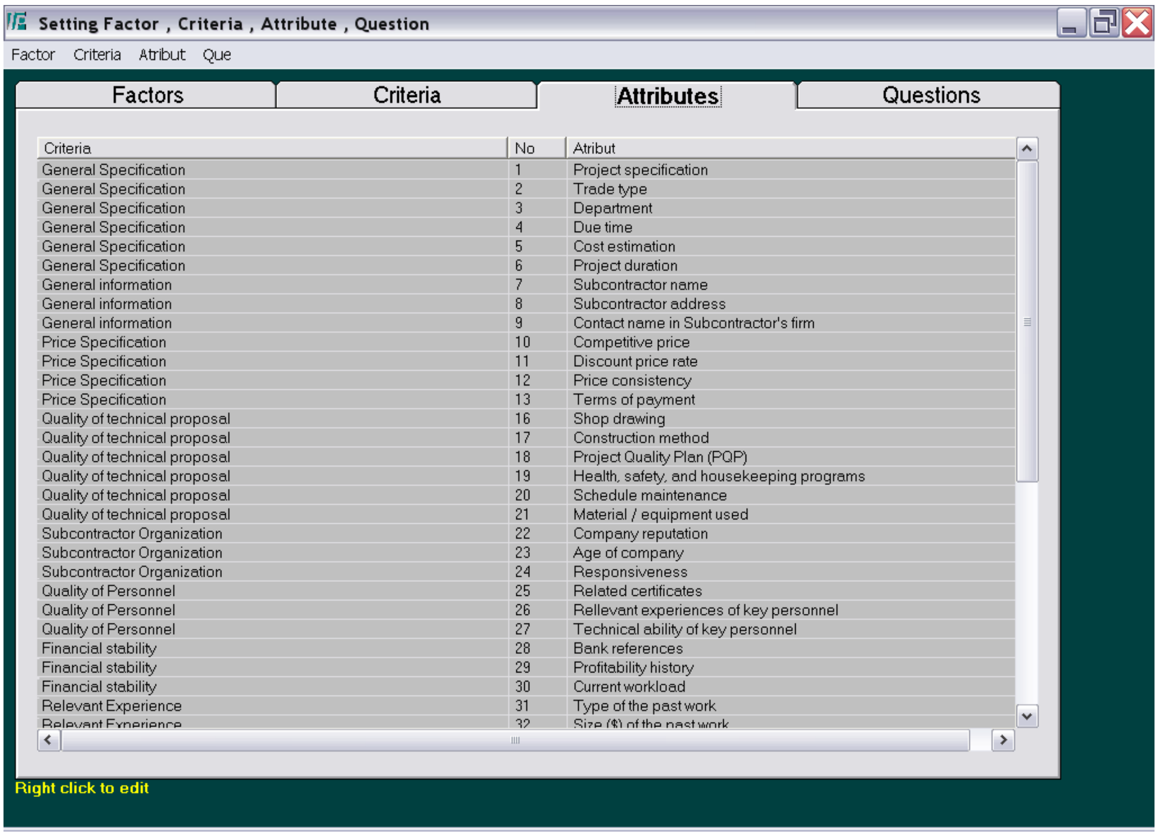


Figure 8.7 Predefined factors, criteria and attributes

8.3.2 Second Step

The second step is to input the general information of the project and the subcontractors' identifications. The user is asked for the general information of the project and the name of the subcontractor being evaluated.

The questions to be gathered for general information include the following:

A. Project identifications

1. What is the project name?
2. What is the subcontractor's telephone number?

3. What is the subcontract work type?
4. What is the division and section in charge?
5. When will the work start?
6. How much is the cost estimation?
7. How long is the estimated project duration?

B. Subcontractors' identification

1. What is the subcontractor's name?
2. What is the address of the subcontractor?
3. Who is the contact person in the subcontractor's firm? (see figure 8.8)

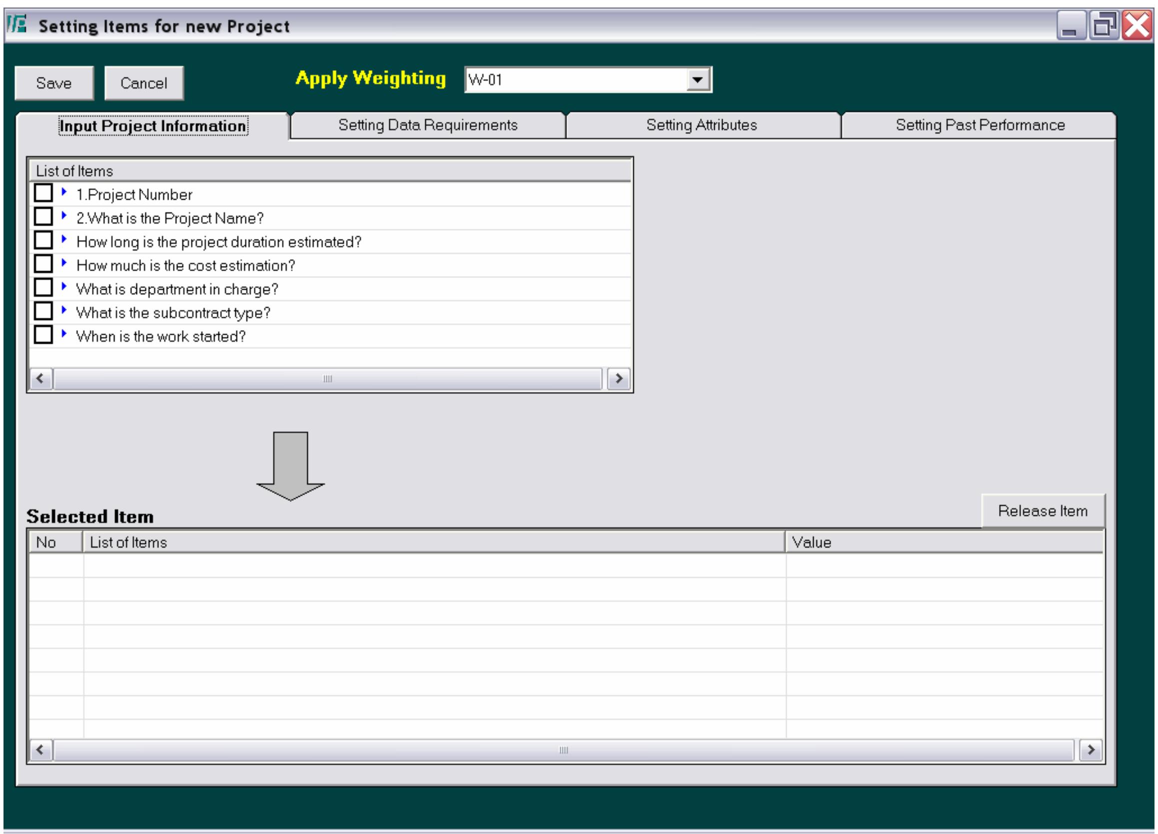


Figure 8.8 Settings for the new projects

8.3.3 Third Step

The data from the subcontractors was collected through a questionnaire, a copy of which is presented in Appendix 4. In the inputs for the subcontractor attributes, the identities of subcontractors were hidden until the end process. This is to avoid the bias of the user. This can be done by separating the form for the subcontractor identification and the form for the subcontractor properties. There is no subcontractor identity in the second part of the form, except for a code for tracing. The past performance data and bank references will be collected from third party referees using the questionnaire as presented in Appendix 5.

Having input all the data, the system processes all the figures. When the DFs are evaluated, the final screen shows a summary of the ratings of each of the three factors plus the final overall evaluation (favorable, average or unfavorable) of whether the subcontractor is right for that type of work. The screen shows the subcontractor's name, type of subcontract work and final evaluation at the top of the screen. Besides that, the screen also shows the statistical analysis of the scores. The screen is as shown in Figure 8.9.

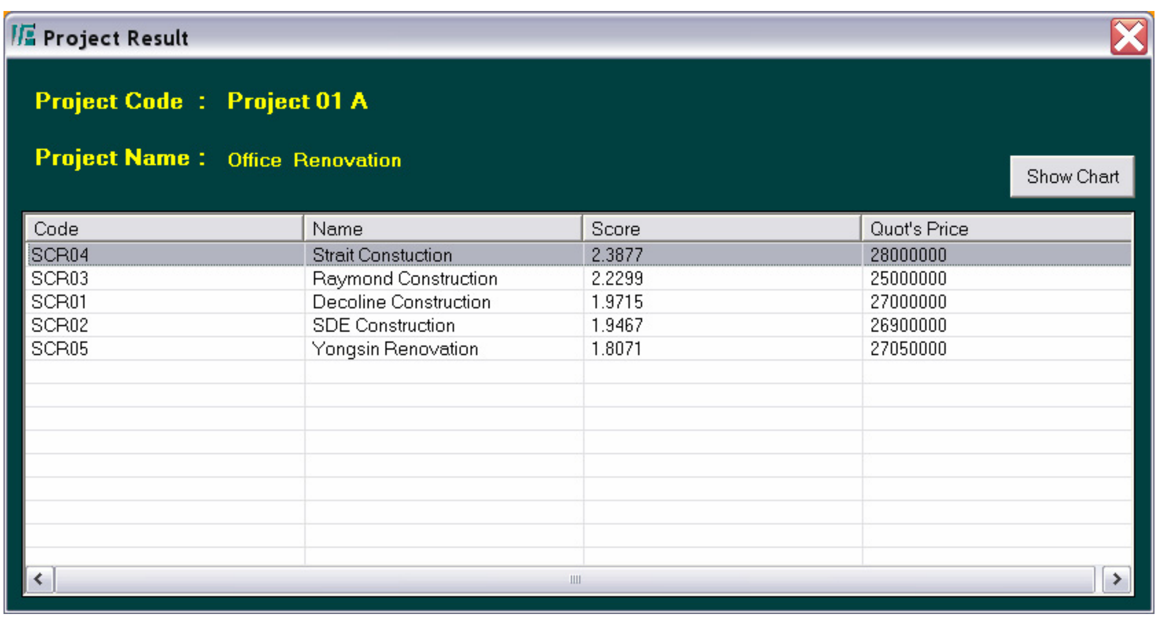


Figure 8.9 Summaries of Ratings

The results derived from the SSDSS were reviewed and were able to confirm that Subcontractor SCr 04 would be the most suitable to handle the subcontract work. Besides that, the screen shows the rankings of the subcontractors as well as graphics which can assist the user easily to check the subcontractors' scores readily. The screen is as shown in Figure 8.10.

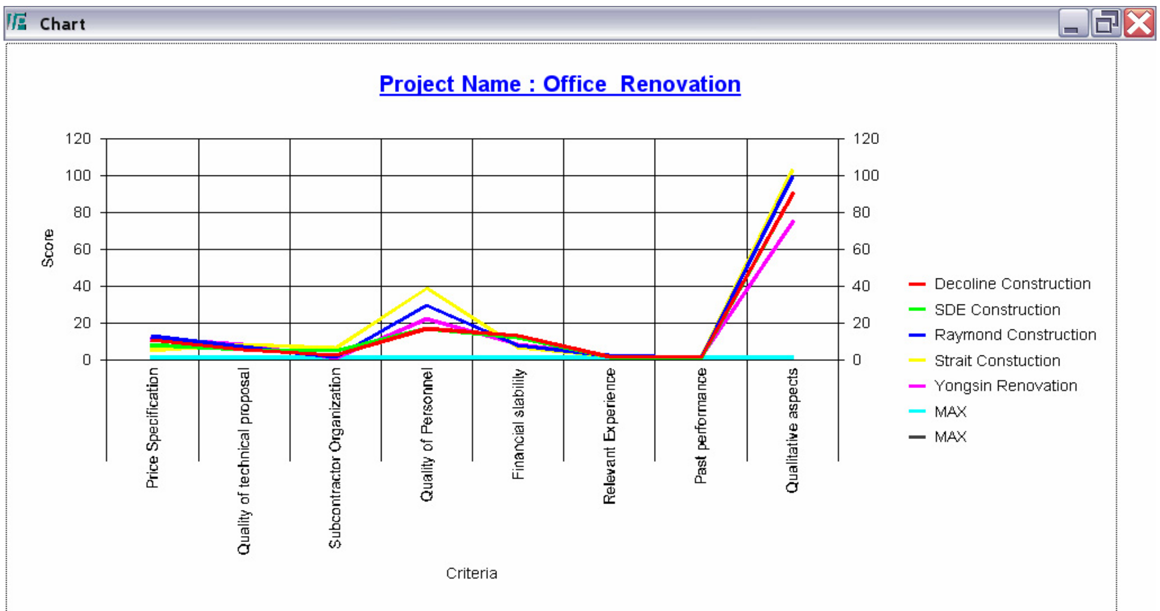


Figure 8.10 Chart of the subcontractors' scores

8.4 Validation of the System

In this present research, the validation involves the following two aspects, performance validation and system utility assessment. Performance validation consists of the execution of formal tests to evaluate: (1) the accuracy and completeness of the knowledge base; (2) the consistency and accuracy of the decision made by the system; and (3) the reasoning process used by the system to make a decision.

System utility assessment involves: (1) Evaluation of the user interface design that impacts on the ease of use and ultimately influences user's acceptance; and (2) user perception of the system's performance and utility. The validation has also considered the criteria for effective CADSS (see Chapter 2).

8.4.1 Performance Validation Results

Validity of the system knowledge can be established by determining what the system knows, does not know, or incorrectly knows. Two procedures suggested by O'Leary (1993) were used to check the validity of the SSDSS's knowledge: (1) direct examination of the system by experts; and (2) Turing test: namely, comparison of the system with experts.

For both the procedures listed above, two types of experts were used: (1) Donor, i.e., experts from whom the knowledge was acquired to develop the system, and (2) Non-donors, i.e. experts who were not involved in the design and implementation of the system. A summary of the results is provided in Table 8.2.

In the direct examination of the system by experts approach, once the SSDSS was implemented, two donors and three non-donors were asked to directly examine the KBS for: (1) knowledge comprehensiveness, (2) knowledge accuracy, and (3) reasoning validation. The structure questionnaire for validation is presented in Appendix 6.

The results in Table 8.2 show that both the donor experts and the non-donor experts rated the system highly on three aspects (the scores were 4.0 or higher on a 5-point scale). Five hypothetically worked examples were used. Each scenario is evaluated by the two donor experts, three non-donors experts and the SSDSS. A comparison between the SSDSS and the experts can be seen in the following:

1. The final recommendation, and

2. The reasoning process used to make a decision, specifically: (a) the attributes and rules, and (b) the inferring process.

System vs. donor experts. The donor experts and the SSDSS reached identical decisions (approve/re-evaluate/reject) for the test scenarios. There was a high degree of one-to-one match between the system and the donors in the use of parameters and rates, as well as the inference sequence. These results suggest that the SSDSS has a high "internal" validity, i.e. the system has not only acquired the knowledge effectively but was also able to use the knowledge/expertise in selecting subcontractors.

Table 8.2 Performance Validation Results

Validation Test	Validation Measures	Validation Result	
		Donor DE	Non-donor DE
Direct examination of system by experts	1. Comprehensiveness of knowledge base (4 items shown in Appendix 6) 2. Accuracy of knowledge base (3 items shown in Appendix 6) 3. Reasoning validity (3 items shown in Appendix 6)	4.8 4.4 4.4	4.0 4.2 4.2
Comparison of system with experts (Turing test)	1. Matched system decisions with experts' decisions 2. Compared the inference process	All scenarios matched Good matches on attributes used and sequence of evaluation.	All scenarios matched Good matches on attributes used and sequence of evaluation.

System vs. non-donors experts. The decision-making process of the system was compared with that of the non-donor experts (obtained from their verbal protocols). Most of the non-donor experts also reached an identical decision with the SSDSS.

These results suggest that the SSDSS performed quite well when compared with the domain experts used in the system development. It also found that the system and a non-donor expert made a different decision because they used different weight values for certain attributes. However, the inference process used by the experts and the SSDSS was quite similar (i.e. used the same evaluation attributes and evaluation sequence) even though the decision was different. This was reflected in the high scores for the reasoning validity of the SSDSS and the non-donor experts whose decisions did not match with the system (see Table 8.2). Thus the system has an "external" validity, i.e. the system matches the performance of domain experts whose knowledge had not been used in its design and development.

8.4.2 Assessment of System Utility

The problem of the chosen domain in the SSDSS relates to the selection of a subcontractor for BR work. This is management's significant problem because the main contractors' firms are dependent on engaging the potentially right subcontractor to ensure the success of the project. The selection task is unstructured and fraught with a high degree of risk.

Both the donor and non-donor domain experts who were involved with the performance validation were asked to assess the three aspects of the system utility: (1) the importance of the utility in screening potential subcontractors, and (2) the system benefits. The domain experts were also asked to rate the SSDSS on the user interface aspect. The detail questionnaire for validation is presented in Appendix 6.

The evaluation results provided by the domain experts are shown in Table 8.3. This suggests that the SSDSS has high system utility. Both the donor and non-donor experts strongly felt that: (1) the SSDSS offers a structured, well-organized approach to select potential subcontractors; (2) the user's interface of the SSDSS has been well designed and facilitated with an easy consultation process; and (3) the SSDSS provides a systematic framework to assist the main contractor in selecting a subcontractor.

Table 8.3 Results of System Utility Assessment

Validation Test	Validation Measures	Validation Result	
		Donor DE	Non-donor DE
Utility of the SSDSS	1. System organization	4.5	4.4
	2. User Interface design	4.8	4.6
	3. Benefits of the system:		
	- Preservation of the expertise	4.4	4.2
	- Training tool	4.5	4.6
	- Ability to store and retrieve information	4.6	4.8
	- Ability to modify criteria weights and values	4.5	4.2

Based on these results, it can be concluded that adequate care has been paid to the key issues that affect the system utility of the SSDSS.

Chapter 9
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

9.1 Summary

The growth in building refurbishment (BR) works and related activities is creating new and interesting financial questions. The management domain of refurbishment, however, remains one of the least understood sectors in Architecture-Engineering-Construction (AEC) practices.

BR projects differ from new-build projects. The former are perceived to be more difficult to manage than new-build projects. Estimating and tendering for refurbishment projects carry higher risks in the face of such uncertainties. In the management of BR projects, the level of management during construction, and the need for effective communication among the project team members (including clients and tenants) is far greater than for a new-build project. Good communication skills are vitally important between the main contractor and subcontractor. Subcontractors perform vital roles in these projects; time and cost over-runs, and contractual disputes are common in these projects. Currently, however, there is a lack of knowledge relating to the selection of subcontractors for BR projects. Typically, the task is performed in an unstructured, intuitive manner with considerable reliance on experience or judgment, and the quotation price seems to be the only consideration.

These gaps justify the need for improving the existing selection procedure. There is a need to develop alternative approaches to improving the effectiveness of decision techniques. This research provides a formalized and structured approach to the selection of subcontractors for building refurbishment projects. To extend the development of decision support system application, this study introduces a computer aided decision support system for assessing a potential subcontractor. This research develops and tests a selection model, encompassing the following stages:

1. Knowledge acquisition to identify the selection criteria and classify significant factors affecting the selection of BR subcontractors.
2. Computer aided decision support system development to implement the criteria, which consists of formulization of knowledge.
3. Hypothetical project to explore the model application.
4. Validation of the model to test the robustness of the model.

9.1.1 Knowledge Acquisition

The knowledge of subcontractor selection for BR work was captured mainly through a comprehensive literature review, interview of DEs (see Chapter 6), and a structured questionnaire survey of BR practitioners (see Chapter 7). The literature review identified the criteria necessary for consideration during subcontractor selection for BR works. It also identified subcontractor attributes worthy of investigation when evaluating the potential of the subcontractor firms. Furthermore, the literature review recognized the knowledge gaps on subcontractor selection for BR works (see Chapters 2 and 3).

The foundation of the hierarchical factors started from a comprehensive review of the relevant literature (see Chapter 5). It showed that the decision to select a subcontractor for BR works is usually made based on the three dimensions of project specifications, subcontractor's profiles and special considerations.

The theoretical background fostered an understanding of the logical relationships among the criteria. The logical background knowledge of criteria mapping was constructed through a logical relationships diagram of the factors, and a logical causal model. This approach was used to explain the background knowledge for the relationships between the main contractor, subcontractor and project characteristics to arrive at a decision. The logical causal approach was used to explain logical relationships of the driving factors affecting the decision maker's achievement of objectives. The importance of the causal model was to understand the organization and its interaction with its environment.

Based on the logical relationships, the 3 factors could be elaborated into 9 criteria and 39 attributes as follows:

1. Project Specifications
    1.1. Price specifications (4 attributes)
    1.2. Time specifications (3 attributes)
    1.3. Quality of technical proposal (5 attributes)
2. Subcontractor profiles
    2.1. Organization characteristics (3 attributes)
    2.2. Personnel qualifications (2 attributes)
    2.3. Financial Performance (3 attributes)
    2.4. Relevant experience (2 attributes)
    2.5. Past performance (13 attributes)
3. Special considerations
    3.1. Qualitative aspects (4 attributes)

In order to check for the admissibility and the level of importance of these factors, criteria and attributes, a national survey was undertaken. Based on the weightings of 39 attributes, the overall top 5 rankings were:

1. Number of references
2. High quality workmanship
3. Responsiveness
4. Safety history
5. Competitive price

In summary, the survey revealed that the subcontractor characteristics, especially past performance related criteria were ranked the highest. This finding does not seem to support the current tender practice that relies on the lowest bid.

9.1.2 Development of Computer Aided Decision Support System

Decision support systems (DSS) are computer-based systems used to assist and aid decision makers in their decision making processes. The computer aided decision support system has several characteristics that may lend assistance to improving subcontractor selection decisions. The development process promotes a better understanding of both the domain's structure and the relevant expertise. This can be particularly beneficial in non-formal, semi-structured managerial domains such as BR works which are characterized by complexity and multiple expertises. Thus, through the development of the KBS, which is called the "subcontractor selection decision support system" (SSDSS), a main contractor can gain a better understanding of the subcontractor selection decision-making process, thereby ensuring that subcontractor selection is carried out in a more systematic and objective fashion. This, however, also revealed that the model is expected to perform as a tool to the decision-makers and not to replace them.

The literature review on knowledge-based systems (KBS) showed that the KBS can be used to document expertise, thereby making this knowledge transferable to non-experts more effectively. The KBS could provide means of consolidating inputs from the multiple DEs, to help minimize human imperfection and bias.

The knowledge of the subcontractor selection process was elicited through interviews with the domain experts. The transcripts of interviews were analyzed and transferred into knowledge rules. The logical evaluation approach of the model is to match the main contractor's objectives with the subcontractor's attributes. The evaluation model adopts both the quantitative and qualitative approaches, considering multiple attributes of subcontractors, and qualitatively rating them against the main contractor's objectives. As pointed out in the earlier chapters, a suitable solution for a qualitative problem was to utilize the basic principle of rule based reasoning (RBR) approach, and the multi-criteria decision making technique (MCDM) for quantitative problems.

The numerical outputs of the evaluation are representative of the performance of the subcontractors for BR works. In addition, the analysis suggests that the higher the criterion scores, the better the attributes would be and the greater would be the performance of the subcontractor. In order to achieve the numerical outputs, the SSDSS processed all values in 10 essential steps:

1. Identify selection criteria
2. Identify control and input type of each attribute
3. Maintain rule base or knowledge base
4. Determine weighting criteria
5. Gather the project data and general information
6. Gather data from subcontractors
7. Collect data from third party references
8. Apply data collected to project requirements
9. Rate and score the result from (8)
10. Establish a final ranking.

In the SSDSS, the first 4 steps relate to the development environment and the rest are related to consultation environment. The development environment can be skipped when the new BR project is comparable to previous BR project. The SSDSS developed combines the knowledge-based and data-based systems, and has the capability to keep the information. Hence, the more projects that are captured in the system the more robust would be the model.

9.1.3 Application and Validation of the SSDSS

In order to apply the model, a hypothetical but realistic project and subcontractors were assessed using the SSDSS (see Chapter 8). The application of the model showed the comprehensive outputs that were facilitated through investigating the subcontractors' attributes. The exercise demonstrated that the lowest price may not necessarily be the dominant criteria. Instead, the highest scores are achieved by the potential subcontractor who has many references and a good past performance record.

Application and validation of the SSDSS has been done through evaluation and selection of hypothetical potential subcontractors. The system demonstrated that the IDSS approach can be successful in the decision-making process for BR works. The validation has also included the criteria for effective CADSS (see Chapter 2). The model developed in this research provides for a consistent evaluation and selection of potential subcontractors and allows for transferability among groups in the organization as well as training of professionals to manage the tender process. The validation results of the system show promise in supporting effective decision-making (see Chapter 8).

9.2 Limitations of Research

In the data gathering process, it was difficult to determine the target population of BR contractors. As there is no formal list of BR contractors in Singapore, the data was gathered from personal contacts and building owners such as NUS' Office Estate and Development (OED), Singapore Polytechnic, Ministry of Education, quantity surveying companies, etc. These data are cross-checked with the "BCA Directory of Registered Contractors" and the "Directory of Contractors" published by the Singapore Contactors' Association Limited (SCAL). This approach may inadvertently exclude some main contractors who have had experience in BR projects.

The KBS was developed based on the knowledge captured through interviews with the domain experts (DEs). However, meeting with qualified DEs was a difficult task. Prerau (1990) suggested that the quality of DEs might be considered through their educational level, work experience, communication skills, cooperation, availability, computer background, and willingness to cooperate in the KBS development process. Although DEs may meet these requirements, they may have difficulties in articulating their experience.

The factors, criteria and attributes of the model were rated based on the respondents' perceptions. The weights derived from respondents' perceptions may not be totally reliable because different respondents may attach different values to different points of scales.

Performance and system utility of the model has been validated; however it was limited in finding a correct selection. More rigorous methods are difficult to implement in construction. The boundaries of the SSDSS, which indicate conditions of the system may give incorrect answers, were untested.

9.3 Conclusions

With rapid development of the construction industry, BR works would play an increasingly important role in the industry. It is a well known fact that BR projects are perceived to be more difficult to manage and with higher risks and uncertainties than new-build projects. Estimating and tendering for BR projects carry a higher risk in the face of such uncertainties. Such projects are more labor intensive than new-build projects, and they typically involve several trade subcontractors from start to finish. It has also been found that although BR work is presently recognized as a distinct sector in Singapore construction industry, hardly any information concerning the selection process of subcontractors for BR works in Singapore.

This present research identifies the main factors, criteria and attributes that need to be considered in selecting BR subcontractors. It would appear that in most of the previous studies, the criteria for subcontractor selection relied heavily on the price factor. However, this present research found that there is a combination of criteria, apart from price, which main contractors should consider when selecting subcontractors for BR projects. This present research found that apart from the price factor, the respondents also desired to involve many qualitative and quantitative factors in their decision-making process.

This present research found that the price factor was one of the 5 most important factors. The price factor, which was ranked highly, is in line with conventional tender practices where the lowest bid is the most dominant criteria. However, the intention to consider more qualitative and quantitative factors would undermine such conventional practices. The number of factors involved in decision-making meant that a proper tool was needed, but no such model existed thus far. Hence, an innovative method was needed to accommodate the motivation and the recent shift from price as a single criterion (low bid procurement) to multiple performance criteria or performance-based systems. This present research developed a decision support approach for selecting BR subcontractors.

This present study provided appropriate variables that should be considered by the main contractor when selecting subcontractors. The use of rankings and weightings would assist the main contractors in evaluating the existing selection methods concerning the criteria employed and the level of importance attached to them.

This present study constructed a hierarchy of factors, criteria and attributes and highlighted the important factors for selecting subcontractors in BR works. However, the study was not intended to identify the most popular subcontractor selection factors. The study worked on the premise that there was a better combination of selection criterion, apart from price, that main contractors should always consider for selecting subcontractors for BR projects. When these criteria and their level of importance were identified and determined carefully, the development of an innovative model for subcontractor selection can be facilitated.

Based on the test of the hypotheses, one sub-hypothesis (attribute) "H2.2.1: Main contractors select subcontractors for BR projects based on their related certificates" was rejected as it was considered to be an unimportant attribute. Therefore this attribute (certificates) was excluded from the system. The rest (39 attributes) were accepted. It can be concluded that the general hypothesis "*There is a combination of criteria, apart from price, which main contractors should consider when selecting subcontractors for BR projects"* was accepted.

According to the statistical test, three specific hypotheses:
"H1. Main contractors select subcontractors for BR projects based on the project specification; H2. Main contractors select subcontractors for BR projects based on the subcontractor's profile; H3. Main contractors select subcontractors for BR projects based on their special considerations", may be supported. The findings were consistent with experts' views that some of the decisions could be based on subjective (qualitative) rather than objective criteria such as low price; and data on subcontractors' profiles are essential for performing an evaluation.

The construction of the hierarchy, aggregating the scores, and ranking of the factors was embedded in the computer model. The significance of the model is that an integrated qualitative and quantitative analysis can be facilitated in one system. This can help the main contractor to make rational decisions for selecting subcontractors for BR projects.

9.4 Contribution to knowledge

There were knowledge gaps in the evaluation methodologies for selecting subcontractors for BR projects. The literature revealed some gaps in the BR work area, an area which remains one of the least understood sectors in the Architecture-Engineering-Construction (AEC) industry. In Singapore, although BR works were recognized as a distinct sector of the construction industry, hardly any publications relating to this field existed.

This research could answer various aspects of the knowledge gaps through synthesizing empirical works that have not been done before. This present research contributed towards enhancing the practice of subcontractor selection in BR works.

This research adds to previous work on the selection of BR subcontractors, especially on a theoretical framework of the factors affecting the selection of subcontractors. This research also yielded a computer model which extended the conventional method of subcontractor selection. Although the present survey was conducted in Singapore, the literature review suggested a general comparison that can be investigated elsewhere.

The research was multi-disciplinary in nature and used different methodologies adapted from earlier studies. Specifically, this research aimed:

1. To develop a formalized and structured approach to the selection of subcontractors for building refurbishment projects.
2. To enhance the main contractor's understanding of the key criteria, and the interrelationships, affecting its selection and appointment decision process.
3. To provide a computer aided decision support system that would facilitate an integrated qualitative and quantitative analysis to help the main contractor in making optimum decisions for selecting subcontractors for BR projects.

4. To initiate a computer tool in a knowledge-based system, hence the main contractors do not necessarily need in-depth experience for subcontractor selection.

9.5 Recommendations for Future Work

The research has raised several important questions, which indicate possible direction in which future work in this area could be pursued.

The process of subcontractor selection needs to be standardized. This research did not differentiate the work type of subcontractors. In fact, the subcontractors exist because of their specializations. Future studies can be done on whether there is a significant difference when subcontractors are evaluated according to their different specializations.

In practice, rating the subcontractor attributes is based primarily on the judgments of the respondents. Hence, a complexity measure for these attributes should be developed. This measure can be applied to a BR project to provide the decision makers with a formalized technique for evaluating the difficulties associated with the BR project.

Additional research on the development of the knowledge base for subcontractor selection should be conducted. More validation of the model may include testing the boundaries of the model, which case can not be solved. By increasing the depth and width of knowledge contained within the knowledge base, a comprehensive decision tool can be developed further.

LIST OF REFERENCES:

Abdeen, T.H. (2002) Company Performance: Does Quality of Work Life Really Matter? *Management Research News*. 25, pp. 8-11.

Abidali, A.F. and Harris, F. (1995). A methodology for predicting company Failure in the construction industry. *Construction Management and Economics,* 13(2), pp. 189-196.

AIA. (1986). *The Building Systems Integration Handbook*. Richard D.R., (editor). The American Institutes of Architects. Boston: Butterworth Architecture.

Aikivouri, A. (1996). Periods of demand for private sector housing refurbishment, *Construction management and Economics*, 14(1), pp. 3-12.

Akintoye, A. (2000). Analysis of factors influencing project cost estimating practice, *Construction Management and Economics*, 18(1), pp. 77-89

Akintoye, A. and Black, C. (1999). *Operational risk associated with partnering for construction*. *Profitable partnering for construction*. New York: E&FN Spon, pp. 25-38.

Akkerman, A. (1989). Criteria and Individual Assessment. Smith, M. and Robertson, I., eds. *Advance in selection*. Chichester: John Wiley.

Altink, W.M.M, Visser, C.F., and Castelijns, M. (1997), Criterion Development: The unknown power of criteria as communication tools. *International Handbook of Selection and Assessment*, Edited by Anderson, N. and Herriot, P. USA: John Wiley & Sons Ltd., pp.287-301.

Andrews, D., L. (2000). How to work with subcontractor and still make money, Andrews Consulting, Inc. (online), Available: http://www.andrewsconsulting-inc.com, (10 March 2003).

Ang, H., S. and Tang, W., H. (1984). *Probability concepts in engineering planning and design,* New York: John Wiley.

Anthony, R., N. (1965). *Planning and Control Systems: A framework for analysis.* Cambridge: Harvard University.

Anumba, C., J. and Ruikar, K. (2002a). Electronic commerce in construction—trends and prospects (Review).*Automation in Construction.* 11, pp. 265– 275.

Anumba, C., J., Ugwu, O., O., Newnham, L., and Thorpe, A. (2002b). Collaborative design of structures using intelligent agents. *Automation in Construction.* 11(2), pp. 89–103.

Aqua Group (1999a). Management and Management Construction Contracts, *Tenders and contracts for building*, Malden: Blackwell Science, pp. 105-116.

Aqua Group (1999b). Early selection: Two-step tender, *Tenders and contracts for building*, Malden: Blackwell Science, pp. 33-44.

Aqua Group (2003). *Pre-contract practice and Contract administration for the building team*, Oxford: Blackwell Science.

Arens, Y., Chee, C., Hsu, C., Knoblock, C. (1993). Retrieving and Integrating Data from Multiple Information Sources. *International Journal of Intelligent and Cooperative Information Systems*, 2(2), pp. 127-158.

Aronoff, S. and Kaplan, A. (1995). *Total workplace performance*. Ottawa Canada: WDL Publications.

Arvin, S., A., and House, D., H. (2002). Modeling architectural design objectives in physically based space planning. *Automation in Construction.* 11(2), pp. 213–225.

Ashworth, A., (1996). *Assessing the life expectancies of buildings and their components in life cycle costing*. Nene College of Higher Education. *COBRA* 1996.

Asiedu, Y. and Gu, P. (1998). Product Life Cycle Cost Analysis: State of the Art Review. *International Journal of Production Research.* 36.

Atkinson, D. (1999). Legal Subcontractor. Surveyor Plus (online). Available: http://www.surveyorsplus.co.uk/surveyorsplus//legal/subcont.asp (16 May 2003).

Augenbroe, G. (1994). An Overview of the COMBINE project. Faculty of Civil Engineering, TU Delft, The Netherlands (online). Available: http://erg.ucd.ie/combine/what_about.html (3 May 2002)

Axelrod, J.L. (2000). *Plans for Adding on and Remodeling*, New York: McGraw Hill.

Badrah, M., MacLeod, A., and Kumar, B. (2000). Design Processing of Regular and Nonstandard Structural Components. *Journal of Computing in Civil Engineering.* 14(4), pp. 223-232.

Balaras, C., A., Drousta, K., Argirious, A., A., and Wittchen, K. (2002). Assessment of Energy and Natural Resources Conservation in Office Building Using TOBUS. *Energy and Building.* 34, pp. 135-153

Balasubramanian, P., Nochur, K., Henderson, J., C., and Kwan, MM. (1999). Managing Process Knowledge for Decision Support. *Decision Support System.* 27 (2), pp. 145-162.

Bar-On, D., and Oxman, R., E. (2002). Context over content: ICPD, A Conceptual Schema for the Building Technology Domain. *Automation in Construction.* 11(4), pp. 467– 493.

Barthorpe, S., Duncan, R. and Miller, C. (1999). A literature review on studies in culture – a pluralistic concept. *Profitable Partnering in Construction Procurement*. Edited by Ogunlana, (ed.), London: S. E&FN Spon, pp. 533-542.

Bartlett, ED and Howard, N. (2000). Informing the decision makers on the cost and value of green building. *Building Research and Information.* 28(5/6), pp. 315–324.

BCA. (2001). *Survey of the Construction Industry 2000,* Singapore: Building and Construction Authority of Singapore.

BCA. (2002). Construction Economics Report. *Building and Construction Authority of Singapore* (Online). Available: http://www.bca.gov.sg (10 April 2002)

BCA. (2003). Directory of Registered Contractors, *Building and Construction Authority of Singapore* (Online), Available: http://www.bca.gov.sg (10 September 2003)

Bejder, E.Z.E., and Kaklauska, A. (1998). Raising the efficiency of the building lifetime with emphasis on maintenance. *Facilities.* 16 (11), pp. 334-340.

Belton, V., and Gear, T. (1983). *On a Shot-coming of Saaty's Method of Analitical Hierarchies*. Omega, pp. 228-230.

Bermudez, J., and King, K. (2000). Media interaction and design process: establishing a knowledge base, *Automation in Construction*, 9, pp. 37-56.

Beston, D. (1983). *Statistical Method, For Building Price Data.* London: E. & F.N. Spon.

Beynon, M., Rasmequen, S., and Russ, S. (2002). A new paradigm for computer-based decision support. *Decision Support Systems.* 33. pp. 127– 142.

Bidgoli, H. (1998). *Intelligent Management Support System.* London: Quorum Book.

Bluyssen, P.M. (2000). EPIQR and IEQ: indoor environment quality in European apartment buildings. *Energy and Building.* 31, pp. 103-110.

Bock, P. (2001). *Getting it right: R&D methods for science and engineering.* London: Academic Press.

Bolloju, N., Khalifa, M., Turban, E. (2002). Integrating knowledge management into enterprise environments for the next generation decision support. *Decision Support Systems.* 33, pp.163– 176.

Bonini, C.P., Hausman, W.H. and Bierman, Harold Jr. (1999). *Quantitative Analysis for Management.* London: IRWIN.

Boose, J.H. (1986). *Expertise transfer for system design.* New York: Elsevier.

Borcherding, K., Eppel, K., and von Winterfeldt, D. (1991). Comparison of weighting judgments in multi-attribute utility measurement. *Management Science.* 37(12), pp. 1603-1619.

Bordass, B. (2000). Cost and value: fact and fiction. *Building Research & Information.* 28(5/6), pp. 338–352.

Bordley, R., and LiCalzi, M. (2000). Decision analysis using targets instead of utility functions. *Decisions in Economics and Finance.* DEF 23, pp. 53 – 74.

Borkowski, A., Branki, C., Grabska, E., and Palacz, W. (2001). Towards collaborative creative design. *Automation in Construction.* 10, pp. 607–616.

Brandon, P.S., and Ribeiro, F.L. (1998). A knowledge-based system for assessing applications for house renovation grants. *Construction Management and Economics.* 16, pp. 57-69.

Broek, J.J., Horva´th, I., Smit, D., Lennings, A.F., Rusa´k, Z., and Vergeest, J.S.M. (2002). Free-form thick layer object manufacturing technology for large-sized physical models. *Automation in Construction.* 11, pp. 335– 347.

Brook, M. (2001). *Estimating and tendering for construction work.* London: Butterworth Heinemann.

Brown, J.D. (2003). What Issues Affect Likert-scale Questionnaire Format? In Statistic Corner (online), Available: http://www.jalt.org/test/bro_7.htm (14 September 2003).

Bubshait, A.A., and Al-Gobali, K.H. (1996). Contractor Prequalification in Saudi Arabia. *Journal of Project Management*, 12(2), pp.50-54.

Buede, D.M., and Maxwell, D.T. (1995). Rank Disagreement: a comparison of multi-criteria methodologies. *Journal of Multi-Criteria Decision Making*, 4(1), pp. 1-21.

Buehlmann, U., Ragsdale, CT., and Gfeller, B. (2000). A spreadsheet-based decision support system for wood panel manufacturing. *Decision Support Systems* 29, pp. 207–227.

Burnett, J., and Chan, Daniel WT. (2001). Performance indicators for indoor environmental quality in air-conditioned office buildings. *Proceeding CIB World Building Congress.* April 2001, Wellington, New Zealand.

Burry, M. (2002). Rapid prototyping, CAD/CAM and human factors. *Automation in Construction.* 11, pp. 313– 333.

Burstein, F. (2001). Decision support in the new millennium. *Decision Support Systems.* 31, pp. 163–164.

Caccavelli, D. and Jean-Louis, G. (2000), Diagnosis of the degradation state of building and cost evaluation of induced refurbishment works. *Energy and Buildings.* 31, pp. 159–165.

Caldas, L.G., and Norford, L.K. (2002). A design optimization tool based on a genetic algorithm. *Automation in Construction.* 11, pp. 173–184.

Calvert, R.E., Bailey, G., and Coles, D. (1995). *Introduction to Building Management*, 6th edition. London: News.

Carlsson, C., and Turban, E. (2002). Introduction DSS: directions for the next decade. *Decision Support Systems*. 33 (2002), pp. 105–110.

Carneiro, A. (2001). A group decision support system for strategic alternatives selection. *Management Decision.* 39(3), pp. 218-226.

Castillo, E., and Alvarez, E. (1991). *Expert systems: uncertainty and learning*. *Computational Mechanics publications.* London: Elsevier Applied Science.

CCMS (2003). The Likert Scale. In Communication Culture and Media Studies (online). Available: http://www.cultsock.ndirect.co.uk/ (22 September 2003).

Chan, D.W. and Kumaraswamy, M.M. (1995). A study of the factors affecting construction duration in Hong Kong. *Construction Management and Economics*, 13(4), pp.319-333.

Chan, D.W. and Kumaraswamy, M.M. (1997). A comparative study of causes of time overruns in Hong Kong construction projects. *International Journal of Project Management.* 15(1), pp. 55-63.

Chan, D.W. and Kumaraswamy, M.M. (1999). Modeling and predicting construction durations in Hong Kong public housing. *Construction Management and Economics*, 17(4), pp. 351-362.

Chang, L. (1991). A methodology for measuring construction productivity. *Cost Engineering*. 3(10), pp. 19-25.

Chase, SC. (2002). A model for user interaction in grammar-based design systems. *Automation in Construction.* 11, pp. 161–172.

Chastain, T., Kalay, Y.E., and Peri, C. (2002). Square peg in a round hole or horseless carriage? Reflections on the use of computing in architecture. *Automation in Construction.* 11(2), pp. 237–248.

Chen, S.J., and Wang, C.L. (1991). Fuzzy Multiple Attribute Decision Making: Methods and Applications, *Lecture Notes in Economics and Mathematical Systems*, No. 375, Springer –Berlin, Germany: Verlag, pp. 531-538.

Cheng, M.Y., Kob, C.H., and Chang, C.H. (2002). Computer-aided DSS for safety monitoring of geo-technical construction. *Automation in Construction.* 11, pp. 375–390.

Chicken, J.C. (1994). *Management Risks and Decisions in Major Projects.* London: Chapman Hall.

Chien, C. C., and Ho, C. C. (1994). A primitive-based generic approach to knowledge acquisition. *Knowledge Acquisition.* 6, pp. 215-242.

CIB. (1997). *Code of practice for the selection of subcontractor*. Construction Industry Board. London: Thomas Telford.

CIB. (1998). *Constructors' key guide to PFI*. Construction Industry Board. London: Thomas Telford.

CIRIA. (1994). A guide to the management of building refurbishment. *CIRIA Report 133. Construction Industry Research and Information Association.* London.

Clark, B. (2002). Measuring Performance: The Marketing Perspective. *Business Performance Measurement.* Cambridge, University Press, pp. 22-40.

Clark, B. (2002). Measuring Performance: The Marketing Perspective. *Business Performance Measurement*. Neely, A., ed. Cambridge, University Press. UK. pp. 22-40.

Cole, R.J., and Sterner, E. (2000). Reconciling theory and practice of life cycle cost. *Building Research and Information,* 28(5/6), pp. 368-375.

Cook, R.L. (1997). Case-based reasoning systems in purchasing: application and development. *International Journal of Purchasing and Material Management.* 34, pp. 32-39.

Couzens; T. and Skitmore, H. (1993). Executive Information System for Construction Contract Building Design. Mathur. K. et al. eds. *Management of Information Technology for Construction*. Singapore: World Scientific Publishing.

Cox, A., and Townsend, M. (1998). *Strategic Procurement in Construction.* London: Thomas Telford.

Coyne, R., Lee, J., Duncan, D., and Ofluoglu, S. (2001). Applying web-based product libraries. *Automation in Construction.* 10, pp. 549–559.

Crowe, T.J., Nuno, J.P., and Padillo, J.M. (1999). A Decision support system for evaluating and selecting projects incorporating strategic business objectives. *Advance Manufacturing System: strategic management and implementation.* Sarkis, J., and Parsei (edt.), London: Gordon and Breach Sciences Publish.

CSTB: France Computer Science Telecommunications Board. (2003). History of INVESTIMMO, (online), Available: http://investimmo.cstb.fr/english/epiqr.asp (25 March 2003).

Davies, H. (1998). Repair methods for tile clad buildings in Hong Kong, *Structural Survey*, 16(1), pp. 34–38.

Davies, M., and Hakiel, S. (1988). Knowledge harvesting: A practical guide to interviewing, *Expert Systems,* 5(1), pp. 42-50.

De Vaus, D. (2002). *Analyzing Social Science Data, 50 Key Problems in Data Analysis*. London: Sage Publication.

Dijkstra, J., and Timmermans, H. (2002). Towards a multi-agent model for visualizing simulated user behavior to support the assessment of design performance. *Automation in Construction.* 11, pp. 135–145.

Dormaz, D.N. and Khoshnevis, B. (1997) Process planning knowledge representation an object-oriented data model. *International Journal Computer Integration and Manufacture.* 10, pp. 92–104.

Dormaz, DN, and Khoshnevis, B. (1997). Process planning knowledge representation an object-oriented data model. *International Journal Computer Integration Manufacture*, 10(1–4), pp. 92–104.

Doubler, D., and Burt, D.N. (1996). *Purchasing and Supply Management, Text and Cases*. USA: The McGraw Hill Companies, Inc.

Douglas, J. (2002). *Building Adaptation.* Oxford: Butterworth.

Druker, J., and White, G. (1996). *Managing People in Construction*, London: Institute of Personnel and Development.

Drummond, H. (1996). *Effective Decision Making.* 2nd edition, London: Kogan Page.

Dulung, A.Z., and Gan, C.E., (2000) Manpower Information System for Repair Jobs. D.S.S. Then, ed. *Facilities Management and Maintenance, International Symposium of the CIB-W70: proceedings*, (Brisbane-Australia- November 2000) 597 - 607.

Dulung, AZ. (1991). Study of The Project Tendering in Indonesian Building Construction. *MSc Thesis (unpublished) University of New South Wales – Australia*.

Dulung, A.Z., and Gan C.E. (2002). Resurgence of Life Cycle Costing. *The Professional Builder.* 13(1), pp. 6-9.

Dulung, A.Z. (2003). Manpower Information System for Building Construction. *MSc. Thesis (unpublished) National University of Singapore*.

Dulung, A.Z., and Gan, C.E. (2003). Costing For Coldroom, Life Cycle Costing of High Technology Building, *Research Report (unpublished), School of Design and Environment, National University of Singapore*.

Dulung, A.Z., and Low, S.P. (2004) A multi-criteria decision making technique for selecting building refurbishment subcontractors. *Proceeding: 4th International Conference on Construction Project Management "Remaking Construction in the Knowledge-Based Economy" 4-5 March 2004 Singapore,* pp. 301-310

Dulung, A.Z., and Low, S.P. (2005) Factors influencing selection of subcontractors in refurbishment works, *Architectural* Science *Review,* 48 (1), pp. 93-104.

Durkin, J. (1994). *Expert systems: design and development*, New York: Maxwell Macmillan International.

Dzever, S., Merdji, M., and Saives, A.L. (2001). Purchase decision-making and buyer-seller relationship development in the French food processing industry. *Supply Chain Management: An International Journal,* 6 (5), pp. 216-229.

Edwards, D.J., Holt, G.D., and Harris, F. (1999). Predicting maintenance expenditure on construction plant: model development and performance analysis. *Journal of Financial Management of Property and Construction,* 4, pp. 31-45, Edwards, D.J., Holt, G.D., Harris, F.C. (2000). Estimating life cycle plant maintenance costs. *Construction Management and Economics.* 18(4), pp. 427 – 435.

Egbu, C.O. (1994). Management Education and Training for Refurbishment Work Within the Construction Industry. *PhD Thesis, Department of Civil Engineering and Construction,* Salford University – UK.

Egbu, C.O. (1997). Refurbishment management: challenges and opportunities. *Building Research and Information.* 25(6), pp. 338-348.

Egbu, C.O. (1999a). Skills, knowledge and competencies for managing construction refurbishment works. *Construction Management and Economics.* 17(1), pp. 29- 43.

Egbu, C.O., Young, B.A. (1999b). Innovation management for refurbishment: Managing innovation for refurbishment. *Facilities Management and Maintenance, the way ahead into the millennium.* Edited by Quah, L.K, CIB – W 70, Singapore: McGraw-Hill Book Co, pp. 255-262.

Egbu, C.O., Young, B.A., and Torrance, V.B. (1998). Planning and control processes and techniques for refurbishment management. *Construction Management and Economics.* 16 (3), pp. 315-325.

Eksrom, M.A., Bjornsson, H.C., and Nass, C.I. (2003). Accounting for rater credibility when evaluating AEC subcontractors, *Construction Management and Economics,* 21, pp. 197-208.

Elkington, P., and Smallman (2002). Managing Project Risks: a case study for the utility sector, *International Journal of Project Management*, 20, pp. 49-57.

Elliot, T. (2001). Enterprise Analytical Application: A guide to the latest development, (online), Available: http://dssresources.com/paper (10 May 2002).

Emblemsvag, J. (2001). Activity-based life cycle costing. *Managerial Auditing Journal.* 16(1), pp. 17-27.

Emblemsvag, J., and Tonning, L. (2003). Decision Support in Selecting maintenance organization. *Journal of Quality in Maintenance Engineering*. 9(1), pp. 11-24.

Enting, J., Huirne, R.B.M., Dijkhuizen, AA., and Tielen, MJM. (1999). A knowledge documentation methodology for knowledge-based system development: an example in animal health management. *Computers and Electronics in Agriculture.* 22, pp. 117–129.

Erridge, A. (1995). *Managing Purchasing: Sourcing and Contracting.* Great Britain: The Chartered Institute of Purchasing and Supply.

Evangelidis, K. (1992). Performance measured is performance gained. *The Treasurer, 2*, pp. 45-70.

Faraj, I. (2001). Verification and spatial clearance of features in a product-modeling environment, *Construction Innovation*, 1, pp. 55–74.

Fellow, R., Langford, D.A., Newcombe, R., and Urry, S. (1983). *Construction Management in Practice*, London: Longman.

Fellows, R., and Liu, A. (1997). *Research Methods for Construction,* Blackwell Science.

Fischer, G. (2000). Leap into future space, *Buildings, Cedar Rapids,* 94 (3), pp. 18-19.

Fitzgerald, S.P. (2002). *Decision Making*, Great Britain: Express Exec. Com.

Flourentzos, F., and Roulet, C.A. (2002). Elaboration of retrofit scenarios, *Energy and Building*, 34, pp. 185-192.

Flourentzos, F; Brandt, E., and Wetzel, C. (2000). MEDIC — a method for predicting residual service life and refurbishment investment budgets, *Energy and Buildings* 31, pp. 167–170.

Fong, P., and Choi, S. (2000). Final contractor selection using analytical hierarchy process, *Construction Management and Economics,* 18(5), pp. 547-557.

Frazer, L., and Lawley, M. (2000). *Questionnaire design and administration: a practical guide*, Brisbane: Willey.

Friedman, D., and Oppernheimer, N. (1997). *The Design of Renovations,* New York, London: W.W.Norton and Company.

Gen, M. and Jong, R.K. (1999). GA-based reliability Design: State of the art survey, *Computers and Industrial Engineering,* 37, pp. 151-155

Genre, JL; Flourentzos; and Stockli, T. (2000). Building Refurbishment: habitat upgrading, *Energy and Building,* 31, pp. 155-157.

Ghalayini, A.M. and Noble, J.S. (1996). The changing basis of performance measurement. *International Journal of Operations and Production Management*. 16(8), pp. 63-80.

Gilleard, J.D. and Lee, Y.C. (1999). Collaborative process for the refurbishment of shopping centers. *Automation in Construction,* 11(6), pp. 535-544.

Gonzalez, A.J., and Dankel, D., (1993). *The Engineering of Knowledge Based Systems, Theory and Practice*, New Jersey: Prentice Hall.

Gorry, G.A., and Scott, M., (1971). A Framework for Management Information Systems, *Sloan Management Review*, 13 (1). pp. 45-67.

Gould, F.E., and Joyce, N.E. (2003). *Construction Project Management*, 2nd ed. Upper Saddle River N.J: Prentice Hall.

Gray, C., and Flanagan, R. (1996). *The changing role of specialist and trade contractors*, A study commissioned and sponsored by the CIOB and CIB – UK.

Greenwood, D.J. (2001). *Power and Proximity: a study of subcontract formation in the UK building industry*, PhD Dissertation, Reading University – UK.

Greed, C. (1997), *Culture change in construction",* Proceedings of the 13th ARCOM Conference, Cambridge. pp. 11-21.

Griffis, F.H., and Farr, J.V. (2000). *Construction planning for engineers*, Boston: McGraw-Hill.

Grunberg, S.L. (1997). *Construction Economics, an introduction*, Hong Kong: Macmillan.

Guevarra, V., (2003). Review of '"Pay when Paid'" clause for Subcontractor, Move is to address non-payment by main contractor, *The Straits Times*, Available: http://straitstimes.asia1.com.sg. (12 June 2003).

Guida, G., and Tasso, C. (1994). *Design and Development of Knowledge-Based Systems. From Life Cycle to Methodology*. New York: Wiley Professional Computing.

Guion, R.M. (1997). Criterion Measures and the Criterion Dilemma, *International Handbook of Selection and Assessment*, Anderson, N. and Herriot, P. USA: John Wiley and Sons, Ltd., pp. 267-286.

Gustaffson, S.I. (2000a). Optimization of insulation measures on existing buildings. *Energy and Buildings*, 33, pp. 49-55.

Gustafsson, S.I. (2000b). Optimization and simulation of building energy systems, *Applied Thermal Engineering*, 20, pp. 1731-1741.

Gustaffson, S.I. (2001). Optimal fenestration retrofits by use of MILPS programming techniques, *Energy and Buildings,* 33, pp. 843-851.

Hamilton, A., Mitchell, G., and Yli-Karjanmaa, S. (2002). The BEQUEST toolkit: a decision support system for urban sustainability, *Building Research & Information,* 30(2), pp. 109–115.

Harris, F. and McCaffer, R. (2001). *Modern Construction Management*, 5th ed. Malden, MA: Blackwell Science.

Harrison, E.F. (1999). *The Managerial Decision-Making Process*, New York: Houghton Mifflin Company.

Hatush, Z., and Skitmore, M. (1997). Criteria for contractor selection, *Construction Management and Economics*, 15(1), pp. 19-38.

Hew, K.P., Awbi, H.B., and Fisher, N. (2000). A Knowledge Sharing Framework for Building and Services Design Using a Knowledge-based Electronic Prototype, *International Journal of Construction Information Technology*, 8(2) Winter 2000.

Hew, K.P., Fisher, N., and Awbi, Hasim, B. (2001). Towards an integrated set of design tools based on a common data format for building and services design, *Automation in Construction,* 10, pp. 459–476.

Highfield, D. (2000). *Refurbishment and Upgrading of buildings*, London: E& FN Spon.

Holm, M.G. (2000a). Service management in housing refurbishment: a theoretical approach, *Construction Management and Economics,* 18, pp. 525 – 533.

Holm, M.G. (2000b). Service quality and product quality in housing refurbishment, *International Journal of Quality and Reliability Management.* 17(4/5), pp. 527-540.

Holt, G.D. (1998). Which contractor selection methodology, *International Journal of Project Management*, 16(3), pp. 153-164.

Holt, G.D., Olomolaiye, P.O., and Harris, F.C. (1994a), Applying multi attribute analysis to Contractor Selection decision, *European Journal of Purchasing and Supply Management*, 1(3), pp. 139-148.

Holt, G.D., Olomolaiye, P.O., and Harris, F.C. (1994b). Factors influencing U.K. Construction Client's Choice of Contractors, *Building and Environment,* 29(2), pp. 241-248.

Hopkin, V.D. (1992). Verification and Validation: Concepts, Issues, and Applications. *Verification and Validation of Complex Systems: Human Factors Issues.* Wise. J.A., Hopkin, V.D., Stager, P., eds. NATO ASI Series. Series F: Computer and Systems Sciences, Berlin: Springer-Verlag, 10, pp. 3-34.

Howie, C.T., Law, K.H., and Kunz, J.C (2000). *A Model for Software Interoperation in Engineering Enterprise Integration*, CIFE Working Paper #61, August 2000, Stanford University.

Hughes, W., Gray, C., and Murdoch, J. (1997). Specialist trade contracting: a review, Special Publication 138, London: *Construction Industry Research and Information Association, Report 133*.

Humpreys, P., McIvor, R., and Chan, F. (2003). Integrating environmental criteria into the supplier selection process, *Journal of Material Processing Technology,* 138 (1-3), pp. 349-356.

IBM Corporation, (1995), *Intelligent Agent Strategy*, IBM Corporation, White Paper. Available: http://www.ibm.com, (3 May 2003).

Iselin, G.D. (1993). *The fourth dimension in building: strategies for minimizing obsolescence, Committee on facility design to minimize premature obsolescence*, Washington DC: National Academy Press,

Ismail, R., Torrance, V.B., and Young, B.A. (1999). Decision-making in the planning and control of refurbishment projects, Facilities management and maintenance: the way ahead into the millennium: *proceedings of the International Symposium on Management, Maintenance & Modernization of Building Facilities, 18th-20th November 1998, Singapore.* Quah, L.K. ed. Working Commission 70, International Council for Building Research Studies & Documentation, pp. 229-236.

Jackson, P. (1999). *Introduction to Expert System*, 3rd. Reading: Addison Wesley.

Jaggs, M., and Palmer, J. (2000). Energy performance indoor environmental quality retrofit - a European diagnosis and decision making method for building refurbishment. *Energy and Buildings,* 31, pp. 97 –101.

Janis, I., and Mann, L. (1977). *Decision making: A psychological analysis of conflict, choice, and commitment*. New York: The Free Press.

JDB (1997). *Industrial Engineering Projects*, The Joint Development Board, The Royal Institution of Chartered Surveyor. UK: E&FN Spon.

Jeangy, A. (2001). Combined parameter and tolerance design optimization with quality and cost, *NT. Journal Production Resources*, 39 (5), pp. 923–952.

Jennings, P., and Holt, G.D. (1998). Pre-qualification and multi-criteria selection: a measure of contractors' opinions. *Construction Management and Economics,* 16(6), pp. 651-660.

Jerke, N. (1999). *The Complete Reference, Visual Basic 6*. USA: McGraw-Hill.

Jessup, L.M. and Valacich, J.S. (1993). *Group Support Systems*. New York: McMillan.

Johnson, J.C., and Weller, S.C. (2002). Elicitation techniques for interviewing, *Handbook of Interview Research Context and Method*, Gubrium, J.F, and Holstein, J.A., eds, London: Sage Publications, pp. 491-514.

Johnstone, I.M. (2001). Periodic refurbishment and reduction in national expenditure, *Construction Management and Economics,* 19(2), pp. 97-108.

Kadefors, A. (2002). Problems of Trust Control in Client Contractor Relations. Procurement System and Technology Transfer. Lewis, T.M. (ed.) Proceedings of the International Symposium of the Working Commission CIB W92 (Procurement Systems), January 14-17, 2002, pp. 451-459.

Kagioglou, M., Cooper, R., and Aoud, G. (2001). Performance management in construction: a conceptual framework. *Construction Management and Economics.* 19, pp. 85-95.

Kalay, Y.E. (2001). Enhancing multi-disciplinary collaboration through semantically rich representation, *Automation in Construction,* 10, pp. 741–755.

Kaldi, M.R. (1995). *Knowledge based contingency analysis for steady state stability of power systems using a graphical user interface and data visualization assemble,* unpublished, PhD thesis, The Pennsylvania State University.

Kamara, J.M., Anumba, C.J., and Evbuomwan, N.F.O. (2000). Computer-based application for the processing of clients' requirements, *Journal of Computing in Civil Engineering,* 14(4), pp. 264-271.

Kang, B.S., and Park, S.C. (2000). Integrated machine learning approaches for complementing statistical process control procedures, *Decision Support Systems.* 29, pp. 59–72.

Kashiwagi, D. and Byfield, R.E. (2002a). Practice Papers: Selecting the best contractor to get performance: on time, on budget, meeting quality expectations. *Journal of Facilities Management*, 1(2), pp. 103-116.

Kashiwagi, D. and Byfield, R.E. (2002b). Testing of Minimization of Subjectivity in Best Value Procurement by Using Artificial Intelligence Systems in State of Utah Procurement. *Journal of Construction Engineering and Management*, 128(6), pp. 496-502.

Kavakli, M. (2001). NoDes: Knowledge-based modeling for detailed design process — from analysis to implementation, *Automation in Construction* 10, pp. 399–416.

Kaymak, S. (2002). *Fuzzy Decision Making in Modeling and Control*, New Jersey: World Scientific.

Kelly, G.A. (1969). A mathematical approach to psychology. In: Clinical Psychology and Personality: *The selected paper of George Kelly.* J. Wiley, pp. 94-113.

Kelly, Thomas J; (1999). Measuring the ROI of IAQ; *Buildings, Cedar Rapids*; Mar 1999; 93 (3); pp. 52-55.

Kersten, G.E. (1999). Decision Making and Decision Support, *DSS for sustainable development a resource book of methods and application,* Kersten, G.E., Mikolajuk, Z., and Yeh, A.G. eds. Boston: Kluwer Academic Publisher, pp. 29-53.

Khaldi, M.R. (1995). *Knowledge-based contingency analyzes for steady-state stability of power systems using graphical user interface and data visualization assemble.* Unpublished, PhD. Thesis, The Pennsylvania State University. The graduate school college of engineering.

Kinnear, P.R., and Gray, C.D. (1994). SPSS for Windows Made Simple, LEA. Hope.

Kishk, M. and Al-Hajj, A. (2000). A Fuzzy Model and Algorithm to Handle Subjectivity in Life Cycle Costing Based Decision-making, *Journal of Financial Management of Property and Construction*, 5(1-2), pp. 93-104.

Klein, J. (2000). Spanning the globe; *Building Design & Construction*, 41(6); pp. 70-74.

Kong, S.C.W., and Li, H. (2001). An e-commerce system for construction material procurement, *Construction Innovation,* 1, pp. 43–54.

Kong, S.C.W., Li, H., and Shen, L.Y. (2001). An Internet-based electronic product catalogue of construction materials, *Construction Innovation*, 1, pp. 245–257.

Konuglu, A., and Aridity, D. (2001). A computer-based information system for architectural design offices. *Construction Innovation*, 1(1), pp. 15-29.

Korman, T.M., and Tatum, C.B. (2001). Development of a Knowledge-Based System to Improve Mechanical, Electrical, and Plumbing Coordination, *CIFE Technical Report #129, July, 2001,* Stanford University, Available: http://www.stanford.edu/group/CIFE/, (3 May 2002).

Krassadaki, E., and Siskos, Y. (2000). Inferring a multi-criteria reference model for rural development projects evaluation, *Decision making: recent development and world application*, Stelio, H.Z., Georgia, D., and Constantin, Z., eds. New York: Kluwer Academic Publisher, pp. 331-346.

Krishnan R., and Chari, K. (2000). Model Management: Survey, Future Directions and a Bibliography, *Interactive Transactions of ORMS,* 3(1), (online), Available: http://www.coba.usf.edu/departments/isds/faculty/chari/research.htm

Kumaraswamy, M.M., and Chan, D.W.M. (1998). Contributor to construction delays, *Construction Management and Economics,* 16(1), pp. 17-29.

Kumaraswamy, M.M, and Walker, D.H.T. (1999). Multiple performance criteria for evaluating construction contractors, *Procurement Systems a guide to best practice in construction*, Rowlinson, S., and McDermot, P., eds. CIB, London: E & FN Son, pp. 228-251.

Kumaraswamy, M.M., and Mattews, J.D (2000). Improved subcontractor selection employing partnering principle, *Journal of Management in Engineering,* 16(3), pp. 47-58.

Kumaraswamy, M.M., and Dissanayaka, S.M. (2001). Developing a decision supports system for building project procurement, *Building and Environment*, 36, pp. 337-349.

Kvan, T., and Kolarevic, B. (2002). Rapid prototyping and its application in architectural design (Editorial), *Automation in Construction,* 11, pp. 277–278.

Lahteenmaki, S., Storey, J., and Vanhala, S. (1998). HRM and company performance: The use of measurement and the influence of economic cycles. *Human Resource Management Journal*. 8(2), pp. 51-65.

Lam, K.P., Mahdavi, A., Gupta, S., Wong, N.H., Brahme., R., and Kang, Z. (2002). Integrated and distributed computational support for building performance evaluation, *Advances in Engineering Software*, 33, pp. 199-206.

Latham, M. (1994). *Constructing the team. Joint review of procurement and contractual agreements in the United Kingdom construction industry: final report*, London: The Stationery Office.

Lebas, M. and Euska, K. (2002). A conceptual and operational delineation of performance. *Business performance measurement.* Neely, A. ed. Cambridge University Press, UK. pp. 65-79.

Lee, J., and Aktan, H.M. (1997). A Study of Building Deterioration, *Infrastructure condition assessment: art, science, and practice: proceedings of the conference sponsored by the Facilities Management Committee of the Urban Transportation Division of the American Society of Civil Engineers / edited by Mitsuru Saito; in cooperation with American Public Works Association ... [et al.].* American Society of Civil Engineers: New York, pp. 1-10.

Lee, S. (1997). Singapore List of Trade Subcontractor (SLOTS), *Proceeding of the First International Construction Industry Development Conference: Building the Future Together,* School of Building and Real Estate, National University of Singapore. December 7-11, pp. 355-365.

Lee, W.Y. (1996). *Management of Nominated Sub-contractors in Large-scale Project*. Academic Exercise, National University of Singapore.

Leedy, P.D. (1997). *Practical Research: Planning and Design,* Upper Saddle river NJ: Prentice Hall.

Leenders, M.R., and Fearon, H.E. (2002). *Purchasing and Supply Management*, 12th edition, USA: IRWIN.

Leeuwen, J.P., Vries, B., Oetelaar, E. (2000). A Decision Support System For Building Refurbishment Design, *Proceeding of the International Conference on Construction Information Technology CIB W7*8, Iceland, June 28-30. (online), Available: http://www.ds.arc.tue.nl

Leglise, M. (2001). Computer-stimulated design: construction of a personal repertoire from scattered fragments, *Automation in Construction,* 10, pp. 577–588.

Levine, D.M., Berenson, M.L., and Stephen, D. (1999). *Statistics for Managers Using Microsoft Excel*, USA: Prentice Hall.

Li, H., and Love, P.T.E.D. (1999). Combining rule-based expert systems and artificial neural networks for mark-up estimation, *Construction Management and Economics.* 17, pp. 169 - 176.

Liebing, R.W. (1998). *Construction Contract Administration*, USA: Prentice Hall.

Ling, Y.Y. (1998). Multi-attribute Decision Making Model for Evaluation and Selection of Consultants for Design Build Project in Singapore, *Unpublished PhD thesis, National University of Singapore*.

Ling, Y.Y., Ofori, G., and Low, S.P. (2003). Evaluation and selection of consultants for design–build projects, *Project Management Journal*, 34(1), pp. 12-22.

Liu, A. and Fellows, E. (1999). Culture Issue. *Procurement Systems: A guide to best practice in construction*. Rowlinson, S and McDermott, (ed.), CIB-W92, E&FN Spon, pp. 141-162.

Liu, A.N.N. (1994). From act to outcome – a cognitive model of construction procurement, in *Proceeding of CIB W-92 International Procurement Symposium, East Meets West*, Department of Surveying, University of Hong Kong, 4-7 December, pp. 169-178.

Loh, W.H., (1998). *Main Contractor Assessment of Singapore List of the Trade Subcontractor*, Academic Exercise, National University of Singapore.

Love, P.E.D., Skitmore, M., and Earl, G. (1998). Selecting a suitable procurement method for building project. *Construction Management and Economics*, 16, pp. 221-223.

Love, P.E.D., Irani, Z., Li, H., Tse, R.Y.C., and Cheng, E.W.L. (2000). An Empirical Analysis of IT/IS Evaluation in Construction, *International Journal of Construction Information Technology*, 8(2), Winter 2000.

Love, P.E.D., Irani, Z. (2001), Evaluation of IT costs in construction (Review), *Automation in Construction*, 10, pp. 649–658.

Low, S.P., (1996) The management of large-scale upgrading programs for public housing in Singapore, *Property Management,* 14(4), pp. 27-32.

Lu, A., Bamford, N., Charters, B., and Robinson, J. (2000). Environmentally Sustainable Development. A LCC Approach to a Commercial Building in Melbourne, Australia. *Construction Management Economics*. 18, pp. 927-934.

Mahdavi, A., Mathew, P., Kumar, S., and Wong, N.H. (1997). Bi-directional Computational design support in the SEMPER environment, *Automation in Construction*, 6, pp. 353-373.

Mak, B., Bui, T., and Blanning, R. (1996), Aggregating and Updating Experts' Knowledge: An Experimental Evaluation of Five Classification Techniques. *Expert Systems with Application*. 10(2), pp. 233-241.

Mann, T. (1992). *Building Economics for Architects,* New York: Van Nostrand Reinhold.

Mansfield, J.R. (2002). What's in name? Complexities in the definition of "refurbishment", *Property Management,* 20(1), pp. 23-30

Marakas, G.M. (1999). *Decision Support Systems in the 21th century*, Upper Saddle River, NJ: Prentice Hall.

Marosszeky, M. (1991). *Office Building Refurbishment*, Building Research Center, The University of New South Wales.

McDaniel, M.A., Schmidt, F.L., and Hunter, J.E. (1988) Job experience correlates of job performance, *Journal of Applied Psychology*, 73(2), pp. 327-330.

McGraw, K.L., and Harbison, B.K. (1989). *Knowledge Acquisition, Principle and Guidelines*, New Jersey: Prentice Hall.

Medley, L.G., (1996) The life-cycle perspective: Managing cost before it occurs; *Cost Engineering*, Morgantown; Oct 1996; 38(10), pp. 35-40.

Medsker, L., Tan, M., Turban, E. (1995). Knowledge Acquisition from Multiple Experts: Problems and Issues. *Expert Systems with Application*. 9(1), pp. 35-40.

Meng, T.K. (2002), Experimental Design and Decision Support. *Expert Systems: the technology of knowledge management and decision making for the 21st century.* Leondes, C.T., ed., San Diego: Academic Press, 1, pp. 119 – 120.

Meyer, W.M. (2002). Finding performance: The new discipline in management. *Business performance measurement.* Neely, A. ed. Cambridge University Press, UK. pp. 51-64.

Mockler, R., J. and Dologite, D.G. (1992). *Knowledge-Based Systems, an Introduction to Expert Systems*. New York: McMillan Publishing Company.

Mohamed, A., and Celik, T. (2002). Knowledge Based System for Alternative Design, Cost Estimate, and Scheduling, *Knowledge Based Systems*, 15, pp. 177-188.

Mohsini, R., and Davidson, C.H. (1991). Building procurement – key to improved performance, *Building Research and Information*, 19(2), pp. 106-113.

Mohsini, R. A., and Davidson, C.H. (1992). Determinants of performance in the traditional building process. *Construction Management and Economics*, 10(4), pp. 343-359.

Mohsini, R.A. (1993). Knowledge Based Design of Project Procurement Process, *Journal of Computing in Civil Engineering*, 7(1), pp. 15-26.

Molenaar, K.R., and Songer, A.D. (2001). Web-based decision support systems: case study in project delivery. *Journal of Computing in Civil Engineering,* 15(4), pp. 259-267.

Moore, P.G., and Thomas, H. (1976). *The anatomy of Decision,* Penguin Books.

Morozumi, M., Shimokawa, Y., and Hommaa, R. (2002). Schematic design system for flexible and multi-aspect design thinking, *Automation in Construction,* 11, pp. 147–159.

Motwani, J., Kumar, A., and Novakoski, M. (1995). Measuring construction productivity: a practical aroach, *Work Study,* 44(8), pp. 18-20.

Moussatche, H. (2000). Life cycle costs in education: Operations & maintenance considered; *Facilities Design & Management*, 19(9), pp. 20 - 22.

Murch, R. and Johnson, T., (1999), *Intelligent Software Agents,* Upper Saddle River, NJ, Prentice Hall.

Nagarur, N.N., and Kaewplang, J. (1999). An object-oriented decision support system for maintenance management, *Journal of Quality in Maintenance Engineering*, 5(3). Pp. 248-257.

Needleman, L. (1965). *The economics of housing*, London: Staples Press.

Nemati, H.R., Steiger, D.M., Iyer, L.S., and Herschel, R.T. (2002). Knowledge warehouse: an architectural integration of knowledge management, decision support, artificial intelligence and data warehousing, *Decision Support Systems,* 33 (2), pp. 143– 161.

Ng, S.T., Chen, S.E., McGeorge, D., and Evans, S. (2001). Current state of IT usage by Australian subcontractors, *Construction Innovation,* 1(1), pp. 3–13.

Nguyen, T.H., and Oloufa, A.A. (2001). Computer-Generated building data: Topological information, *Journal of Computing in Civil Engineering*, 15(4), pp. 274-264.

Nkado, R.N. (1995). Construction time influencing factors: the contractor perspective. *Construction Management and Economics*, 10(6), pp. 489-509.

Norris, G.A. and Marshall, H.E. (1995). Multi-attribute Decision Analysis Method for Evaluating Buildings and Building Systems, *Building and Fire Research Laboratory National Institute of Standards and Technology*, USA: U.S. Department of Commerce.

Nwana, H.S., Capon, T.J.M, Paton, R.C., and Shave, M.J.R. (1994). Domain-driven knowledge modeling for knowledge acquisition, *Knowledge Acquisition*, 6(3), pp. 215-341.

O'Leary, D.E. (1993). Verifying and Validating Expert Systems, *Expert Systems in Business and Finance: Issues and application*, Watkins, P.R, and Elliot, L.B., eds. Chichester, New York: Wiley, pp. 181-208.

Ofori, G., and Debrah, Y.A. (1998). Flexible management of workers: review of employment practices in the construction industry in Singapore, *Construction Management and Economic*, 16(4), pp. 397-408

Okoroh, M.I. (1992). *Knowledge Based Decision Support for the Selection of Sub-contractors for Refurbishment Contract.* Unpublished PhD. thesis, Loughborough University of Technology – UK.

Okoroh, M.I., and Torrance, V.B., (1999). A Model for Sub-contractor Selection in Refurbishment Project, *Construction Management and Economics*, 17, pp. 315-327.

Olievera, R.C., and Lourenco, J.C. (2002). A multi-criteria model for assigning new orders to service suppliers. *European Journal of Operational Research*, 139, pp. 390-399.

Pal, K., and Palmer, O. (2000). A decision-support system for business acquisitions, *Decision Support Systems,* 27, pp. 411–429.

Pamerol, J.C. (2001). Scenario development and practical decision making under uncertainty, *Decision Support Systems,* 31, pp. 197–204,

Papamichael, K. (2000). Green building performance prediction/assessment, *Building Research and Information* 28(5/6), pp. 394–402

Park, K.S., and Kim, S.H. (1997). Tool for interactive multi-attribute decision making with incompletely identified information, *European Journal of Operation Research*, 98(1), pp. 111-123.

Park, C.S. (2003). Knowledge capturing methodology in process planning. *Computer-Aided Design*, 35, pp. 109-117.

PCCB, (2002). Operational framework of the voluntary subcontractor registration scheme, Provisional Contribution Co-ordination Board – Hong Kong (online), Available: http://www.pcib.gov.hk/eng/consult (19 May 2002).

Pollack, P.W., and Rees, K. (1991). The potential for expert systems in the interpretation of building contracts, *Building Research and Information, 19(2),* pp. 114-117.

Pooler, V.H. and Pooler, D.J. (1997). *Purchasing and Supply Management: Creating the Vision*. USA: Chapman & Hall.

Poon, P., and Wagner, C. (2001). Critical success factors revisited: success and failure cases of information systems for senior executives, *Decision Support Systems,* 30, pp. 393–418

Power, D.J. (1997). A Brief history of Decision Support, Systems, (On line), Available: http:/dssresources.com/history/dsshistory.html (3 May 2002).

Power, D.J. (2000). Web-based and Model Driven Decision Support Systems, Concepts and Issues, (on line), Available: http:/dssresources.com/history/dsshistory.html, (3 May 2002).

Power, D.J., and Kaparti, S. (2002). The Changing Technological Context of Decision Support System, (on line), Available: http://dssresources.com/papers/dsscontext/index.html, (3 May 2002).

Power, M. (2001). Building blind, *Builder,* 24(1), pp. 232-242.

Prerau, D.S. (1990). *Developing and Managing Expert Systems. Proven Techniques for Business and Industry*. USA: Addison – Wesley Publishing Company.

Pugh, C. (1990), The Cost and Benefits of Rehabilitation and Refurbishment. Quah. L.K (ed), *Proc. Of the International Symposium on Property Management and Modernization*, 7-9 March 1990, Singapore, pp. 451-462.

Puuronen, S. and Terziyan, V. (1999). Knowledge Acquisition from Multiple Experts Based on Semantics of concepts. *Knowledge Acquisition, Modeling and Management.* 11th European Workshop, EKAW 99', Germany, May 26-29, 1999: Proceedings. Fensel, D. and Rudi, S. eds. Lecture Notes in AI 1621. (Berlin, New York): Springer, pp. 259-274.

Quagrainie, K., K., McCluskey, J., J., and Loureiro, M., L. (2003). A laten structure approach to measuring reputation. *Southern Economic Journal*. 69(4), pp. 966-977.

Quah, L.K. (1988). *An Evaluation of the Risk in Estimating and Tendering for Refurbishment Work.* Unpublished PhD thesis, Heriot-Watt University – UK.

Quah, L.K. (1989). *Variability in tender bids for refurbishment work*, Occasional Paper 43, London: The Chartered Institute of Building - UK.

Ra, J.W. (1999). Chain-wise Paired Comparison, *Decision Science.* 30(2), pp. 581-532

Raghu, R., and Gehrka, J. (2003). *Database Management Systems*, Boston: Mc Graw Hill.

Rahman, M., Kumaraswamy, M., Rowlinson, S., and Palaneeswaram. (2002). Transform Culture and Enhanced Procurement: Through relational contracting and Enlightened Selection. Procurement System and Technology Transfer. Lewis, T.M. (ed.) *Proceedings of the International Symposium of* *the Working Commission CIB W92 (Procurement Systems)*, January 14-17, 2002, pp. 383-401.

Rajagopai, S., and Bernard, K.N. (1994). Creating strategic change in procurement orientation: A strategy for improving competitiveness, *European Journal of Purchasing and Supply Management* 1(3), pp. 149-160.

Raju, K.S., and Pillai, T. (1999). Multi criteria decision making in performance evaluation of irrigation system. *European Journal of Operation Research*, 112 (1999), pp. 479-488.

Ram, S., and Ram. (1996). Validation of Expert Systems for Innovation Management: Issues, Methodology, and Empirical Assessment, *Journal of Product Innovation Management*, 13(1), pp. 53-68.

RECC. (2002). Refurbishment Project Management, *Real Estate Construction Center*, (online), Available: http://www.recc.com.sg, (3 May 2002).

Reed, W.G., and Gordon, E.B. (2000). Integrated design and building process: what research and methodologies are needed? *Building Research and Information,* 28(5/6), pp. 325–337

Rehman, S. (1998). A methodology for modeling manufacturing costs at conceptual design. *Computers & Industrial Engineering*. 35(3-4), pp. 623-627.

Render, B. and Stair, R.M. (2000). *Quantitative analysis for management*, 7th edition. USA: Prentice Hall International.

Reselman, B., and Peasley, R. (1999). *Practical Visual Basic 6*. USA: QUE.

Rey, E.M., and Bonillo, V.M. (2000). Validation of intelligent systems: a critical study and a tool, *Expert Systems with Applications*, 18(1), pp. 1–16.

Reyers, J., and Mansfield, J., (2001). The Assessment of Risk in conservation refurbishment projects, *Structural Survey,* 19(5), pp. 238-244.

Riding, D. (1996). *Sub-Contracts DOM/1 and DOM/2, A guide to rights and obligation*, Oxford: Blackwell Science.

Roe, R.A. (1989). Designing Selection Procedures. *Assessment and Selection in Organizations*. Edited by Herriot, P. John Wiley and Sons, NY., pp. 127-142.

Rosenfeld, Y. and Shohet, I.M. (1999). Decision support model for semi-automate selection of renovation alternatives, *Automation in Construction,* 8(4), pp. 503-510.

Rougvie, A. (1987). *Project Evaluation and Development,* London: Mitchel.

Rowlinson, S. (1999). Selection Criteria. *Procurement Systems a guide to best practice in construction*, Rowlinson, S., and McDermot, P., eds. CIB, London: E & FN Son, pp. 276-299.

Rowlinson, S. and Root, D. (1997). The impact of culture on project management. *Final Report*. HK/UK Joint Research Scheme. Hong Kong: Department of Real Estate and Construction.

Russell, J.S. (1992). Decision models for analysis and evaluation of construction contractors, *Construction Management and Economics.* 10(2), pp. 185-202.

Ryder, G., Ion, B., Green, G., Harrison, D., and Wood, B. (2002). Rapid design and manufacture tools in architecture, Rapid Design and Manufacture (RDM) Center, Rapid Prototyping Group, *Automation in Construction.* 11, pp. 279–290,

Saaty, T.L. (1980). *The analytical hierarchy process*, New York: McGraw-Hill.

Sacks, R., Warszawski, A., and Kirsch, U. (2000). Structural design in an automated building system, *Automation in Construction.* 10, pp. 181–197.

Sambasivarao, K.V., and Deshmukh, S.G. (1997). A decision support system for selection and justification of advanced manufacturing technologies. *Production Planning and Control.* 8(3), pp. 270 – 284.

Sanger, M. (1998). Supporting the balanced scorecard. *Work Study*. 47(6), pp. 197-200.

Sanvido, V., Groble, F., Parfitt, K., Guvenis, M. and Coyle, M. (1992). Critical Success Factors for Construction Project. *Journal of Construction Engineering and Management*, 118(1), pp. 95-111.

SCAL (2003). *The Contractor's Directory*, The Singapore Contractors Associtation Ltd.

Schmoldt, D.L., and Rauscher, H.M. (1994). A knowledge management imperative and six supporting technologies. *Computer and Electronic in Agriculture*. 10, pp. 11–30.

Schmoldt, D.L., and Rauscher, H.M. (1996). *Building Knowledge-Based Systems for Natural Resource Management*. New York: Chapman and Hall.

Schreiber, G., Wielinga, B., de Hoog, R., Akkermans, H., van de Velde, W., (1994). CommonKADS: a comprehensive methodology for KBS development. *IEEE Expert,* 12, pp. 28–37.

Sestito, S., and Dillon, T.S. (1994). *Automated Knowledge Acquisition*, New York: Prentice Hall.

Shash, A.A. (1998). Subcontractor's bidding decision, *Journal of Construction Engineering and Management*, 124(2), pp. 101-106.

Shelly, G.B., Cashman, T.J., and Mick, M.L. (1999). *Visual Basic 6, Complete Concepts and Technique*, Cambridge: Course Technology.

Shen, L.Y., Lu, W., Shen, Q., and Li, H. (2003). A computer-aided decision support system for assessing a contractor's competitiveness, *Automation in Construction,* 12, pp. 577-587.

Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R., and Carlsson, C. (2002). Past, present, and future of decision support technology, *Decision Support Systems,* 33, pp. 111 –126.

SIA (1999). *Conditions of sub-contract for use in conjunction with the main contract,* 2nd ed. Singapore: Singapore Institute of Architects.

Simon, H. (1977). *The new science of management decision*, Englewood Cliffs, NJ: Prentice Hall.

Simondetti, A. (2002). Computer-generated physical modeling in the early stages of the design process, *Automation in Construction,* 11, pp. 303– 311.

Skitmore, R.M. (1989). *Towards an Expert Building Price Forecasting System*, London: Surveyor.

Smith, C.L. (1998). *Computer-Support Decision Making, Meeting the Decision Demands of Modern Organization*, London: Ablex Publishing Corp.

Smith, L, J. (1994). *Avoid claims in building contracts*, Butterwoth Architecture Legal Series, UK: Butterworth Heinemann.

Smith, V.C., Sims, J., and Dancaster, C. (2000). *Contract Documentation for contractors*, 3rd edition, Oxford: Blackwell Science.

Snow, C. and Alexander, M. (1992). Effort the illustrative variable in the productivity problem, *Industry Management*. 39(3), pp. 31-32.

Song, Y., Clayton, M.J., and Johnson, R.E. (2002). Anticipating reuse: documenting buildings for operations using web technology, *Automation in Construction,* 11, pp. 185–197.

Songer, A.D., Diekmann, J.E., and Rasheed, K.A. (2001). Construction scheduling using 3-D CAD and walk-thru, *Construction Innovation*; 1, pp. 191–207.

Sriram, R.D. (1997). *Intelligent Systems for Engineering: A Knowledge-Based Approach.* USA: Springer.

Stat-Soft Inc. (2003). Multiple Regressions, Stat-Soft Inc. (online). Available: http://www.statsoftinc.com/textbook/stmulreg.html#index (24 September 2003)

Stewart, R.A., and Sherif, M. (2001). Utilizing the balanced scorecard for IT/IS performance evaluation in construction, *Construction Innovation.* 1, pp. 147–163.

Stylianou, A.C., Smith, R.D., and Madey, R. (1995). An empirical model for the evaluation and selection of Expert System Shell, *Expert System with Application*. 8(1), pp. 15-25.

Swam, W., Wood, G., McDermott, P. and Cooper, R. (2002). Trust in construction: Conception of trust in project relationships. Procurement System and Technology Transfer. Lewis, T.M. (ed.) *Proceedings of the International Symposium of the Working Commission CIB W92 (Procurement Systems),* January 14-17, 2002, pp. 461-470.

Swierczek, F.W. (1994). Culture and conflict in joint ventures in Asia. International Journal of Project Management. 12(1), pp. 39-47.

Szalapaj, P. (2001). *CAD Principles, for Architectural Design, Analytical Approach to Computational Representation of Architectural Form,* Oxford: Architectural Press.

Szczerbicki, E., and White, W. (1998). System Modeling and simulation for predictive maintenance, Cybernetics and Systems: *An International Journal*, 29, pp. 481- 498.

Tah, J.H.M., and Carr, V. (2001). Knowledge-based approach to construction project risk management, *Journal of Computing in Civil Engineering,* 15(3), pp. 170-177.

Tam, C.M. and Harris, E. (1996). Model for assessing building contractors' project performance. *Engineering, Construction and Architectural Management.* 3(3), pp. 163-86.

Tan, H.Y. (2003). Upgrading delay: Many get toilet bowls, finally, *The Straits times, June 10, 2003*.

Tan, K.C., Kannan, V.R. and Hanfield, R.B. (1998). Supply Chain Management: Supplier Performance and Firm Performance. *International Journal of Purchasing and Material Management.* 34(30), pp. 2-9.

Tang, M.X., and Frazer, J. (2001). A representation of context for computer supported collaborative design, *Automation in Construction* 10, pp. 715–729.

Teo, D.H.P. (1990). *Decision Support and Risk Management System for Competitive Bidding in Refurbishment Contracts*, Unpublished, PhD. Thesis, Herriot-Watt University Edinburgh – UK.

Teo, D.H. (1991). *Risk perception of contractors in competitive bidding for refurbishment work*, London: Royal Institute of Chartered Surveyor.

Tirole, J. (1996). A theory of collective reputation: Application to the persistence of corruption and to firm quality. *Review of Economic Studies.* 63, pp. 1- 32.

Tiwari, M.K., and Baneree, R. (2001). A decision support system for the selection of a casting process using analytic hierarchy process, *Production Panning and Control*, 12(7), pp. 689–694.

Triantaphyllou, E., Kovalerchuk, B., Lawrence, M., and Knapp, G. (1997). Determining the most important criteria in maintenance decision-making, *Journal of Quality in Maintenance Engineering*, 3(1), pp. 16-28.

Triantaphyllou, E. (2000). *Multi-criteria decision making methods: a comparative study*, Boston: Kluwer Academic Publisher.

Tserng, H.P. and Lin, P.H. (2001) An accelerated subcontracting and procuring model for construction projects, *Automation in Construction* 11(6), pp.105-125.

Tung, L.L., amd Quaddus, M.A. (2002). Cultural differences explaining the differences in results in GSS: implications for the next decade, *Decision Support Systems* 33 (2002), pp. 177– 199.

Turban, E., and Aronson, J.E. (2001). *Decision Support System and Intelligent System*, Upper Saddle River: Prentice Hall.

Tzafestas, S.G. and Tzafestas, E.S. (1997). Recent Advance in Knowledge Acquisition Methodology. *Knowledge Based Systems, Advanced concepts technique and applications.* Tzafestas, S.G., ed. New Jersey: World Scientific, pp. 15-25.

Vaus, (2002). *Analyzing Social Science Data,* London: Sage Publications.

Vegte, W.F., Pulles, J.P.W., and Vergeest, J.S.M. (2001). Towards computer-supported inclusion and integration of life cycle processes in product conceptualization based on the process tree, *Automation in Construction* 10, pp. 731–740.

Vokurka, R.J., Choobineh, J., and Vadi, L. (1996). A prototype expert system for the evaluation and selection of potential suppliers, *International Journal of Operation and Production Manager*, 16(12), pp. 106-126.

Wagner, W.P., Otto, J., and Chung, Q.B. (2002). Knowledge Acquisition for Expert Systems in Accounting and Financial Problem Domains, *Knowledge Based Systems*, 15, pp. 439-447.

Walker, D.H.T. (1997). Choosing an appropriate research methodology. *Construction Management and Economics*. 6, pp. 149-159.

Walker, D.H.T. and Shen, Y.J. (2002). Project understanding, planning, flexibility of management action and construction time performance: two Australian case studies. *Construction Management and Economics*. 20, pp. 31-44.

Walker, D., Hampson, K., Ashton, S. (2003). Developing an innovative culture through relationship-based procurement system. *Procurement strategies: A relationship based approach,* Walker, D. and Hampson, K. eds. Oxford: Blackwell Science, pp. 236-257.

Wang, H., Liao, S., and Liao, L. (2002), Modeling constraint-based negotiating agents, *Decision Support Systems* 33, pp. 201– 217.

Wang, K.H., and Sivazlian, B.D. (1997). Life Cycle Cost Analysis for Computers & Availability System with Industrial Parallel Components. *Computers & Industrial Engineering.* 33.

Wang, Y., and Duarte, J.P. (2002). Automatic generation and fabrication of designs, *Automation in Construction,* 11, pp. 291– 302.

Wangemann, M.A. (2000). *2001 Subcontractor Management Manual*. San Diego: Harcourt Professional.

Ward, S.C., Curtis, B. and Chapman, C.B. (1991). Objectives and performance in construction projects. *Construction Management and Economics*. 9(4), pp. 343-353.

WBDG (2001). Whole Building Design Guide, (online), Available: http:/www.wbdg.org/index.asp (3 May 2002).

Weiss, B. (1999). *Do it with an architect: how to survive the refurbishment of your home*, London: RIBA publication.

Welch, P.J., and Welch, G.F. (1992). Economic theory and practice, 4th ed. Texas: Dryden Press.

West, M.A., and Allen, NJ. (1997). Selecting for Team, *International Handbook of Selection Assessment,* Anderson, N., and Herriot, P., eds. John Wiley and Sons Ltd.

Westberg, K., Norén, J., and Kus, H. (2001). On using available environmental data in service life estimations, *Building Research & Information* 29(6), pp. 428–439.

Westney, R.E. (1997). *The Engineer's Cost Handbook*, New York: Marcel Dekker, Inc.

Wickwire, J.M. (1995). *Subcontracting Manual: Practice guide with forms*, New York: Wiley Law Publication.

Wong, N.H., and Mahdavi, A. (2000). Automated generation of nodal representations for complex building geometries in the SEMPER environment, *Automation in Construction,* 10, pp. 141–153.

Woods, D.W. (2000). Handbook for IQP Advisors & Students: Part VI: Quantitative Methods for IQPs: Chapter 12: Investment Decisions - Life Cycle Costing (online), Available: ttp://www.wpi.edu/Academics/Depts/IGSD/IQPHbook/tocdetail.html (23 July 2003).

Woodson, R.D. (1997). Be a successful building contractor, New York: McGraw Hill.

Woodward, D. (1997). Life cycle costing - theory, information acquisition and application. *International Journal of Project Management*, 15(6), pp. 335-344.

Yang, H., Anumba, C.J., Kamara, J.M., and Carrillo, P. (2001). A fuzzy-based analytic approach to collaborative decision making for construction teams, *Logistics Information Management,* 14 (5/6), pp. 344-354.

Yang, J., and Peng, H. (2001). Decision support to the application of intelligent building technologies, *Renewable Energy*, 22, pp. 67 – 77.

Yeap, C.K. (2000). *Selection Criteria for nomination of subcontractors*, Academic Exercise, National University of Singapore.

Yoon, K., and Kim, G. (1989). Multiple attribute decision making with imprecise information, *IEE Transaction* 21(1), pp. 21-26.

Yoon, K.B. (1992). *A Constraint Model in Space Planning,* Southampton UK: Computational Mechanics Publications.

Yoon, Y., Guimaraes, T. and Swales, G. (1994). Integrating artificial neural network with rule-based expert systems. *Decision Support Systems*. 11, pp. 497-507.

Yoon, Y. and Guimaraes, T. (1995). Assessing Expert Systems Impact on Users' Jobs. *Journal of Management Information Systems.* 12(1), pp. 225-249.

Younis MA, and Wahab MA. (1997). A CAPP expert system for rotational components. *Computer Industrial Engineering*, 33(3–4), pp. 509–512.

Zak, D. (2001). *Program with Visual Basic 6, enhance edition*, Course Australia, USA: Technology, Thomson Learning,

Zbayrak, M., and Bell, R. (2003). A knowledge-based decision support system for the management of parts and tools in FMS, *Decision Support Systems,* 35, pp. 487– 515.

Zeleznikow, J., and Nolan, JR. (2001). Using soft computing to build real world intelligent decision support systems in uncertain domains, Decision Support Systems. 31, pp. 263–285.

Zolin, R., Levitt, R.E., Fruchter, R., and Hinds, P.J. (2000). Modeling & Monitoring Trust in Virtual A/E/C Teams, *CIFE Working Paper #62, December, 2000, Stanford University* (online). Available: http://www.stanford.edu/group/CIFE/ (3 May 2002).

APPENDIX 1

Detail of Knowledge Acquisition and Computer Techniques

1. Knowledge-base Engineering

The process of developing a KBS is called knowledge-base engineering. This often involves a collaborative process between the knowledge engineer, and single or multiple DEs. Construction of a KBS helps the experts to articulate what they know. The KBS can be viewed as having two environments: the development environment and the consultation environment. The earlier environment is knowledge-based engineering, which is used by a KBS engineer to build the component and put knowledge into the KBS. On the other hand, the consultation environment is used by a non-expert to obtain expert knowledge and advice.

The knowledge engineer elicited knowledge from the DEs, refined it with the expert, and represented it in the knowledge base. The knowledge engineering process, which is shown in Figure A1.1, consists of five consecutive but overlapping activities (Marakas, 1999; Durkin, 1994):

1. Problem assessment
2. Knowledge acquisition
3. Model Development
4. Model Application
5. Validation.

The first activity (problem assessment) has been justified in Chapter 1. In this chapter, only the method of Knowledge Acquisition is discussed. The model development, system application, and validation are presented in Chapter 8.

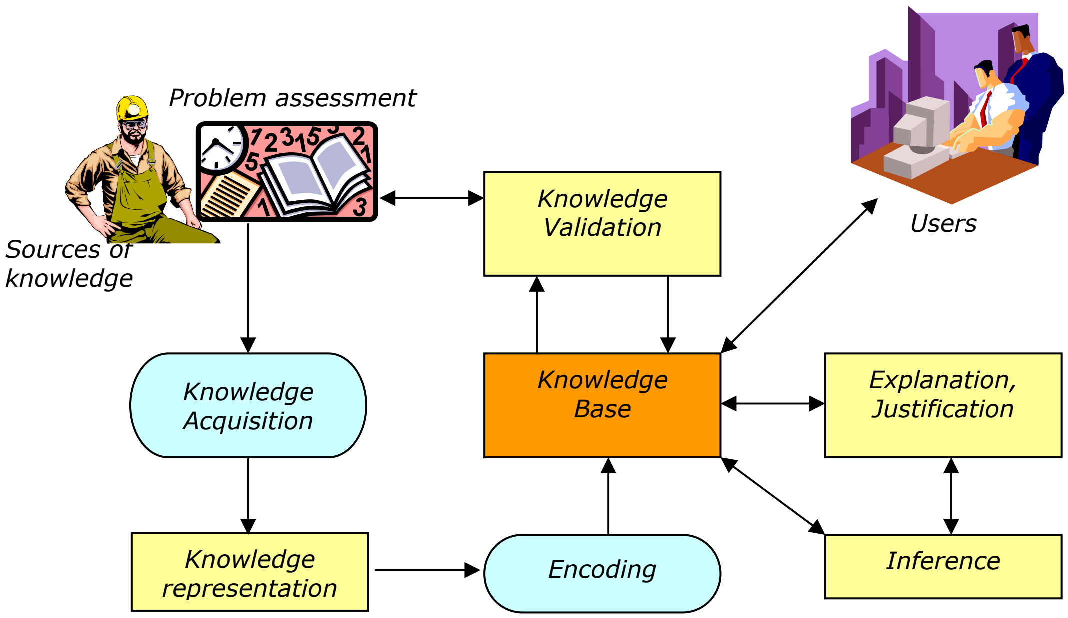


Figure A1.1 Process of Knowledge-based Engineering

2. Method of Knowledge Acquisition (KA)

Having the problem assessment concluded, the KA was carried out. The KA is one of the major bottlenecks in the development of KBS. It was technically challenging and time consuming because the process was hard to formalize, the knowledge representation between KBS and sources of knowledge might be widely mismatched, and the methodologies for knowledge acquisition were fairly few (Chien and Ho, 1994; Nwana, et al., 1994).

The artificial intelligence literature identified several methods that could be used for KA. These consist of direct methods such as structured and unstructured interviews, protocol analysis, and onsite observation and indirect methods such as general weight networks, repertory grid analysis, etc. Most of these methods were imported from psychology practices (Durkin, 1994; McGraw et al, 1989; Medskar et al, 1995; Scheiber, 2000). These methods can be classified into three broad approaches of KA: automatic, semi automatic and manual methods (Turban and Aronson, 2001; Schmoldt and Rauscher, 1996). More information concerning this topic can be found in Turban and Aronson (2001), and Schmoldt and Rauscher (1996).

This research applied the manual methods. Turban and Aronson (2001) noted that manual methods are an advantage if the knowledge engineers have knowledge about the domain. In this case, the author, as a knowledge engineer, has knowledge and experience on building construction projects.

2.1 Interviews

The most common technique used for knowledge elicitation today is the interview technique (Gonzalez and Dankel 1993; McGraw and Briggs, 1989; Schmoldt and Rauscher, 1996). The purpose of this interview model was to allow the knowledge engineer to obtain a deep-seated rule structure concerning DE's performance on tasks.

The interview can be distinguished into two methods: unstructured and structured methods. Each method can be appropriate given the goals of a session (Davies and Hakiel, 1988; Johnson and Weller, 2002; McGraw and Briggs, 1989). An unstructured interview is without details and characterized by lack of organization. This technique might be useful during initial stages of knowledge acquisition, as "ice breaker" communication technique, or when the knowledge engineer wants to explore an issue. Its lack of structure permits a sort of free association dialogue that may illuminate many of the major issues that are important but may also have some drawbacks. This method is therefore, sometimes inefficient at collecting knowledge because of redundancies and omissions (Schmoldt and Rauscher, 1996).

On the other hand, a structured interview provides a structure by developing a carefully pre-planned series of ordered questions (Johnson and Weller, 2002). It is appropriate when the knowledge engineer desires specific information (i.e.

issue of clarification). Sestito and Dillon (1994) noted that the structured interview is the most widely used in practice, and it has been found by some researchers to be the most effective. This is because the technique forces the DEs to attend to the interview task systematically. Mockler and Dologite (1992) added that the structured interview technique is generally effective only after the initial KBS has been established, and used to refine the KBS.

However, Wagner, et al. (2002) argued that although unstructured interviews have many criticisms, they still have a valuable place in the knowledge engineer's tool kit since they allow the greatest possible freedom for the knowledge engineer and expert to explore the topic. The unstructured interview could enhance the result of the structured interview.

In this present research, both the unstructured and structured interviews were adopted. The unstructured interview was applied in the initial step to explore the knowledge of the subcontractor selection process for a BR project, before the structured interview was carried out.

2.2 Questionnaires

In this present research, the attitudes and beliefs of the respondents regarding the weighting criteria in selecting BR subcontractors were elicited through mailed questionnaires. The questionnaire design was developed following the guidelines mentioned by Frazer and Lawley (2000); and Guida and Tasso (1994):

1. It must be clear, unambiguous, uniformly workable, and easy to answer.
2. It should be designed to minimize potential biases and errors from respondents.
3. It should help to engage the interests of the respondents since people's participation in the survey is voluntary.

The questionnaire used in this investigation consists of three parts: (1) respondents classification, (2) rating the impact of criteria utilized in decision making for BR subcontractor selection, and (3) inviting respondents to add further criteria. The format, structure, and decision criteria used in this questionnaire were based on the results described in the literature review and DEs interview.

The first part of the questionnaire included the category of the company represented (BCA registration work-heads) and financial classification. Besides that, the questionnaire covered the way in which the organization makes decisions for subcontractor selection, such as, decision policies, methods, and tools. The questions on respondent's designation, and years of company experience in BR projects were also asked to determine if the respondent had the relevant experience and knowledge.

For ease of the respondents, the questionnaire facilitated a combination of a nominal and contingency question. In the nominal question, the respondents tick the appropriate boxes. In the contingency question, the respondents tick "yes" and "no" answers. They then specify their answers if they chose "yes".

In the second part of the questionnaire, the respondents were requested to decide which attributes affect their decisions. The decision attributes are essential because they influence the objectives of the decision makers directly. According to the literature review, a decision is mostly related to project specifications, subcontractor characteristics, and/or special consideration (qualitative aspects).

Although a long questionnaire has the advantage of increasing reliability with more items to be measured, studies have found that long questionnaires cause a fatigue effect and would not generally be filled out carefully (Borcherding, 1991). To reduce the number of questions, one question may represent two comparable attributes, for example, material and equipment used. The strategic grouping of the factors is necessary to reduce the length of the questionnaire. However, it should be carried out carefully since grouping factors may produce ambiguity.

In this present survey, 40 attributes were tested. The attributes were defined as an item used to facilitate a more refined decision associated with a decision criterion. The numbers of questions were assumed to balance the increase of reliability when more items were being measured against a potential decrease in reliability due to measurement error that may arise from the fatigue effect.

The weighted decision criteria of respondents were measured on an interval level. There were some opinions regarding interval rating, from 1-3 to 1-11, either using odd or even numbers. This present research uses the most common 1-to-5 rating or bipolar scale, which is also called the Likert response scale. In this present research, ranking the attributes was requested in the order of [1] representing “very unimportant”, [2] for “unimportant”, [3] for “good to have”, [4] for “important”, and [5] for “very important”. Justification for using the 5-point Likert scale is discussed in Section 2.1.5.2.

The third part of the questionnaire consisted of two “open” questions. The respondents were invited to add further criteria that affected their selection of BR subcontractors and to rate the level of importance of these criteria. In addition, the respondents were requested to give any miscellaneous information describing their BR subcontractor selection process. The questionnaire form is presented in Appendix 2.

2.3 Improving the Success Rate

The questionnaire used mainly the "closed" type of questions to identify the respondents' choice of important level of criteria. The closed type questions have more advantages than open type questions because these are easier to respond to and consequently will improve the response rate, and the terminology is limited and standardized which then simplifies into subsequent analysis (Nkado, 1995).

Another way to improve the success rate for completion of this questionnaire was to use the following technique:

1. Supplying a self-addressed and pre-stamped envelope.
2. A number of respondents were personally contacted by telephone and e-mails.
3. Assurance was given on the cover letter of the questionnaire that all information would be treated in the strictest confidence.

2.4 Pilot Survey

Pilot survey is one of the methods used to improve the success rate of the survey. Before the questionnaires were posted, a pilot survey was conducted. Walker (1997) suggested that a pilot or pre-test questionnaire often helps to ensure that the instrument meets the essential guidelines. A pilot survey helps to confirm the severity of the problems identified, and checks whether the questionnaire contains all the criteria viewed as important features for subcontractor selection.

A pilot survey is usually carried out among a small sample before a full-scale sample is realized (Fellows and Liu, 1997). The draft questionnaires were discussed with the two DEs and a group of researchers at School Design and Environment, National University of Singapore who have done extensive research in construction management.

In general, feedback from this pilot survey indicated that the attributes listed in the questionnaire were appropriate. The two DEs suggested changing the format of the questionnaire. They found difficulties following the long list of questions in the table format, and reported that they were likely to get lost in the middle of the questionnaire.

The group of researchers advised revision of Part A of the questionnaire (respondents' particulars). They suggested that a number of questions should be added to elicit more details about the respondents, such as the methods used by the contractor to assist in decision-making for the selection of subcontractors. Another suggestion was to use nominal questions (multiple choices), where range category answers was provided. The multiple choices question makes it easier for the respondents to answer the questionnaire, and could improve the success rate. Based on this feedback, the questionnaire was revised.

The feedback from this pilot survey was used to refine the questionnaire. The revision of Part A of the questionnaire was to add the number of questions from 5 to 7. The table format of the questionnaire was revised to be more readable and organized than the initial draft.

2.5 Data Analysis

Integrating the opinions of several experts is an important step. According to Mak et al (1996), the elicitation of knowledge from several experts can be aggregated using several methods such as the ID3 pattern classification method, neural network and statistical method. Mak et al (1996) evaluated these methods and found that the main advantage of the ID3 procedure is the ease in which it can be automated. However, ID3 method cannot readily update the decision without having to build the entire tree.

The neural network method outperformed the other methods in robustness and predictive accuracy. However, in spite of its better ability to validate and predict, the neural network method has been criticized for its poor explanatory capability. It is difficult to explain why a particular conclusion was reached (Yoon et al, 1994; Garson, 1991).

The statistical method is the most common technique used. It can be a combination of rule-base and statistical methods; however, they are not known for their ability to explain how they reach conclusions (Carlson and Turban, 2002; Castillo and Alvarez, 1991). In developing the SSDSS, explanatory capability, why and how the decision is made, is essential.

There are three popular approaches of the statistical methods; multiple regression analysis, mean of Likert scale, and test of the mean.

2.6 Multiple Regression Analysis Method

The general purpose of multiple regressions (the term was first used by Pearson, 1908) is to learn more about the relationship between several independent or predictor variables and a dependent or criterion variable (Stat-Soft, 2003). Multiple regressions is a powerful and flexible method in analyzing the relationship between a set of independent variables and a single dependent variable (De Vaus, 2002). Multiple regression can also be used to obtain weights of criteria. The mathematical equation of the multiple regression model would be:

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_n X_n \text{ ....(A1.1)}$$

where:

Y is the value of respondent variable,

X_1, X_2, ...X_n are independent variables

β_1, β_2, ...β_n are constants for X_1, X_2, ...X_n

α_1 is an additional constant.

Following a regression equation application, the parameter α and β values are determined. For application in the weighting criteria, value of the dependent variable, Y (for example, performance of subcontractor) and independent variables, X_1, X_2, ...X_n (for example, quotation price, quality of technical proposal, experience, and past performance), and β_1, β_2, ...β_n are weights for independent variables.

However, regression analysis has several limitations for weighting criteria. It works best with variables on the interval and ratio scales i.e. quantitative variables (De Vaus, 2002). The regression analysis is complex and needs holistic judgments. In order to apply the multiple regression models, the independent variables have to be tested for multicollinearity or singularity (Kinnear and Gray, 1994). If the predicted variables are inter-correlated, the results are non-unique. In practice, the qualitative variables are difficult to test for multicollinearity or singularity, and the value of Y is difficult to obtain. Based on these reasons, this method is not suitable for this present research.

2.7 Likert Scale

Rensis Likert (1932) was the first to introduce a measurement method, called the Likert scale, used in attitude surveys. The Likert technique presents a set of attitude statements. The Likert scale items are useful for gathering respondents' feelings, opinions, attitudes, etc. on any language-related topic. Respondents are asked to express agreement or disagreement on a number-point scale. Each degree of agreement is given a numerical value from one to five. Thus, a total numerical value can be calculated from all the responses (CCMS, 2003).

Likert scale items are most often used to investigate how a respondent rates a series of statements by having them circle or mark a numbered category, for examples, 1-to-3, 1-to-5, 1-to-7, or 1-to-9 (Brown, 2003). The scores are used to elicit the attitude, and they are converted to a mean important rating, and then further converted to an attribute weight. For instance, in the five-point scale, the mathematical equation of mean importance rating would be:

$$a_h = \frac{1(n_1) + 2(n_2) + 3(n_3) + 4(n_4) + 5(n_5)}{(n_1 + n_2 + n_3 + n_4 + n_5)} \quad \text{................................(A1.2)}$$

where:

a_h is the mean importance rating of an attribute,

n_1 , n_2 , n_3 , n_4 , and n_5 represent the number of subjects who rated the attribute as 1, 2, 3, 4, and 5 respectively on the Likert scale.

The mean importance rating is normalized through the value of an attribute divided by the sum of all mean importance rating. This is similar to a relative index of the Equation A1.2. The mathematical equation would be:

$$W_i = \frac{a_i}{\sum_{i=1}^{n} a_i} \quad \text{..(A1.3)}$$

where:

W_i is the weight of attribute

A_i is the mean importance rating of an attribute

The mean Likert method has been widely used in AEC research, such as, Ling et al (2003), Bubshait and Al-Gobali (1996), Tam and Harris (1996), Holt (1992), and Russell (1989). This technique is relatively straightforward by asking the decision maker to indicate the level of importance of an attribute on a fixed scale. Because of these reasons, the method is suitable for this present survey.

Limitations and Point Scale

One of the limitations of the Likert method is the difficultly in establishing consistency between people. It is difficult to ascertain the mental scales individuals use when they express opinions as ratings, for example, in a similar statement, one decision maker is a 2 while others might be a 3. This limitation can be reduced in a number of ways to make ratings more consistent so that comparisons between individuals are more reliable. For example, the way rating scales are labeled and the number of values in the scale can greatly affect consistency of the data.

The number of values and labels should be bipolar, as shown in Figure A1.2, which means that there is a neutral point and the two ends of the scale are at opposite positions of the opinion, for example:
1 for “very unimportant”
2 for “unimportant”
3 for “good to have”, ---- neutral
4 for “important”
5 for “very important”

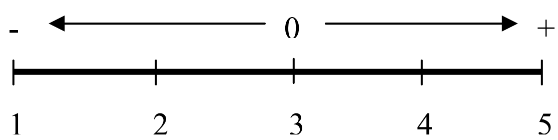


Figure A1.2 Bipolar of Likert scale

There are some different views regarding the number of points on the scale, for example, whether to use an even number of options (say 4-point scale) or odd number of options (say 3, 5, or 7-point scales). Given the possibility of a neutral option (like the 3, 5, or 7), such respondents will tend to take that neutral option. The even number of options is to provide those respondents who tend to "sit on the fence" on Likert scale items. If respondents are forced to express a definite opinion one-way or the other, an even number of options (1, 2, 3, and 4) may be used, from which they must choose either in the positive or negative direction.

Brown (2003) found that when using such four-option Likert scale items, most respondents will still tick 2 or 3, but they are at least expressing some opinion, one way or the other. However, even so, Brown (2003) has found a few respondents who are prone to select the neutral answer that they circled the space between the 2 and the 3 in the 4-point scale, which means they needed a neutral point.

Furthermore, using an even number of options forced a majority of the respondents to go one-way or the other. However, by doing that, the questionnaire may have forced the respondents to have an opinion when they really did not. For attitude measurement, the neutral rating is actually a good indicator and a desirable score (Aronoff and Kaplan, 1995). In such cases, the respondents will be given an odd number of options with a neutral position in the middle. For these reasons, the odd number of options is superior to the even number of options.

The odd number of options would be a reliable indicator of the respondent's opinion. For instance, the 5-point scale of extremely important to extremely unimportant (see Figure A1.2), comparing a rating of 2 to a rating of 3 is more certain than comparing a rating of 1 to a rating of 2. The difference between a 3 and a 2 is more certain, because it is a qualitative difference between neutral and positive opinion. Therefore, it would be quite confident that someone rating the statement with a 2 really thinks it is unimportant than someone rating with a 3. For these reasons, several researchers used a three-point scale.

For the three-point scale, individuals will clearly understand the meaning of each option, and different people will understand them the same way. However, the precision of the measurement has been decreased by giving only one degree of important or unimportant instead of two. The more closely the labeling and size of the scale match the way people think about their preference, the better will be the trade-off between accuracy and precision.

Several researchers have stretched the scale up to 7 or 9 points. However, the subtle shades of meaning offered by the larger scales are interpreted inconsistently by respondents and an increasing level of random error in data can occur. The additional values in the seven or nine-point scale create uncertainty about the best way to choose an answer; it does not represent the true distinctions in people's opinions. In this case, the additional levels in the seven-point scale would be more likely to add random error to the data than to contribute any additional information.

Although an attitude survey typically use scales with ranges of three to eleven items, the most common used is a five-point Likert scale. Aronoff and Kaplan (1995) also found that a five-point scale generally works best for diagnostic type questionnaires.

In addition, Brown (2003) suggested that the respondents with similar background or expertise would reduce possible inconsistency. In this research, the contractors who have experience and similar background in BR projects were asked to review the weighting criteria. Based on the discussions above, the odd number of options within the five-point scale was utilized in this survey.

2.8 Statistical tests of the mean

After calculating the mean importance rating, the most important attributes according to the BR contractors' population were assessed. Statistical tests of the mean were carried out to check whether the population considered the attributes important or not. This test aims to test the research hypotheses.

There are five general steps to take in the application of a statistical test to any null hypothesis:

1. A statement of the null hypothesis

In each attribute, the null hypothesis stated that the attribute was unimportant while the alternative hypothesis stated that the attribute was important. The null hypothesis is represented by this equation:

$H_0 : \mu \leq \mu_0$ .... (A1.4) against the alternative hypothesis that would be presented by the equation:

$$H_1 : \mu > \mu_0 \text{ .... (A1.5)}$$

2. Setting the level of risk associated with the null hypothesis

The significance level (α) for this study was set at 0.05 following the conventional risk level. This means that there was a 95% certainty that the result was not due to chance and that the finding was significant at the 0.05 level.

3. Selection of the appropriate test statistics

In this research, the most appropriate test statistics for examination of the importance of the variables was the ***t*** test.

4. Computation of the test statistics value

The ***t*** test value was computed using this equation:

$$\frac{\bar{X} - \mu_0}{S_x / \sqrt{n}} = t_{(n-1,\alpha)} \text{ .... (A1.6)}$$

where: the random variable $\boldsymbol{t}_{(n-1)}$ follows a Student's t-distribution with n-1 representing the degrees of freedom.

$\bar{X}$ is the sample mean, which is similar to the attributes mean (a_h)

S_x is the sample standard deviation

n is the sample size

μ_0 is the critical rating above which the attribute has considered important. In this study it was fixed at 3 because by the definition given in the Likert rating scale, ratings above 3 represented "important" and "very important"

5. Determination of the value needed for rejection of the null hypothesis

The decision rule was to reject H_0 when the calculated ***t*** value was smaller than $\boldsymbol{t}_{(n-1,\ \alpha)}$ as shown in Equation 4.9.

$$\frac{a_h - \mu_0}{S_x / \sqrt{n}} > t_{(n-1,\alpha)} \quad \text{...(A1.7)}$$

3. Determining the Computer Language

Choosing which software tool to use is a major decision in the development process and depends on several important factors. For example, is the programming capability available in-house, and if so, which languages are used? What type of computer system will be used to develop the software and what are the users' host computers?

The fastest and easiest approach to build a KBS is to use an ES shell. The ES shell is handy to use for knowledge engineers who have limited experience with software or high-level languages. The most popular AI languages or Expert System (ES) Shells are the List processing (LISP), Programming in logic (PROLOG), and Official Production System 5.5 (0P5.5). However, ES Shells cannot be delineated in popularity because most of ES shell are domain-specific. Hence, a popular ES shell in one domain may not be popular in another domain (Stylianou, et al., 1995).

Some applications of the ES Shells have been implemented in the AEC areas including the following examples: the Kappa-PC version 2.1 (e.g. Brandon and Ribeiro, 1998); the Level 5 Object release 3.6 (e.g. Mohammed and Celik, 2002); and the Leonardo Expert Shell system (e.g. Okoroh and Torrance, 1998). However, the latter model has a weakness in that it has poor performance at the user interface, because the operating DOS system is unable to develop a fine graphical user interface (GUI).

In addition, other critics argued that because the ES shell is inflexible, the ES shell should be developed particularly for certain problem domains. Most of the ES shell software that is available in the market is developed for specific tasks. They are unable to subdivide rules into various sets that can be arranged into a hierarchy.

On the other hand, the high-level language is very flexible; it tends to run more efficiently than the AI language (e.g. ES Shell) on the personal computer (Stylianou, et al 1995). Presently, many commercial vendors have moved away from the ES shells (LISP and PROLOG) toward high-level languages such as Java, C++ and toward shells and other tools that run on standard hardware.

In this present research, the high-level language (HL) was chosen using the IBM PC platform with the Microsoft Windows operating system. The reasons HL was selected over other software include:

1. The execution of HL is generally faster compared to the ES shells.
2. The flexibility HL has as a general-purpose high-level computer language, which is a great advantage over the ES shells. The latter tends to be restrictive and is only ideally suited to a relatively narrow band of applications.
3. Accessing data in files and input/output in general are much more straightforward in HL than in the ES shells.
4. The HL lends itself very well to portability between different types of computers and different operating systems.
5. The wide availability of off-the-shelf software that is based on HL can be used to enhance the user interface.

Based on the superiority of HL over the ES shells, the Visual Basic (VB) V.6 was chosen for the following reasons:

1. The author is familiar with VB, which performs the same job with other HL such as C++, Java, FORTRAN, etc.

2. Most PCs utilize the Microsoft (MS) Windows as the operating system, and VB was produced by MS. Hence, the programs under VB will be robust when operating in a MS environment.
3. VB can be linked effectively and easily to the SQL database Microsoft Access (Reselman and Peasley, 1999).
4. VB is powerful for the development of a friendly GUI. VB became widely popular when it was first introduced because of its ability to build easily and quickly Windows-based user interface. It has a number of features that assist the user in designing a Windows compatible GUI (Jerke, 1999; Shelly et al, 1999; Zak, 2001).
5. Unlike the old version, the new version of VB adapts readily to object-oriented (OO) software (Reselman and Peasley, 1999). Hence, it is comparable to other popular OO software, e.g. Java.

Finally, a major goal in knowledge engineering is to construct programs that are modular and transparent in nature such that additions and changes can be made in one module without affecting the workings of other modules. In this case, VB is appropriate for implementation in this research.

4. Designing User Interface

User interface serves to provide the end user with a friendly means of communicating with the computer program. This interface can be used for enabling the computer program to pose questions to the user about the problem at hand, providing explanations, displaying the results, and many other functions.

Most of the early KBS were designed to interact with the user using only text, such as KBS of contractors/subcontractor selection by Holt (1998), Russell (1992), and Okoroh and Torance (1998). However, viewing display monitors for extended periods of time causes eye fatigue and pain in some cases (Turban and Aronson, 2001). In an attempt to increase user efficiency and productivity, the monitor should display full graphic technology. Today, many software offer a host of features to suit the needs of the user. GUI provides the capabilities that enable the user to interact with the model management and data management subsystems (Gallo and Hancock, 2002; Shelly, 1995; Turban and Aronson, 2001).

For this present research, the GUI of the SSDSS environment was developed to be user friendly. It also follows the criteria of effective IDSS (see Section 2.6). To realize this objective, Durkin (1994) suggested that the three keys to effective GUI design are:

1. Consistent screen format
2. Clarity of presented materials
3. Screen control and color.

For example, in a consistent screen format, each screen usually has certain types of materials to present, such as title, question and area for answers, placed in the same location. The user must always feel that he or she is in control when working on the system. These requirements place additional demands on the design of the GUI.

APPENDIX 2

SURVEY ON CRITERIA TO BE CONSIDERED IN THE SELECTION OF SUBCONTRACTORS FOR BUILDING REFURBISHMENT PROJECTS

Part A: Respondent's Particulars

Please tick the appropriate boxes.

1. Category of your company in BCA registration work-head:

General building contractor:
[] A1 [] A2 [] B1 [] B2 [] C1 [] C2 [] C3

Repairs and redecorations:
[] L1 [] L2 [] L3 [] L4 [] L5 [] L6

2. Does your company have a written policy or guidelines for the selection of your subcontractors?
[] Yes [] No

3. Does your company have a pool of subcontractors from which you regularly select to carry out your subcontracting works?
[] Yes [] No

4. Does your company have any computer systems to support data processing with regards to selection of your subcontractors?
[] Yes [] No

If yes, please specify the name or type of the software:
____

5. What methods were used by your company to assist decision-making in the selection of subcontractors?

[] Individual decision-making based upon experience and intuition

[] Group decision-making based upon informal discussion and using experience and intuition

[] Others (*please specify*): ___________________________

6. How many years of experience has your company had in building refurbishment/upgrading works?

[] <5 yrs [] 5-10 [] >10 yrs.

7. Position of respondent in the firm?

[] Director [] Project manager
[] Site manager [] Estimator
[] Others (*please specify*): ________________________

PART B: The following factors deal with the selection of subcontractors for building refurbishment projects. Please indicate the importance of the following factors for subcontractor selection.

Please circle a number on the scale that you think the factors have an impact on subcontractor selection (each line should have one circle).	*1 Very unimportant*	*2 Unimportant*	*3 Good to have*	*4 Important*	*5 Very important*
1. PROJECT SPECIFICATIONS					
1.1 Price factors					
How do you rate the importance of the following price factors?					
1.1.1 a low quotation price	1	2	3	4	5
1.1.2 discount price rates	1	2	3	4	5
1.1.3 consistent price rate in the price quotation analysis	1	2	3	4	5
1.1.4 fair terms of payment (e.g. without an advance payment)	1	2	3	4	5
1.2. Time factors					
How do you rate the importance of the following time factors?					
1.2.1 short project duration	1	2	3	4	5
1.2.2 an appropriate time schedule in accordance with main contractor's program	1	2	3	4	5
1.2.3 appropriate schedule of maintenance (or after sale service including warranty)	1	2	3	4	5

Please circle a number on the scale that you think the factors have an impact on subcontractor selection (each line should have one circle).	*1 Very unimportant*	*2 Unimportant*	*3 Good to have*	*4 Important*	*5 Very important*
1.3 Quality of technical proposal					
How do you rate the importance of quality of the following factors in the subcontractor technical proposal?					
1.3.1 appropriate shop drawings in accordance with the specifications and drawings of the main contractor	1	2	3	4	5
1.3.2 appropriate construction methods in accordance with the main contractor's plans	1	2	3	4	5
1.3.3 appropriate and good quality of materials and equipment used	1	2	3	4	5
1.3.4 a project quality plan (PQP)	1	2	3	4	5
1.3.5 appropriate health, safety, and house keeping program	1	2	3	4	5
2. SUBCONTRACTOR PROFILES					
2.1 Organization characteristics					
How do you rate the importance of the following subcontractor organization's characteristics?					
2.1.1 image (e.g. company with good reputation)	1	2	3	4	5
2.1.2 company age (e.g. an adequate number of years practicing in the building refurbishment works)	1	2	3	4	5
2.1.3 responsiveness (e.g. ability to respond quickly to the requests and instructions of the main contractor)	1	2	3	4	5
2.2 Personnel qualifications					
How do you rate the importance of the following subcontractor personnel qualifications?					
2.2.1 related degrees or certificates	1	2	3	4	5
2.2.2 relevant experience in building construction	1	2	3	4	5
2.2.3 technical abilities (e.g. ability to interpret and use contract documents)	1	2	3	4	5

Please circle a number on the scale that you think the factors have an impact on subcontractor selection (each line should have one circle).	*1 Very unimportant*	*2 Unimportant*	*3 Good to have*	*4 Important*	*5 Very important*
2.3 Financial performance					
How do you rate the importance of the following aspects for financial performance for subcontractor?					
2.3.1 bank references	1	2	3	4	5
2.3.2 profitability over the past two years	1	2	3	4	5
2.3.3 enough workforce (e.g. currently not working for other main contractors)	1	2	3	4	5
2.4 Relevant experience					
How do you rate the importance of the following relevant experience for subcontractor?					
2.4.1 similar type of projects to the proposed work	1	2	3	4	5
2.4.2 similar size ($) of projects to the proposed work	1	2	3	4	5
2.5 Past performance (the last 3 years)					
How do you rate the importance of the following aspects of past performance for subcontractor?					
2.5.1 number of references	1	2	3	4	5
2.5.2 always completing past contracts	1	2	3	4	5
2.5.3 completing past contracts on time	1	2	3	4	5
2.5.4 completing past contracts on original budget	1	2	3	4	5
2.5.5 never engaged in illegal and fraudulent activities before	1	2	3	4	5
2.5.6 no fatal accident on any site under its control in the last 3 years	1	2	3	4	5
2.5.7 showing close cooperation and coordination with the main contractor in past projects.	1	2	3	4	5
2.5.8 showing good knowledge of design and regulations which are relevant to the building refurbishment work	1	2	3	4	5
2.5.9 producing good quality in past works	1	2	3	4	5
2.5.10 employing high quality workmanship in past projects	1	2	3	4	5
2.5.11 employing highly skilled of operators in past projects	1	2	3	4	5
2.5.12 showing stable financial performance in past projects	1	2	3	4	5
2.5.13 showing integrity/honesty in the past projects	1	2	3	4	5

Please circle a number on the scale that you think the factors have an impact on subcontractor selection (each line should have one circle).	*1 Very unimportant*	*2 Unimportant*	*3 Good to have*	*4 Important*	*5 Very important*
3. SPECIAL CONSIDERATIONS					
3.1 Qualitative aspects					
How do you rate the importance of the following qualitative aspects?					
3.1.1 subcontractor has similar culture with the main contractor	1	2	3	4	5
3.1.2 subcontractor has relationships with the main contractor	1	2	3	4	5
3.1.3 subcontractor can be trusted (e.g. submitting reliable information)	1	2	3	4	5
3.1.4 subcontractor has ability in communication	1	2	3	4	5

PART C: Please indicate below any other factors that need to be considered for the selection of subcontractors for building refurbishment works:

Please specify and rate the level of importance:					
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

Other comments regarding the selection of subcontractors for building refurbishment projects (*please specify*):

____

____

End of survey

Thank you very much for your cooperation.

APPENDIX 3

USER'S GUIDE

The user's guide has been prepared to facilitate the use of the program operation. There are four options that may be selected while the main menu is in view, namely: Consultation; KBES Development; Windows; and Help. Please follow the instructions below to operate the SSDSS program.

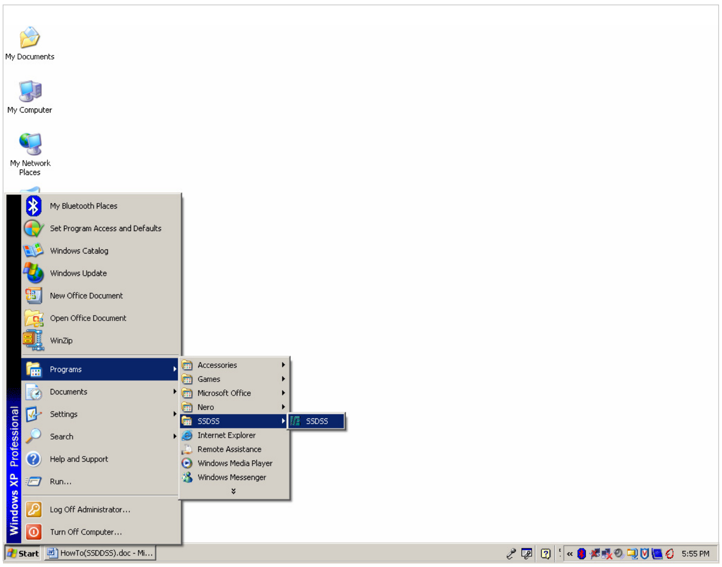
I. Login Module Figure

Login is an access bordered page. User has to insert the user name and password so as to be able to continue to the next page. User on SSDSS application is diverged into 2 (two), namely administrator and operator.

1. Administrator
   Administrator has unlimited access, not only can it open the consultation menu, but it can also develop or edit the KBES development module. If Login user uses this type, the user will be able to utilize **KBES Development** and **Consultation Module Facilities**.
2. Operator
   Operator has limited access which can only open consultation menu; such as input the new project or edit the existing project. If login user uses this type, the user will merely be able to utilize **Consultation Module Facilities**.

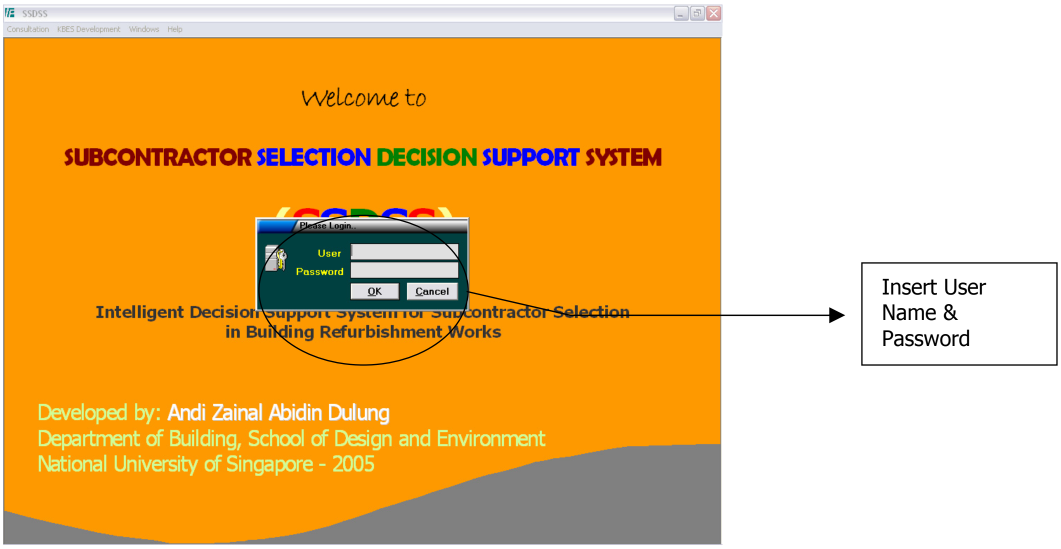
Steps:

a. Click on start button, direct it to SSDSS and click on SSDSS.



Picture I.1. Figure of SSDSS Opening

b. Afterwards a figure will come up as the picture below, then insert the invented user name and password



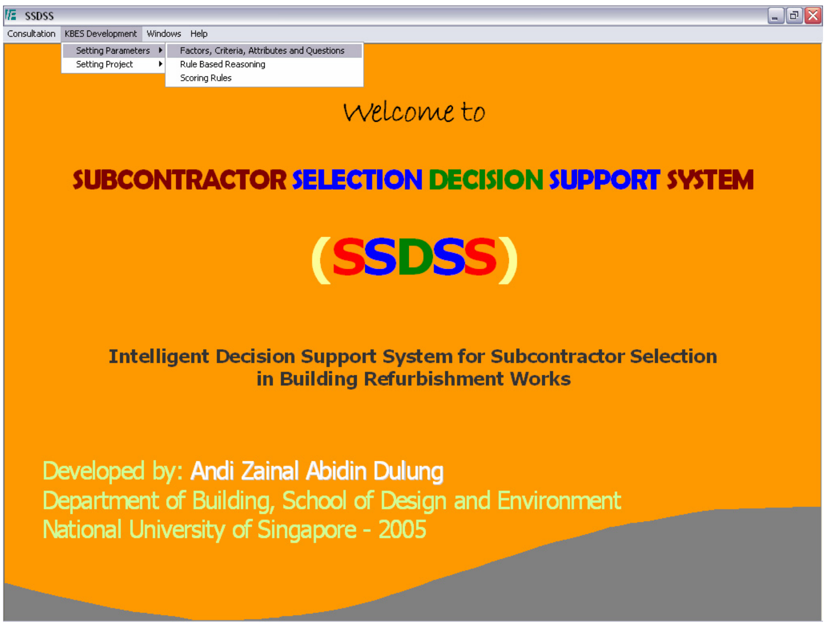
Picture I.2. Figure of Login

As default in the program, Operator has user name "OPR" and password "1234" and Administrator has user name "SPV" and password "1234".

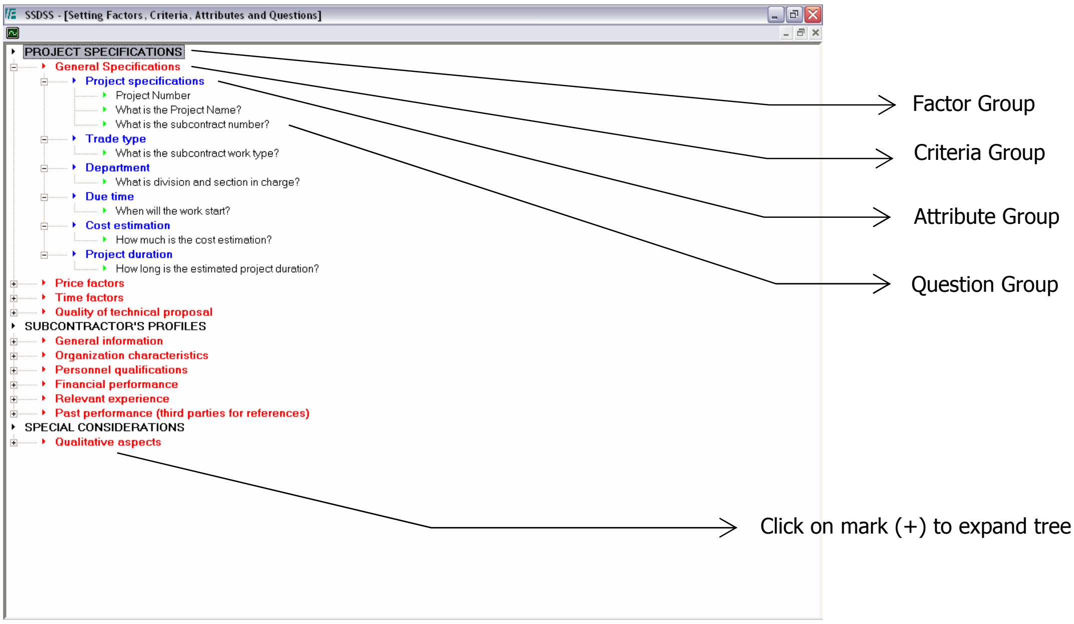
II. KBES Development Module

KBES Development Module consists of menus and sub menus:

1. Setting Parameters
   a. Factor, Criteria, Attribute and Question
   b. Rules Base Reasoning
   c. Scoring Rules
2. Setting Project
   a. Edit Project
   b. Create New Project
   c. Input Weighting Criteria



Picture II.1. Figure of KBES Development Menu & Sub menu.

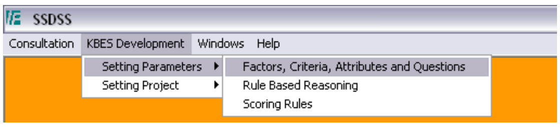


Picture II.2. Figure of Setting Factors, Criteria Attributes and Question

II. 1. Add, Edit and Delete Factor

Steps:

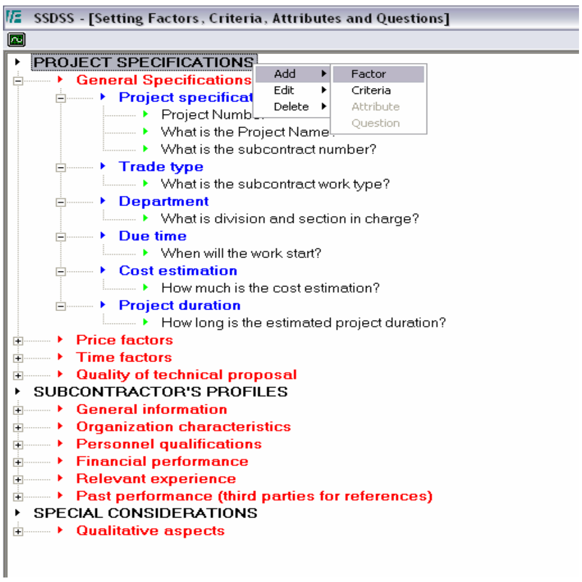
a. Direct pointer to KBES Development Menu, select Setting Parameter. Click on Factors, Criteria, Attributes, and Questions.



Picture II.3. Figure of Setting Parameters of Factors, Criteria, Attributes and Questions

b. Direct pointer to Factor Group (Black colored text and bold type), click on right side, select Add, and select Factor.

c. In dialogue confirmation box, insert Factor title and click on Ok.



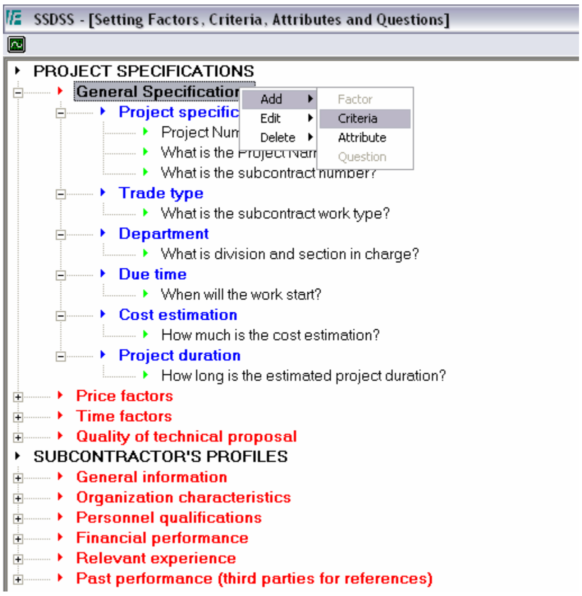
Picture II.4. Figure of Factors Increasing

d. Accordingly, if you want to change the invented Factor title, do steps a, b then select Edit and continue to Ok.
e. Erase Factor by the means of step d, and then select Delete.

II. 2. Add, Edit and Delete Criteria

Steps:

a. Direct pointer to KBES Development Menu, select Setting Parameter. Click on Factor, Criteria, Attribute and Question.
b. Direct pointer to Factor Group (Red colored text and bold type), click right select Add, and select Criteria.
c. In dialogue confirmation box, insert Criteria title then click on Ok.



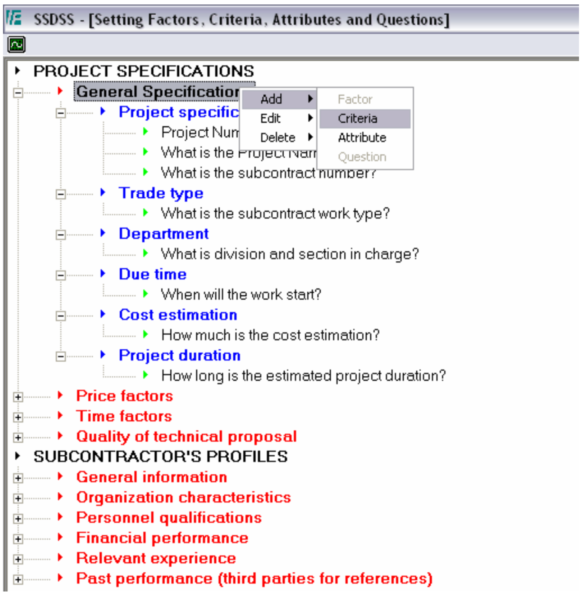
Picture II.5. Figure of Criteria Increasing

d. Accordingly, if you want to change the invented Criteria title, do steps a, b then select Edit and continue to Ok.
e. Erase Criteria by means of step d, and then select Delete.

II. 3. Add, Edit and Delete Attributes

Steps:

a. Direct pointer to KBES Development Menu, select Setting Parameter. Click on Factors, Criteria, Attributes and Questions.
b. Direct pointer to Question Group (Blue colored text and bold type), click right select Add, and select Attributes.
c. In confirmation box dialogue, insert Attribute title then click on Ok.



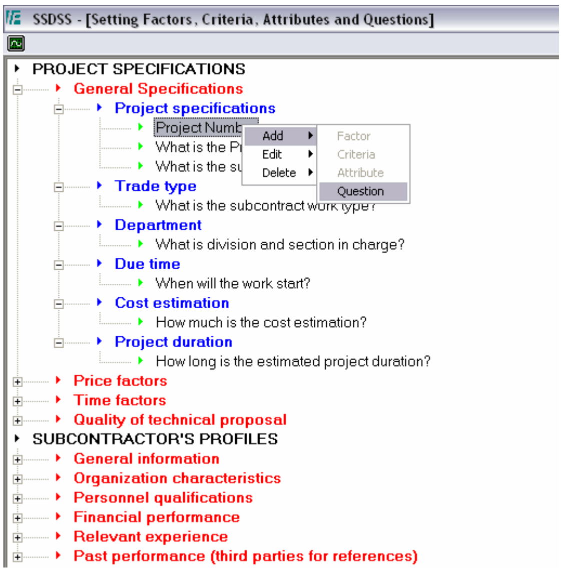
Picture II.6. Figure of Attribute Increasing

d. Accordingly, if you want to change the insert Attribute title, do steps a, b then select Edit and continue to Ok.
e. Erase Attribute by the means of step d, and then select Delete.

II. 4. Add, Edit and Delete Questions

Steps:

a. Direct pointer to KBES Development Menu, select Setting Parameter. Click on Factors, Criteria, Attributes and Questions.
b. Direct pointer to Question Group (Black colored text and bold type), click right select Add, and select Attributes.
c. Accordingly, if you want to change the inserted Question title, do steps a, b then select Edit and continue to Ok.



Picture II.7. Figure of Criteria Increasing

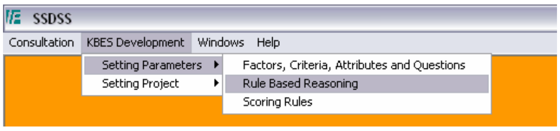
d. Accordingly, if you want to change the insert Question title, do steps a, b then select Edit and continue to Ok.

e. Clear Question by means of step d, and then select Delete.

II. 5. Setting Parameter: Rule Based Reasoning

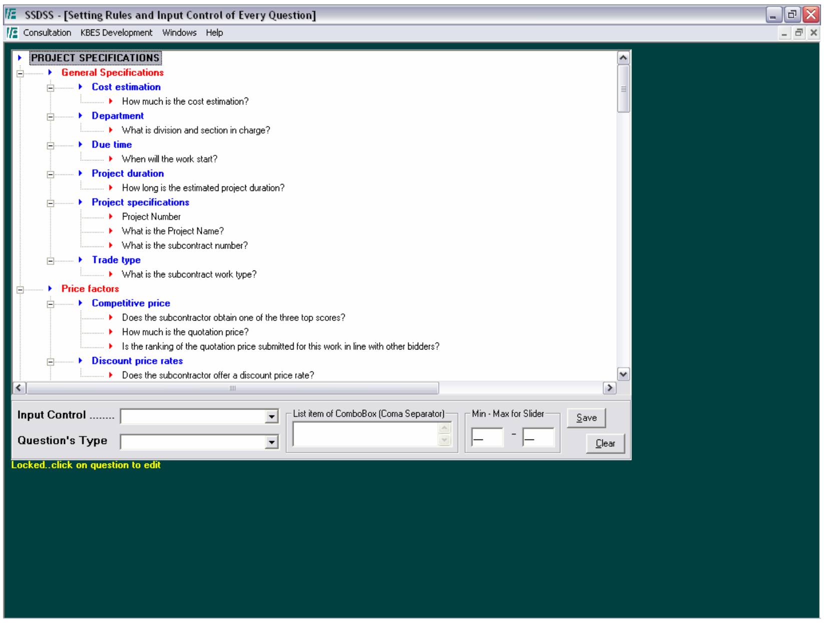
Steps:

a. Direct pointer to KBES Development Menu, select Setting Parameter. Click on Rule-based reasoning, Criteria, Attribute and Question.



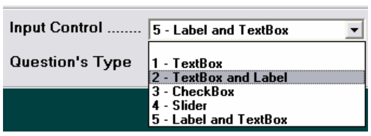
Picture II.8. Figure of Opening of the Rule Based Reasoning Setting Picture.

b. Next, a figure will appear like the picture below.



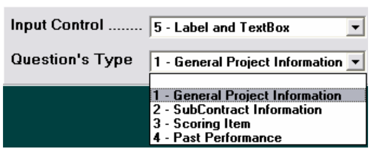
Picture II.9. Figure of Rule Based Reasoning Setting

c. Select desired question and select Rules Input Control:



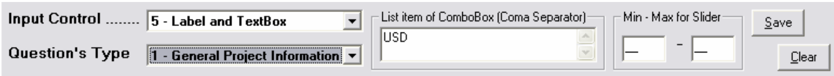
Picture II.10 Figure of Drop Dawn input Control Menus

d. Erase Question by the means of step d, and then select Question types:



Pictures II.11. Figure of Drop down Question type Menu

e. Insert item list value of Combo Box (Coma Separator) and min – max slider features



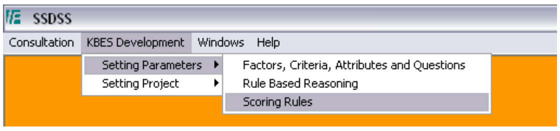
Picture II.12 Figure of Item list input of Combo Box

f. Click on safe button when finished and clear when finished; clear it also when redoing is desired.

II. 6. Setting Parameter: Scoring Rules

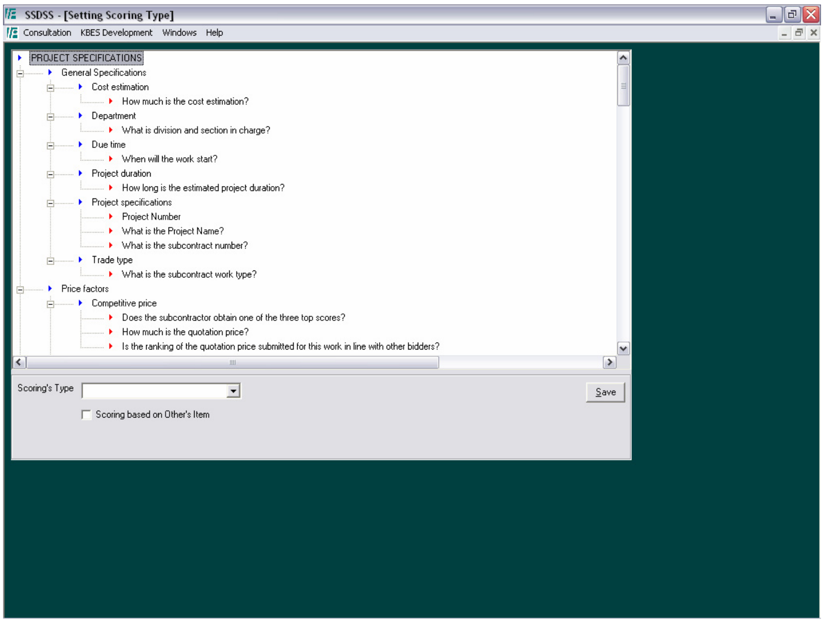
Steps:

a. Direct pointer to KBES Development Menu, select Setting Parameter. Click on Scoring Rules.



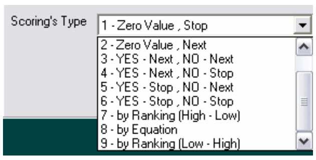
Picture II.12 Figure of Setting Parameters for Rule Scoring

b. Next, a figure will appear like the picture below.



Picture II.13. Figure of Scoring Type setting.

c. Select desired Questions and select Scoring's type :



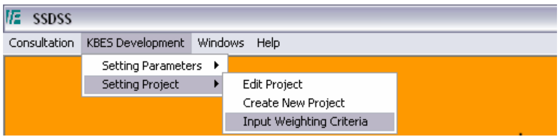
Picture II.14 Figure of Drop down Scoring Type menu

d. Click on save button when finished.

II. 7. Setting Project: Input Weighting Criteria

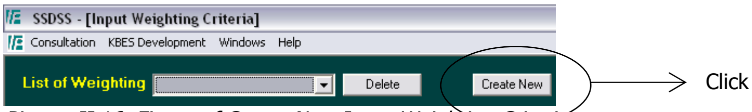
Steps:

a. Direct pointer to KBES Development Menu, select setting Project. Click on Input Weighting Criteria.



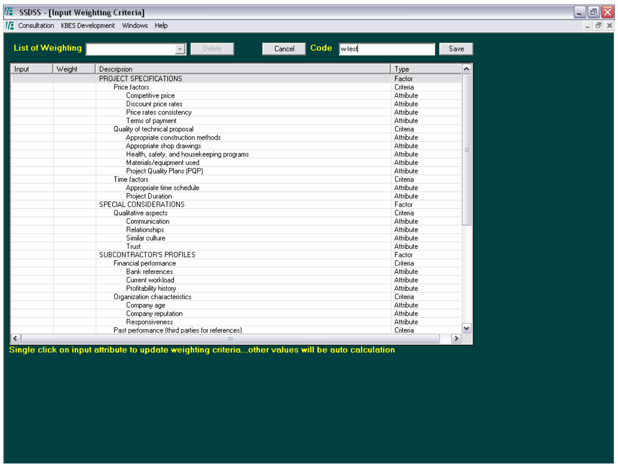
Picture II.15. Figure of Setting Project: Input Weighting Criteria.

b. A figure will come up, and click on create new button.



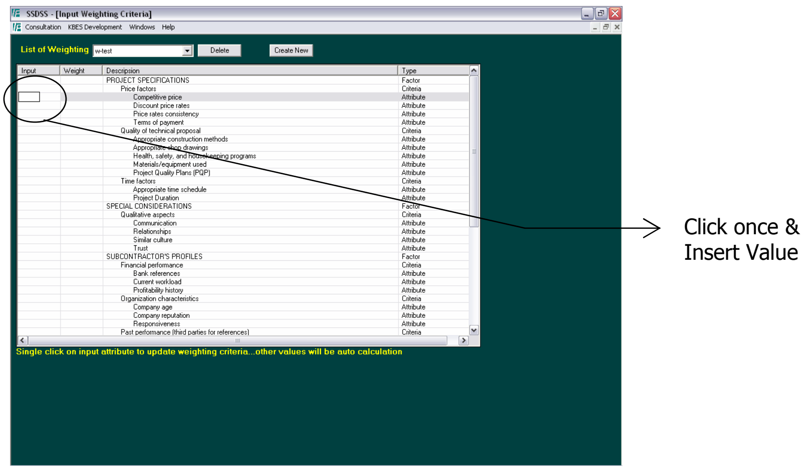
Picture II.16. Figure of Create New Input Weighting Criteria

c. Insert Code Weighting then click on save button.



Picture II.17. Figure of Save Input Weighting Criteria

d. Select Weighting invented on the list of Weighting. Then click once on Input Column – Attribute Line/Row and click desired value.

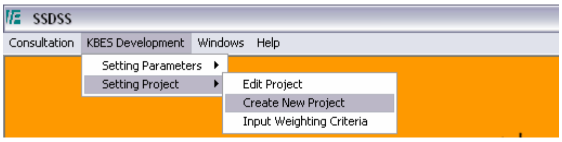


Picture II.18. Figure of Input Weighting Value

II. 8. Setting Project: Create New Project

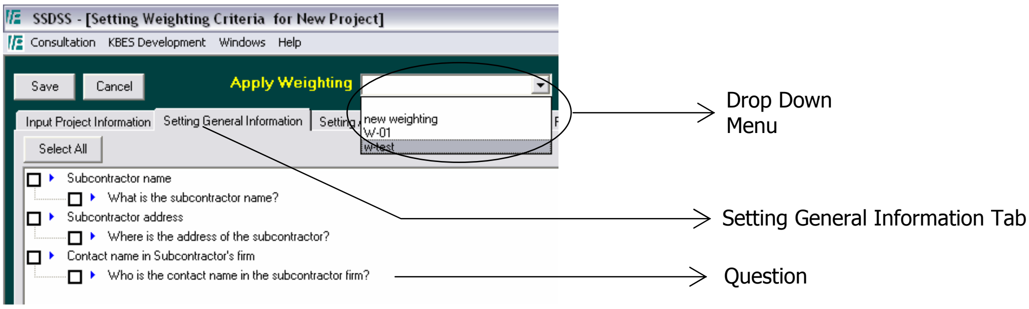
Steps:

a. Direct pointer to KBES Development Menu, select setting Project. Click on Input Weighting Criteria.



Picture II.19. Figure of Setting Project: Create New Project

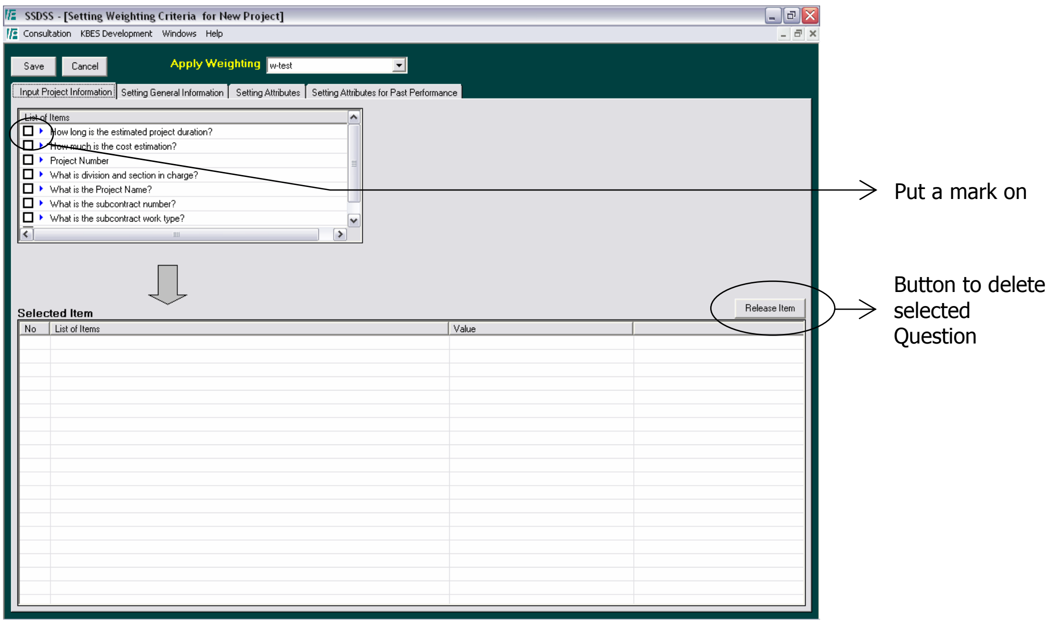
b. A figure will came up. Click on drop down Apply weighting Menu and select pre (formerly) invented Weighting.



Picture II.20. Figure of Setting Apply Weighting

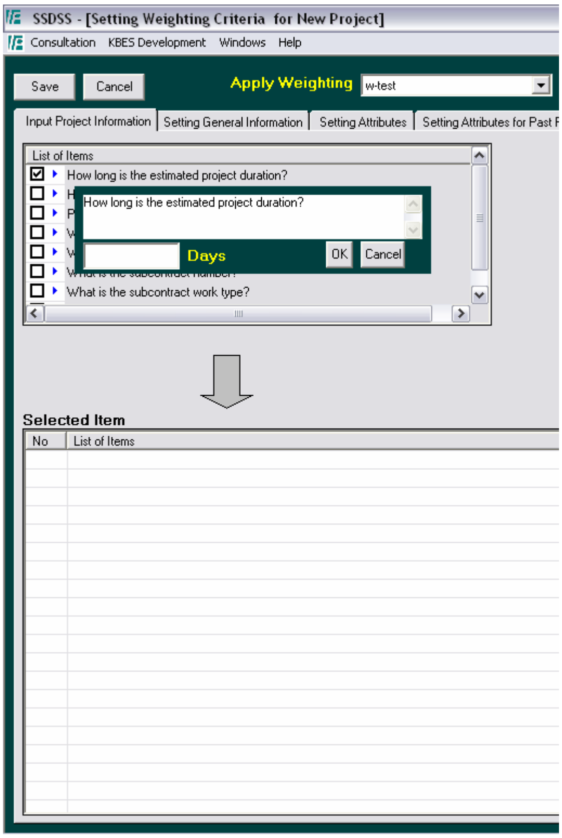
c. On setting General Information Tab, put a mark on checkbox.

d. Move to input Project information, then select desired question from list of item by putting a click mark on Checkbox



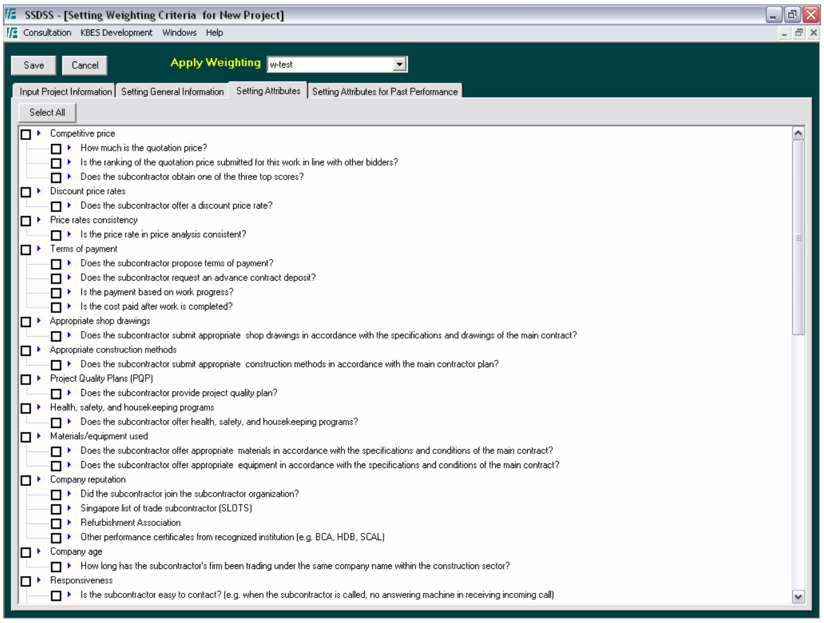
Picture II.21. Figure of selected Question

e. After a check mark is put on the Checkbox, the feature like the picture below will came up; insert the desired value. The selected Question will move to selected item. To cancel that choice push Release item button/Tab.



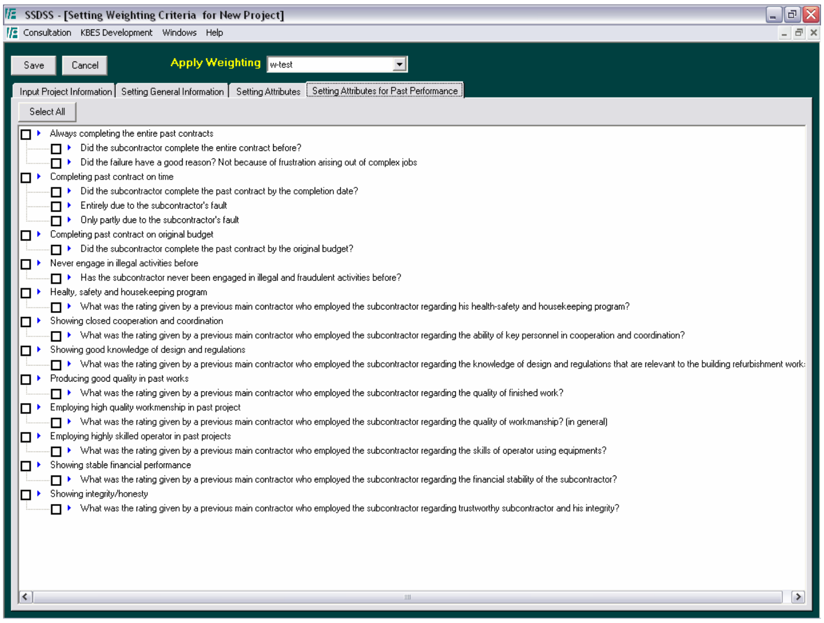
Picture II.22. Figure of Input Parameter Question

f. Click on setting Attributes button and put a check mark in the check box on the selected question.



Picture II.23. Figure of selected Question

g. Click on Setting Attributes Tab for Past Performance and put a check mark in the check box or the selected Question list.



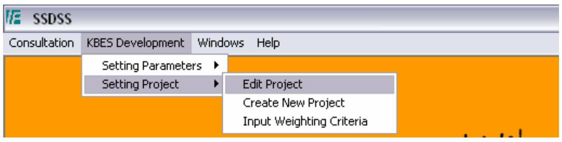
Picture II.24. Figure of Question Choice

h. Click on save after finishing making a choice.

II. 9. Setting Project: Edit Project

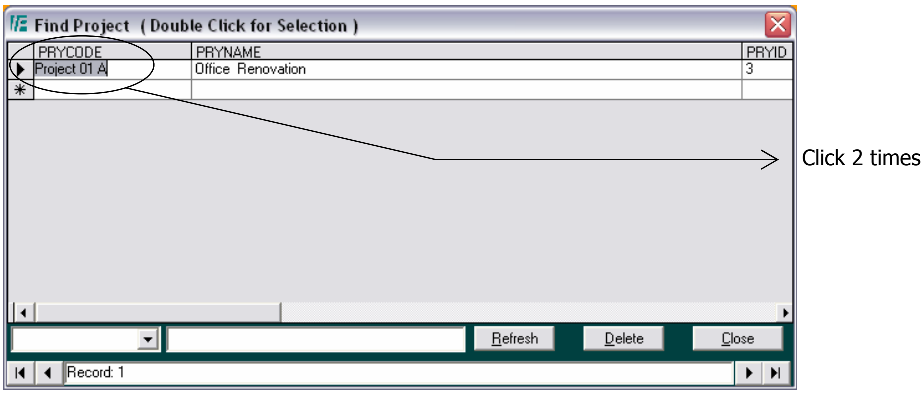
Steps:

a. Direct pointer to KBES Development Menu, select setting Project. Click on Input Weighting Criteria.



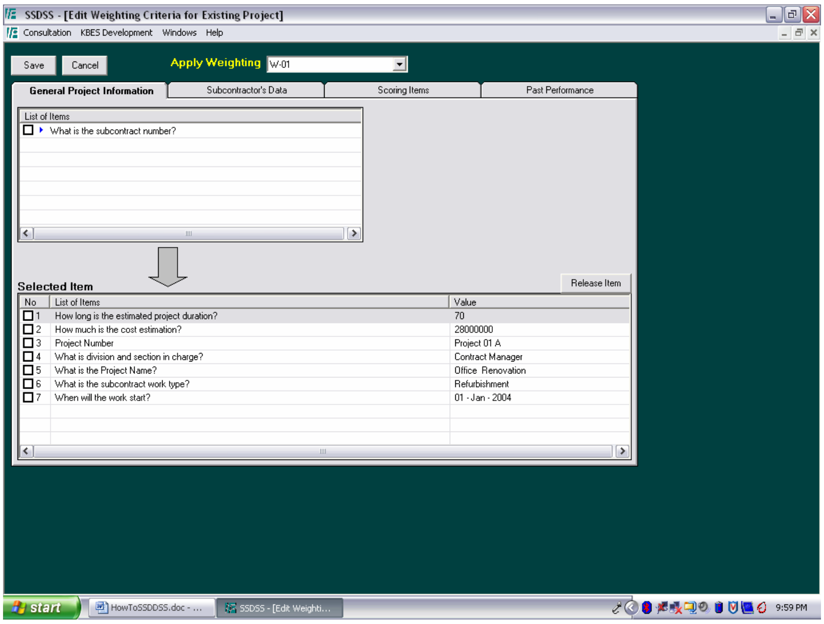
Picture II.25. Figure of Setting Project: Edit Project

b. Following, a figure will appear like the picture below. Click 2 (two) times.



Picture II.26. Figure of Edit Project

c. The result will appear as follows:



Picture II.27. Figure of Edit Question

d. Edit unnecessary questions by putting a check mark in the checkbox. Then click a Release item button.
e. On subcontractor's data score the item. Past performance Tab, erase check box.
f. Click Save button when finished.

III. Consultation Module

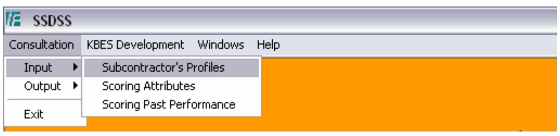
Consultation Module consists of menu and sub menu:

1. Input
   a. Subcontractor's Profiles
   b. Scoring Attributes
   c. Scoring Past Performance
2. Output
   a. Get advice
3. Exit

III. 1. Input: Subcontractor's Profiles

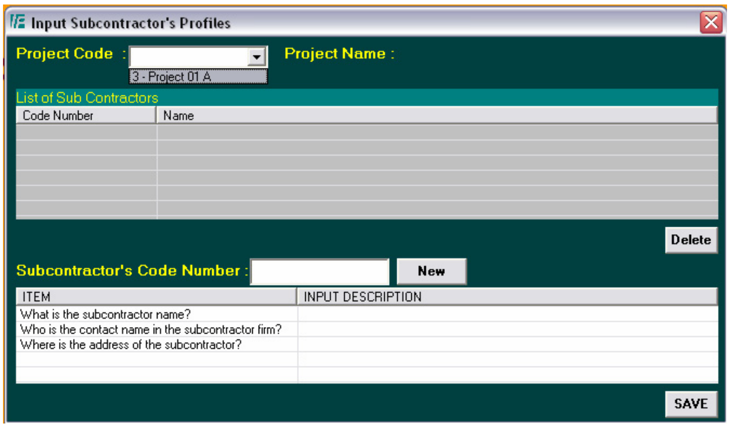
Steps:

a. Direct pointer to consultation menu, select input, click on Subcontractors' Profiles.



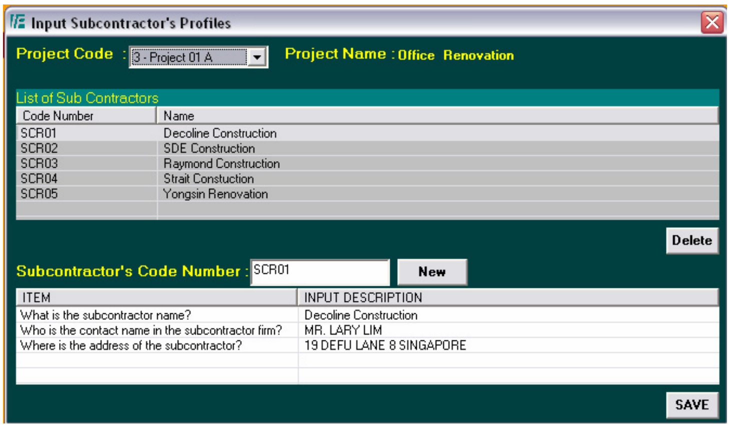
Picture III.1. Figure of Input: Subcontractor's Profiles

b. As the result, a figure will appear like the picture below.



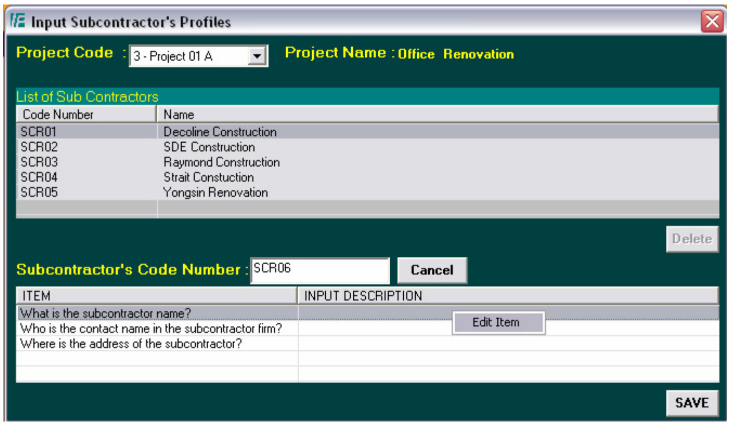
Picture III.2. Figure of Input Project Code

c. Click on Drop Down Project Code Menu and select desired project so that feature will change to :



Picture III.3. Figure of Create New Subcontractor's Code Name

d. Click on new Subcontractor's Code name and type code number to start inserting Subcontractor Code Number.



Picture III.4. Figure of Create New Subcontractor's Code Name

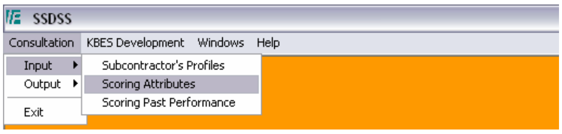
e. In the input Description Column, click right side and click Edit Item to insist that the information matches the question.

f. Save button can be clicked on when all questions have been responded to entirely.

III. 2. Input: Scoring Attributes

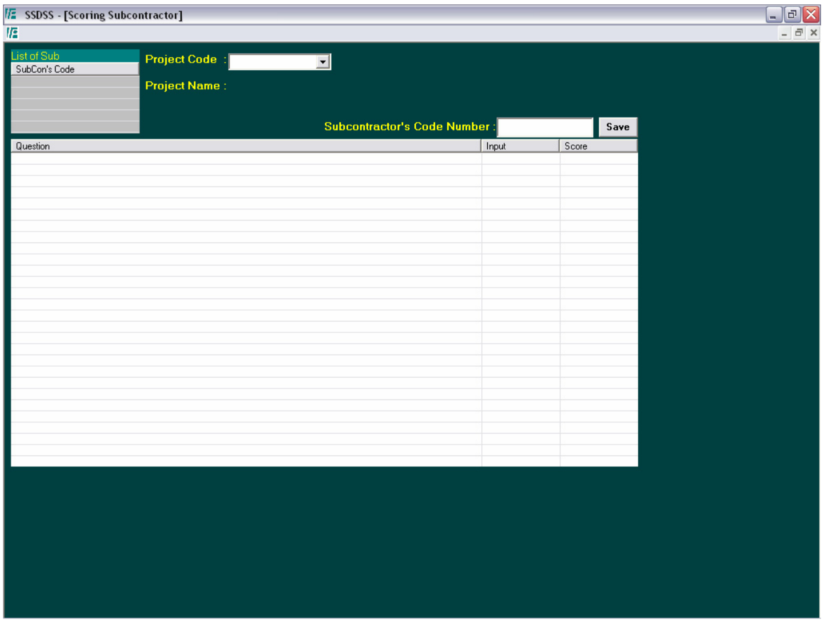
Step:

a. Direct pointer to consultation menu, select input, click on Scoring Attributes.



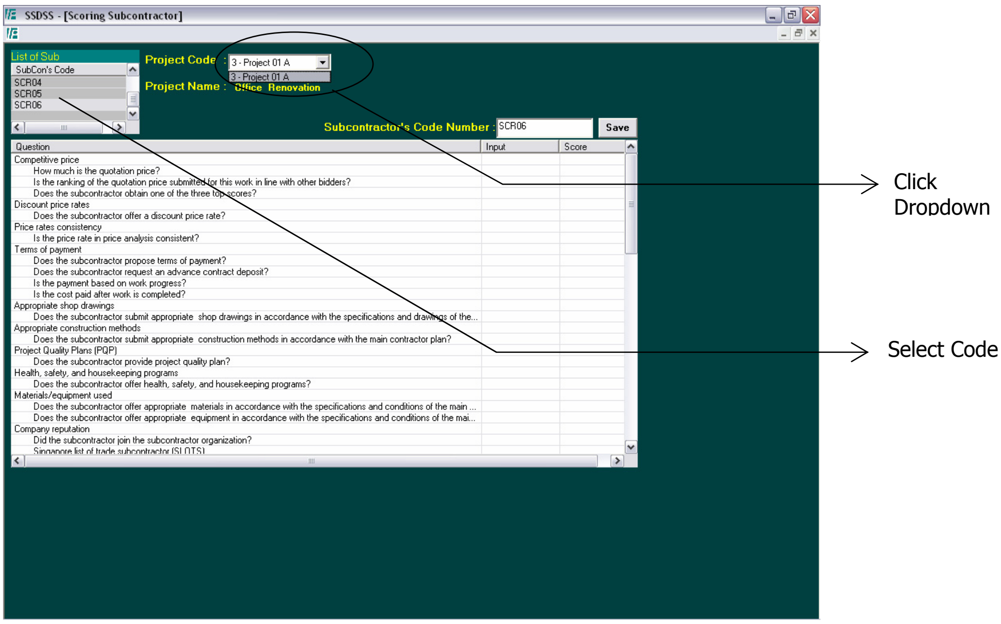
Picture III.5. Figure of Input: Setting Attribute

b. As a result, a figure like the picture below will come up.



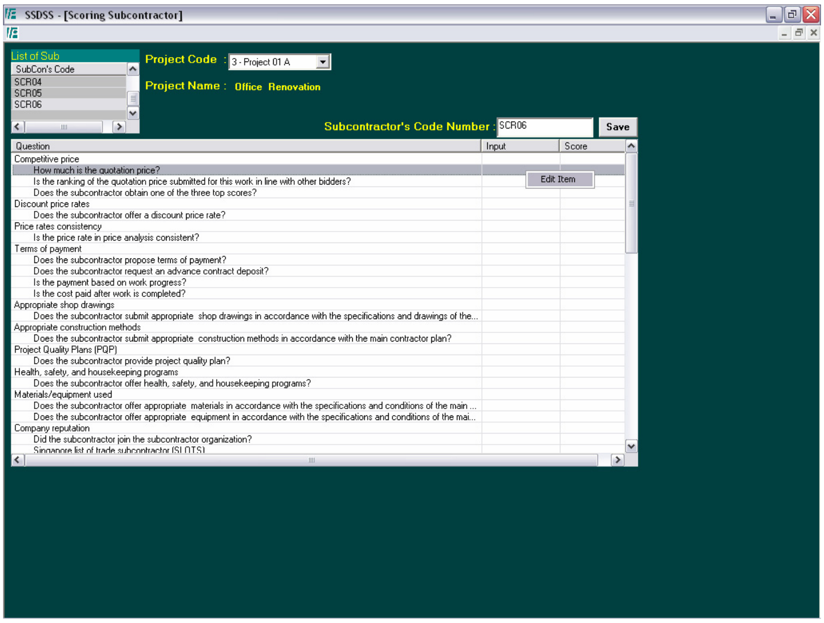
Picture III.6. Figure of Scoring Subcontractor's

c. Click on Drop down Project Code Menu and select desired project on Subcontractor's Code. Select Subcontractor's Code Number which has been made so that the feature will change to:



Picture III.7. Figure of Showing List of Questions

d. Start responding to questions by clicking on right side of input column and click on Edit Item.



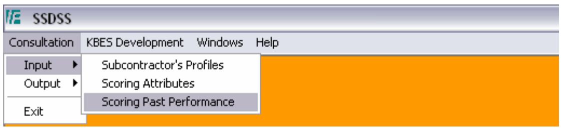
Picture III.8. Figure of Question Responding.

e. Click save button when finished.

III. 3. Input: Scoring Past Performance

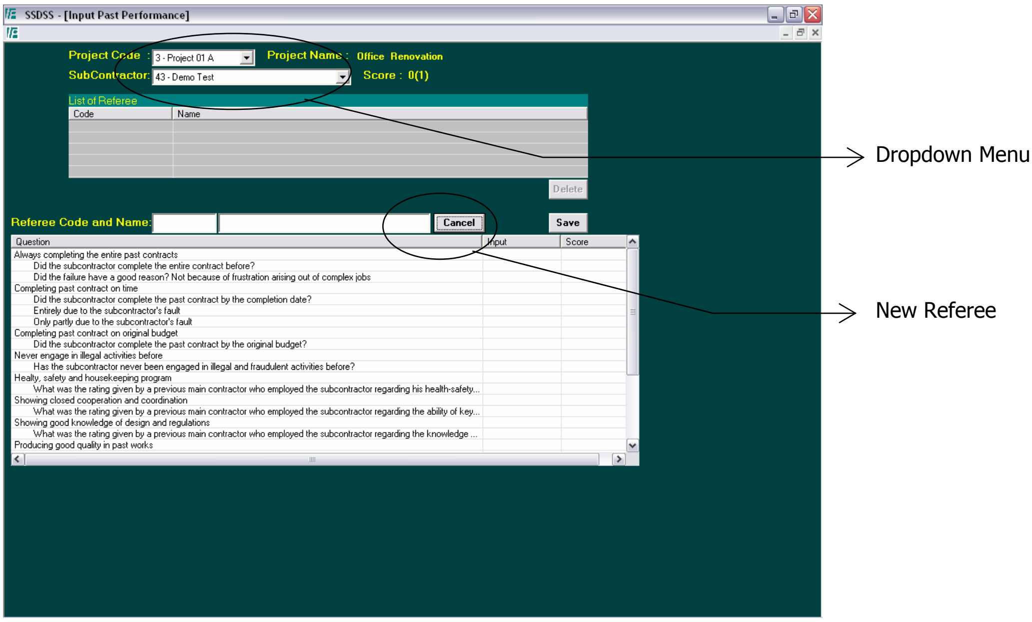
Steps:

a. Direct pointer to consultation menu, select input, click on Scoring Past Performance.



Picture III.9. Figure of Input: Scoring Past Performance

b. As a result, a figure will appear like the picture below.



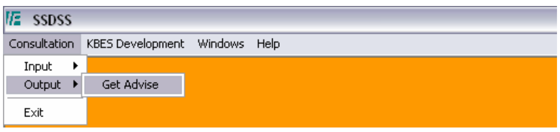
Picture III.10. Figure of Input Past Performance

c. Click on Drop down Project Code and Subcontractor Menu then select the desired project and Subcontractor.
d. Click on now Referee button to insert Referee Code and Name.
e. Start answering questions in Input column like the steps on Scoring Attributes.
f. Click Save button when finished.

III. 4. Output: Get Advice

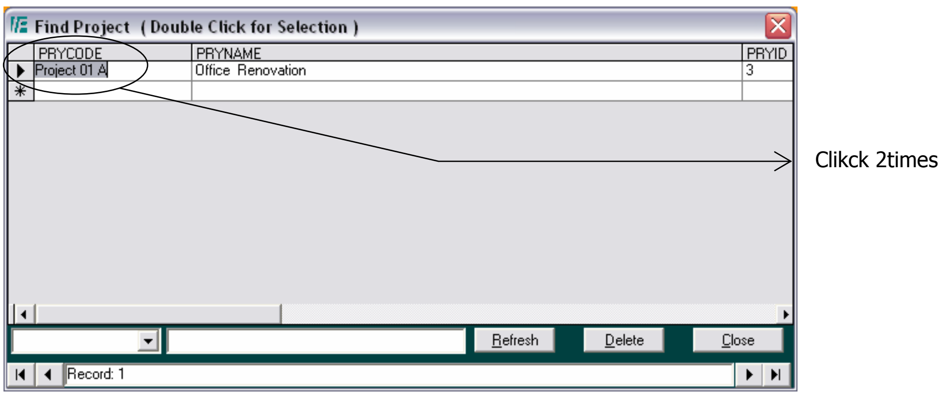
Steps:

a. Direct pointer to Consultation menu, select Output and click on Get Advice.



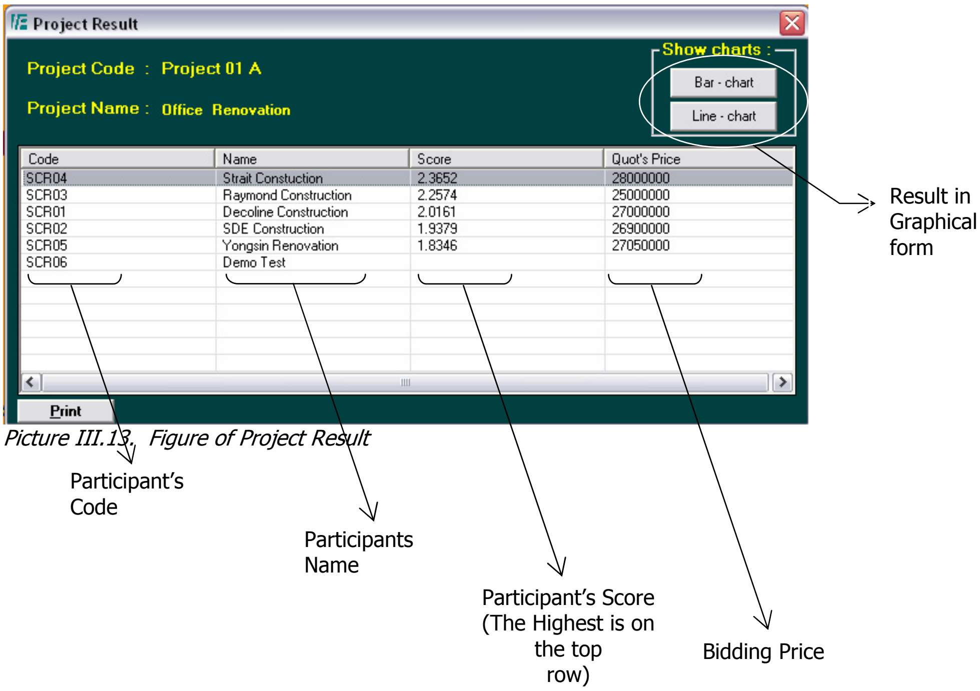
Picture III.11. Figure of Output: Get Advise

b. As a result, a figure will appear like the picture below.



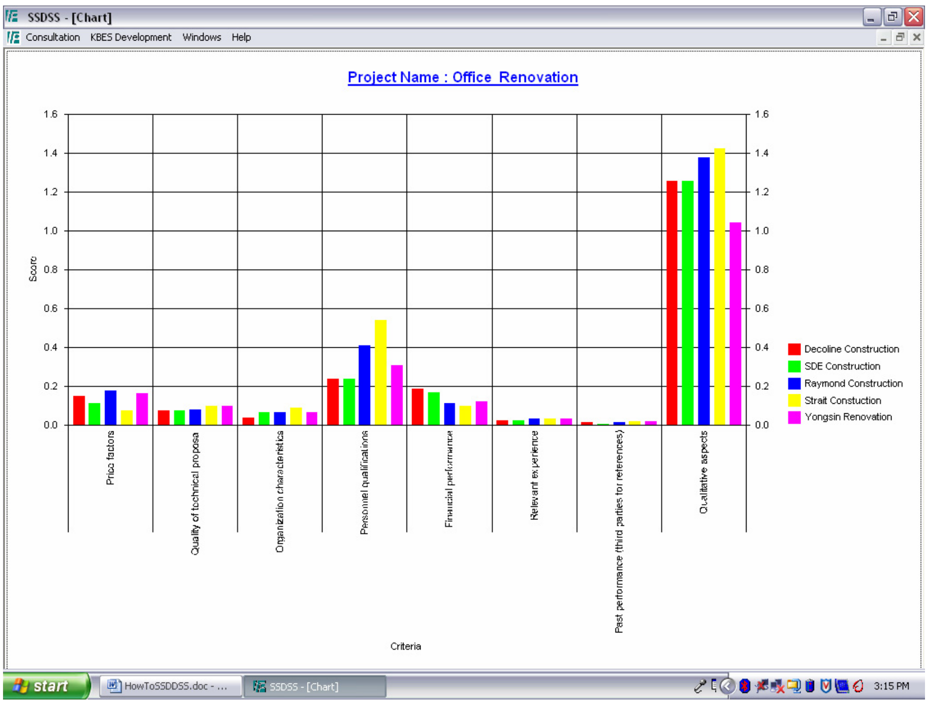
Picture III.12. Figure of Project Selecting

c. Click 2 times on Project Code to show Project Result.



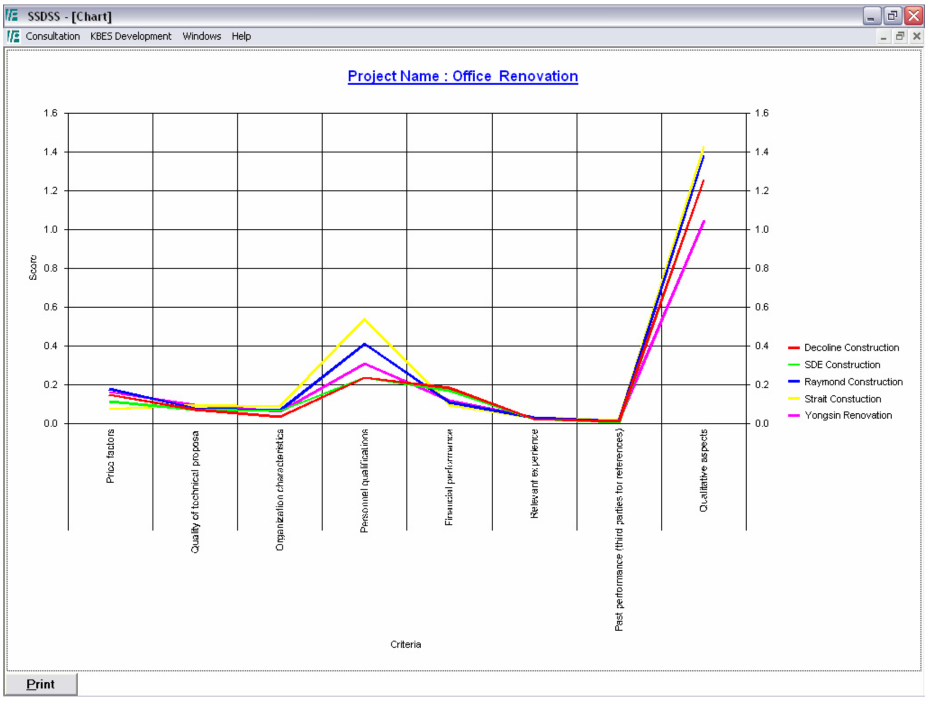
Picture III.13. Figure of Project Result

d. Click on Bar – Chart to figure Project Result in the form Bar-Chart.



Picture III.14. Figure of Bar–Chart result.

e. Click on Line – Chart to figure Project Result in the form of Line-Chart.



Picture III.15. Figure of Line – Chart result

IV. Help Module

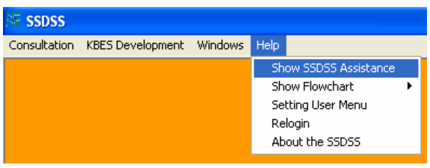
Help Module consists of sub menus:

1. Show SSDSS Assistance
2. Show Flowchart
    a. Animation
    b. Static
3. Setting User Menu
4. Re-login
5. About the SSDSS

IV. 1. Show SSDSS Assistance

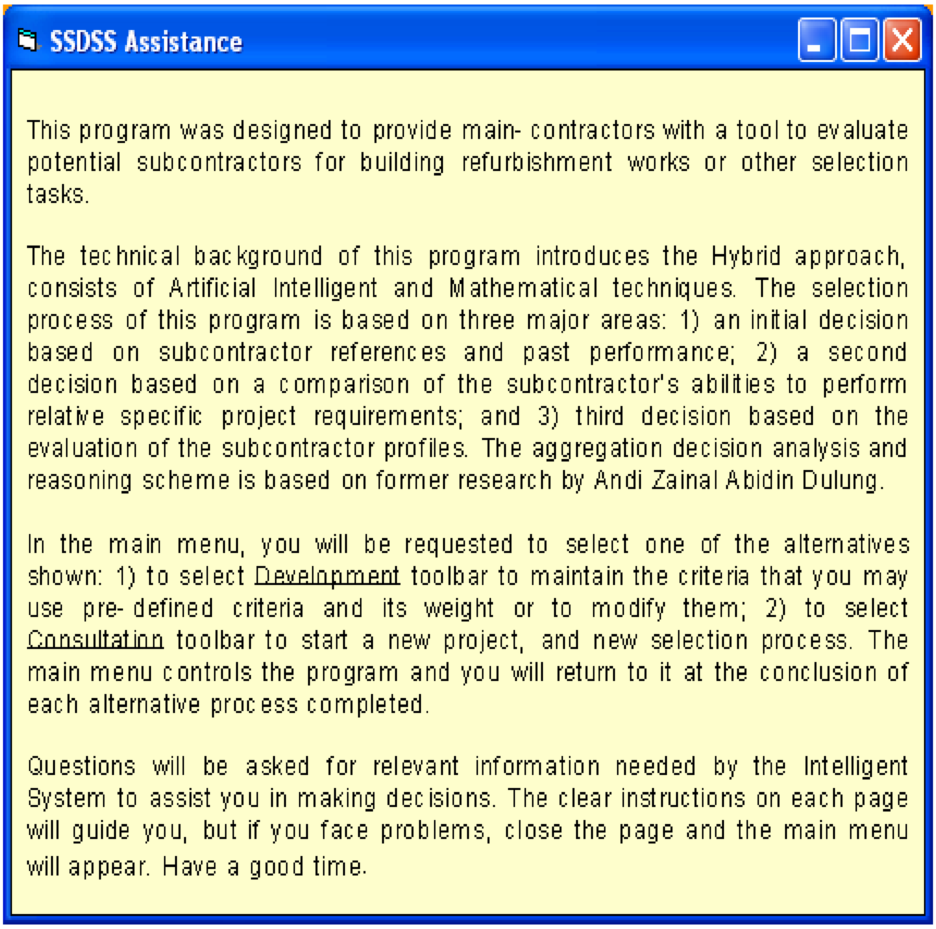
Steps:

a. Direct pointer to Help menu and click on Show SSDSS Assistance.



Picture IV.1. Figure of Sub Menu of Show SSDSS Assistance

b. As a result, a figure will appear like the picture below.

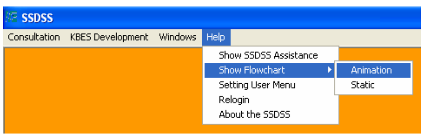


Picture IV.2. Figure of SSDSS Assistance

IV. 2. Show Flowchart

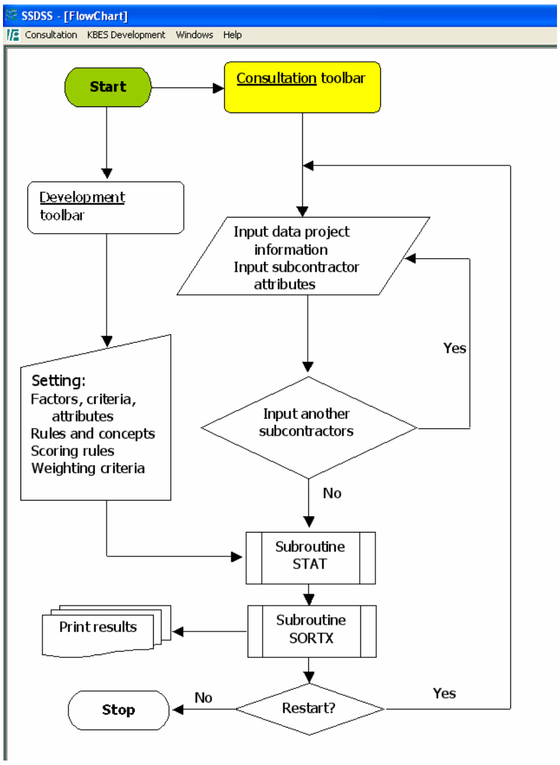
Steps:

a. Direct pointer to Help menu, select Show SSDSS Assistance and click Animation.



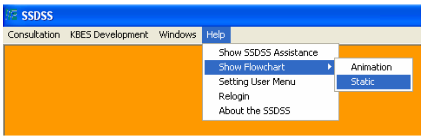
Picture IV.3. Figure of Sub Menu of Show Flowchart: Animation

b. As a result, a figure will appear like the picture below.



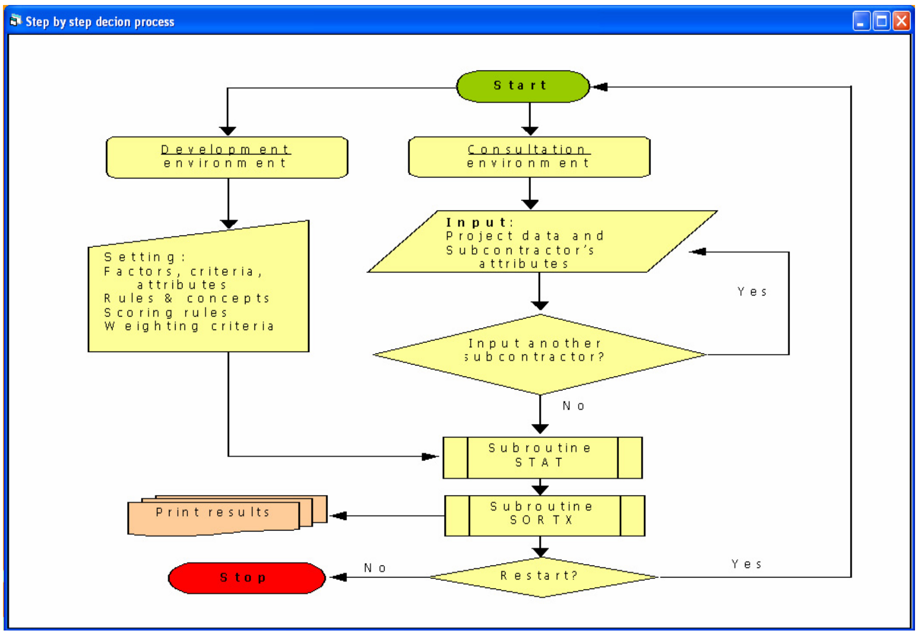
Picture IV.4. Figure of Flowchart: Animation

c. Direct pointer back to Help menu, select Show SSDSS Assistance and click on Static.



Picture IV.5. Figure of Sub Menu of Show Flowchart: Static

d. As a result, a figure will appear like the picture below.

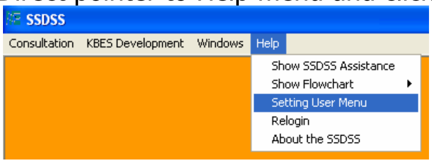


Picture IV.6. Figure of Flowchart: Static

IV. 3. Setting User Menu

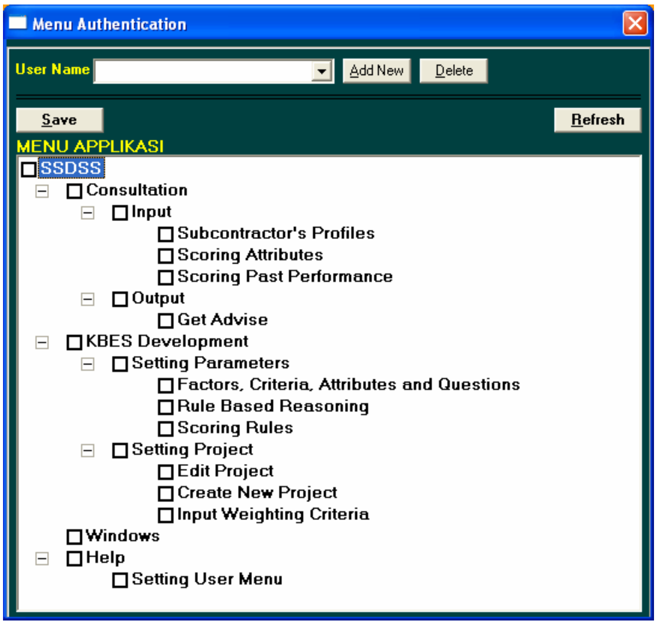
Steps:

a. Direct pointer to Help menu and click Setting User Menu.



Picture IV.7. Figure of Sub Menu of Setting User Menu

b. As a result, a figure will appear like the picture below:



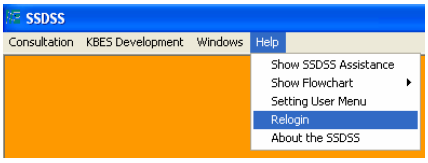
Picture IV.8. Figure of Authentication Sub Menu

c. If wishing to add a new user, type desired user (e.g. "admin") on User Name and click on Add New button.

IV. 4. Re-login

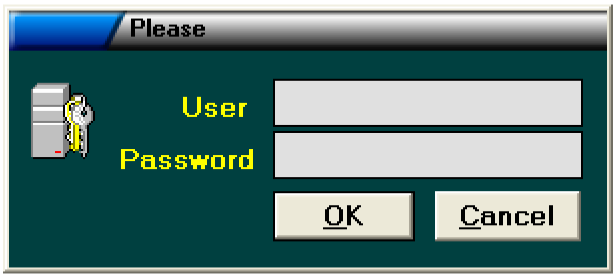
Steps:

a. Direct pointer to Help menu and click Re-login.



Picture IV.11. Figure of Re-login Sub Menu

b. As a result, a figure will appear like the picture below.



c. Insert newly made username and insert given password, then click on OK button.

APPENDIX 4

Evaluation Form for Subcontractor Selection

Name of subcontractor : ________________________________

Contact of subcontractor : ________________________________

Address and contact number : ________________________________

Contact Person : ________________________________

Code number :_______

____

Code number :_______

Rating scale uses a 5-point Likert scale (1 = Poor, 2 = Average, 3 = Good, 4 = Very good, and 5 = Excellent)

1. Project Specifications

1.1 Price specifications

1.1.1 How much is the quotation price? $……………………..

1.1.2 Does the subcontractor offer a discount price rate? | Yes | No |

1.1.3 Is the price rate in price analysis consistent? | Yes | No |

1.1.4 Does the subcontractor propose terms of payment? | Yes | No |

1.1.5 Does the subcontractor request advance contract deposit? | Yes | No |

1.1.6 Is the payment based on work progress? (Pay when paid) | Yes | No |

1.1.7 Is the cost paid after work is completed? | Yes | No |

1.2. Technical Proposal

1.2.1 How long is the duration of work until completed? ………….. days

1.2.2 Is the duration of work proposed comparable to the main contractor program? | Yes | No |

1.2.3 Is the duration of work proposed shorter than the main contractor program? | Yes | No |

1.2.4 Does the subcontractor submit an appropriate time schedule in accordance with the main contractor program? | Yes | No |

1.2.5 Does the subcontractor offer appropriate schedule maintenance in accordance with the specification and conditions of the main contract? | Yes | No |

1.2.6 Does the subcontractor submit appropriate shop drawings in accordance with the specification and drawing of the main contract? | Yes | No |

1.2.7 Does the subcontractor submit appropriate construction methods in accordance with the main contractor plan? | Yes | No |

1.2.8 Does the subcontractor offer appropriate materials in accordance with the specification and conditions of the main contract? | Yes | No |

1.2.9 Does the subcontractor offer appropriate equipment in accordance with the specification and conditions of the main contract? | Yes | No |

1.2.10 Does the subcontractor provide project quality plan? | Yes | No |

1.2.11 Does the subcontractor offer health, safety, and housekeeping programs? | Yes | No |

2. Subcontractor's Profiles

2.1 Organization Characteristics

2.1.1 Did the subcontractor join the subcontractor organization? | Yes | No |

a. SLOTS | Yes | No |

b. Refurbishment Association | Yes | No |

c. Other performance certificates from recognized institution (e.g. BCA, HDB, SCAL, MOM) | Yes | No |

2.1.2 How long has the subcontractor's firm been trading under the same company name within the construction sector? ....months/years

2.1.3 Is the subcontractor easy to contact? (e.g. when the subcontractor is called, no answering machine in receiving incoming call) | Yes | No |

2.1.4 Is the subcontractor quick to respond when receiving requests and instructions of the main contractor? (How long = hours) .... hours

2.2 Personnel Qualification

2.2.1 What percentage (%) of the subcontractor's key personnel have good technical ability?	……… %
2.2.2 Has the key personnel of the subcontractor experienced working in building refurbishment work before?	Yes / No
2.2.3 How many projects have been completed?	……. units
2.2.4 Does the key personnel of the subcontractor have technical ability to interpret and use contract documents?	Yes / No

2.3 Financial Stability

2.3.1 How long has the subcontractor's firm been with the same bank?	……… months/years
2.3.2 What was the rating given by the bank referee regarding the company's financial performance?	1 / 2 / 3 / 4 / 5
2.3.3 Has the subcontractor's firm shown profitability over the last 2 years?	Yes / No
a. Return on sales	Yes / No
b. Return on assets	Yes / No
2.3.4 Is the subcontractor currently working for other main contractors?	Yes / No
2.3.5 Is the subcontractor currently working for other two or more main contractors?	Yes / No

2.4 Relevant Experience

2.4.1 Did the subcontractor provide details of subcontracting jobs completed within the past 5 years?	Yes / No
2.4.2 How many refurbishment works have been completed?	……… units
2.4.3 How many new building works have been completed?	……… units
2.4.4 Did the subcontractor experience a similar size ($) project to the proposed work within the past 5 years? (More or less 20%)	Yes / No

2.4.5 Is the proposed work of a size ($) most often undertaken by the subcontractor company?

Yes	No

2.5 References on Past Performance (refer to other form)

2.5.1 How many references does the subcontractor have? ……….. referees

3. Special Considerations

3.1 Qualitative Aspects

3.1.1 What rating would you give to the similarity of the culture of your company with the subcontractor?

1	2	3	4	5

3.1.2 What rating would you give to the subcontractor regarding the relationship of your company with the subcontractor?

1	2	3	4	5

3.1.3 What rating would you give to the subcontractor regarding the relationship of your site staff with the subcontractor's site personnel?

1	2	3	4	5

3.1.4 What rating would you give to the subcontractor regarding his trustfulness?

1	2	3	4	5

3.1.5 What rating would you give to the subcontractor regarding his ability in communication?

1	2	3	4	5

APPENDIX 5

Evaluation Form for Past Performance of Subcontractors

(by a main contractor who employed the subcontractor before)

Subcontractor name : _________________________

Subcontractor address : _________________________

Referee : _________________________

Rating scale uses a 5-point Likert scale (1 = Poor, 2 = Average, 3 = Good, 4 = Very good, and 5 = Excellent)

Past Performance of the Subcontractor

1. Did the subcontractor complete the entire contract before?	Yes / No
a. Did the failure have a good reason? Not because of frustration arising out of complex jobs.	Yes / No
2. Did the subcontractor complete the past contract by the completion date?	Yes / No
a. Entirely due to the subcontractor's fault	Yes / No
b. Only partly due to the subcontractor's fault	Yes / No
3. Did the subcontractor complete the past contract by the original budget?	Yes / No
4. Has the subcontractor never been engaged in illegal and fraudulent activities before?	Yes / No
5. What rating may you give the subcontractor regarding his health-safety and housekeeping program?	1 2 3 4 5
6. What rating may you give the subcontractor regarding the ability of key personnel in cooperation and coordination?	1 2 3 4 5
7. What rating may you give the subcontractor regarding the knowledge of design and regulations that are relevant to the building refurbishment works?	1 2 3 4 5
8. What rating may you give the subcontractor regarding the quality of finished previous work?	1 2 3 4 5
9. What rating may you give the subcontractor regarding the quality of workmanship? (In general)	1 2 3 4 5

10. What rating may you give to the subcontractor regarding the skills of operator using equipments?

1	2	3	4	5

11. What rating may you give the subcontractor regarding the financial stability of the subcontractor?

1	2	3	4	5

12. What rating may you give the subcontractor regarding trustworthy subcontractor and his integrity?

1	2	3	4	5

APPENDIX 6

Structured Questionnaire for Validation of the SSDSS

The following questions are used to measure the constructs knowledge comprehensiveness, knowledge accuracy, reasoning and benefits of the SSDSS. Measures for the construct knowledge use a 5-point Likert scale (1=strongly disagree, 2=disagree, 3=undecided, 4=agree, and 5=strongly agree).

Evaluator's name: ______________________________

Please evaluate the constructs of the SSSDSS by circling a number on the scale (each line should have one circle)	*1 Strongly disagree*	*2 Disagree*	*3 Undecided*	*4 Agree*	*5 Strongly agree*
1. Measures for Performance Validation					
1.1. Construct: Knowledge Comprehensiveness					
How do you rate the knowledge comprehensiveness of the SSDSS?					
1.1.1 The SSDSS contains all relevant factors for selecting subcontractors	1	2	3	4	5
1.1.2 The SSDSS contains all relevant criteria for selecting subcontractors	1	2	3	4	5
1.1.3 The SSDSS contains all relevant attributes for selecting subcontractors	1	2	3	4	5
1.1.4 The SSDSS has a comprehensiveness set of evaluation rules to select subcontractor	1	2	3	4	5
1.2. Construct: Knowledge Accuracy					
How do you rate the knowledge accuracy of the SSDSS?					
1.2.1 All the parameters are accurately presented in the SSDSS	1	2	3	4	5
1.2.2 All the evaluation factors are accurately represented in the SSDSS	1	2	3	4	5
1.2.3 The SSDSS's rule base is an accurate representation of the evaluation rules for selection of subcontractors	1	2	3	4	5

Please evaluate the constructs of the SSDSS by circling a number on the scale (each line should have one circle).	*1 Strongly disagree*	*2 Disagree*	*3 Undecided*	*4 Agree*	*5 Strongly agree*
1.3 Construct: Reasoning Validity					
How do you rate the reasoning validity of the SSDSS?					
1.3.1 The reasoning process of the SSDSS closely resembles that of a domain expert	1	2	3	4	5
1.3.2 The SSDSS considers all the relevant rules in arriving at a decision	1	2	3	4	5
1.3.3 The SSDSS utilizes the inference rules in the right sequence for the evaluation process	1	2	3	4	5
2. Measures for System Utility Assessment					
2.1 Construct: Utility in Selecting Subcontractors					
How do you rate the utility of the SSDSS?					
2.1.1 The SSDSSS offers a structured, well-organized approach to select potential subcontractors	1	2	3	4	5
2.1.2 The user interface of the SSDSS is user friendly	1	2	3	4	5
2.2 Construct: System Benefits					
How do you rate the benefits of the system?					
2.2.1 The SSDSS can preserve the expertise of professional staff who leave our organization	1	2	3	4	5
2.2.2 The SSDSS can be used as a training tool for novices and management trainees within our organization	1	2	3	4	5
2.2.3 The SSDSS's ability to store and retrieve information in separate data base is useful	1	2	3	4	5
2.2.4 The SSDSS's ability to modify criteria weights and values and examine effect on decision is useful	1	2	3	4	5

Other comments regarding the SSDSS (*please specify*):

End of survey

Thank you very much for your cooperation.