CONTRACTOR SELECTION
USING
MULTIATTRIBUTE UTILITY THEORY

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Contents

LIST OF TABLES

LIST OF FIGURES

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LIST OF ABBREVIATIONS

CSC = Contractor selection criteria

PSF = Project success factor

u(t) = Time utility function

u(c) = Cost utility function

u(q) = Quality utility function

k_t = Time scaling constant

k_c = Cost scaling constant

k_q = Quality scaling constant

k = General Scaling constant

E = Sample expected mean

S = Sample standard deviation

μ = Population expected mean

r = Population standard deviation

CONTRACTOR SELECTION USING MULTIATTRIBUTE UTILITY THEORY

ABSTRACT

Literature and past research suggests that one of the reasons for the poor performance of the construction industry is due to the inappropriateness of the awarded contractor. In order to ensure a successful completion of a project, a comprehensive and careful assessment of contractors data in a prequalification stage is required. Appointing an appropriate contractor to carry out the construction work, therefore, becomes one of the most important tasks to ensure the success of a project.

In this thesis the author has made a preliminary survey to investigate the bidding process currently used in the construction industry through literature survey, extensive interviews with the construction professionals and an industry wide questionnaire. The investigation has focused on the procedures of prequalification and bids evaluation, it also covers the list of criteria considered for selecting contractors in prequalification and bid evaluation stages.

The thesis investigated the perceived relationship between contractor selection criteria (CSC) currently in use and predominant project success factors (PSF) in terms of time, cost and quality involving a sample of experienced construction professionals.

This research is based on the premise that selection should concentrate on determining contractor potential for achieving project goals in terms of time, cost and quality. The study presented a quantitative technique to combine the contractor data in terms of these goals. The study also presented an evaluation strategy that involves the consideration both of the client goals as ends and contractor data as the means, the strategy based on the multiattribute utility theory for the final selection or rank ordering of the contractors. The selection is ultimately based on the preferences and the attitude of the decision maker toward risk.

A real case study was used to validate the proposed methodology for contractor prequalification.

The benefit of this work is that it provides a means using the PERT methodology to incorporate uncertainty and/or imprecision associated with the assessment of contractors data, this all in terms of the ultimate project success factors of time, cost, and quality.

The utility technique proposed should help clients in selecting contractors and the contractors themselves for selecting sub-contractors in offering a means of broadening their analysis of tenderers beyond that of simply relying on tender values. It also alerts contractors to the importance of increasing their ability to satisfy the needs of the clients in terms of their ultimate project goals.

1. INTRODUCTION

CHAPTER 1

Introduction

1.1 BACKGROUND

Despite the increasing use of alternative forms of project delivery systems in the last two decades, the performance of the construction industry has declined as many projects end up with sub-standard work, delays and cost over-runs.

Literature and past research suggests that one of the reasons for this poor performance is due to the inappropriateness of the awarded contractor. The methodologies and procedures for bid evaluation, selecting contractors and awarding contracts have remained relatively unchanged since the 1940's (Merna and Smith 1990). Systems of bid evaluation in the public sector clients are dominated by the principle of acceptance of the lowest price (Holt et al 1993).

In order to ensure a successful completion of a project, a comprehensive and careful assessment of contractors data in a prequalification stage is required. Appointing an appropriate contractor to carry out the construction work, therefore, becomes one of the most important tasks to ensure the success of a project.

The main purpose of this research is to offer a rational method for selecting contractors during the prequalification stage in particular. This requires collection of the contractor selection criteria (CSC); investigating the effect of the CSC on predominant project success factors(PSF) in terms of time, cost and quality; the experience of how the evaluation decisions have been made, and what was the outcome from those decisions. Multiattribute utility methodology has been utilised to solve the selection problem.

1.2 OBJECTIVES

The main aim of this thesis is to develop a decision support system to rank order contractors for a standing or project list in terms of time, cost and quality. There are a number of objectives for how the aim is going to be managed. The principal objectives of the research are as follows:

a) To examine the current methods used in tendering and bid evaluation for UK construction contracts.

b) To investigate the common characteristics in different procurement arrangements in respect of the contractor selection.

c) To identify contractor selection criteria for prequalification and bid evaluation and the means by which different emphases can be accommodated to suit the requirements of clients and projects.

d) To investigate the effect of contractor selection criteria (CSC) on project success factors (PSF) in terms of time, cost and quality.

e) To develop a systematic multiattribute decision analysis technique for assessing and evaluating contractor data for the purpose of prequalification using utility theory.

1.3 SCOPE OF STUDY

The management of contractor selection at prequalification stage is a pre-tender process used to investigate and assess the capabilities of contractors to satisfactorily carry out a contract if it is awarded to them. Bid evaluation, on the other hand, involves similar processes but occurs at the post-tender stage and involves the consideration of the bid amount in addition to the contractors' capabilities. The research has concentrated on the contractor selection at a prequalification stage.

The study is limited to the investigation of the effects of contractor selection criteria on the three predominant project success factors in terms of time, cost and quality.

A systematic multiattribute decision analysis technique using utility theory was developed for the purpose of contractor selection. The technique uses contractor selection criteria (CSC) as means and project success factors (PSF) as ends for assessing and evaluating contractor data for the purpose of prequalification.

1.4 METHODOLOGY

The following methodologies were used in the study:

a) Literature review

b) interviews

c) Questionnaire survey.

d) Hypothetical case studies

e) Real case study

The significance of contractor selection issue was a matter of concern that was raised in many occasions by the author and his colleagues in construction industry in his home country. Serious discussions with academic staff members and colleagues in and outside the department provided an insight into the current awareness of this matter and gave an initial response and suggestions on this subject.

The main research method initially, was a literature review of construction management and decision analysis techniques with multiple objectives. A comprehensive literature survey on contractor selection has revealed that this issue is a key matter that has to be taken seriously for the success of our future projects. Literature survey was also conducted on the current techniques that subsequently enabled me to consider different types of quantitative and qualitative attributes, special attention was given to multiattribute utility theory due to its increasing successful application in other fields.

An initial survey in the form of interviews was held with professionals who were directly involved with tendering procedures, prequalification of contractors and bids evaluation and those who have had experience working in this field. The interviews investigated deeply the numerous types of contractor selection criteria, their sources of information, and the way they are measured.

To support the findings of the interviews, a questionnaire survey was conducted to retrieve information from a wider geographical area. The survey produced a good response in terms of participation.

Second round of interviews using Delphi method investigated the perceived relationship between contractor selection criteria (CSC) and project success factors (PSF) in terms of time, cost and quality .

A hypothetical case study, was used to apply the multiattribute utility theory in the field of contractor selection, an encouraging and promising new tool was achieved that hopefully will be adopted for selecting the suitable bidders for the job. A real case was then used to test the decision tool.

Five papers were prepared during the period of the research, the first one covers the current procedure of contractors prequalification and bids evaluation, while the second is devoted to listing the criteria that are considered in contractor prequalification and bids evaluation(Construction Management and Economics), the third paper is to apply the simplest model of utility theory to select contractor. Paper four covers the effect of contractor selection criteria on time, cost and quality(Construction Management and Economics), the last paper proposes a methodology for the evaluation of contractor data(Construction Management and Economics).

1.5 HYPOTHESIS

The research on which this thesis is based, rests on the premise that there is a possible common set of contractor selection criteria and these criteria have an impact on the project success factors. If these criteria are identified, their levels of importance determined, and the relationship between these criteria and project success factors is investigated, the development of an objective quantitative selection framework could be facilitated. Construction clients may then apply more objective contractor selection methods as a means of identifying the most suitable contractor for a project. This alternative approach could avoid duplication of effort (with a commensurate reduction in individual clients' resource costs).

1.6 ORGANISATION OF THE THESIS

This thesis consists of eleven chapters. Appendix 1 Shows the organisation of the thesis which is described briefly below.

Chapter 2: Contains a general review of the state of the art of contractor prequalification and bids evaluation procedures. It also consists of literature review in these issues and a preliminary live investigation through interviews with professionals in the construction industry.

Chapter 3: Is a continuation of chapter 2. It covers a review of the contractor selection criteria (CSC) considered during prequalification and bid evaluation. It consists of literature review and interviews conducted for the purpose of chapter two.

Chapter 4: Is also part of the literature review focusing on the decision models used for selection of contractors, special attention was focused on the multiattribute utility theory in the last sections of the chapter.

Chapter 5: In this chapter a questionnaire survey was conducted to identify criteria for prequalification and bid evaluation and the means by which different emphases can be accommodated to suit the requirements of clients and projects.

Chapter 6: Presents the principles of utility theory and its different models. It also covers the use of an additive utility model for contractor selection through a hypothetical case study.

Chapter 7: In this chapter a Delphi study investigating the perceived relationship between the contractor selection criteria (CSC) currently in use and project success factors (PSF) in terms of time, cost and quality is described.

Chapter 8: Describes the use of PERT approach for the assessment of contractor data in terms of the three predominant project success factors in terms of time, cost and quality.

Chapter 9: Presents the decision analysis technique using multiplicative utility model. Time, cost and quality are the three attributes used in this model. In order to apply the utility theory in identifying and ranking the suitable contractor a detailed hypothetical case is offered.

Chapter 10: Is devoted to test the decision technique, real data were used for the validation.

Chapter 11: Concludes the current work of the research and recommends suggestions for future work.

Most of the chapters start by an introduction and end with a conclusion and forward to the next chapter. The tables, figures and equations were numbered for each chapter separately, for example Table 2.3, the first number refers to the chapter while the second refers to the sequence of the Table inside the chapter. References were given for each chapter at the end of the particular chapter.

2. TENDERING AND BID EVALUATION PROCEDURES

CHAPTER 2

Tendering and Bid Evaluation Procedures

2.1 INTRODUCTION

The bidding (tendering) process, is an important stage in the project development cycle. It is said to comprise two different activities. The first comprises the compilation of bids and formulation of bidding strategies and is normally carried out by contractors in the preparation and tendering of contract bids. This activity has experienced steady development and received attention by many authors (eg., Drew and Skitmore, 1990; Skitmore, 1989; Ahmad and Minkarah, 1988; Ibbs and Crandall, 1982; Fellows and Langford, 1980). The second activity involves the analysis and evaluation of bids and is normally carried out by owners (clients) and/or their representatives (consultants), and leads to the selection of a contractor to undertake the contract. This activity has received considerably less attention (Moselhi and Martinelli, 1990; Herbsman and Ellis, 1992; Merna and Smith, 1990; Russell and Skibniewski, 1987; Nguyen, 1985).

Despite the increasing use of alternative forms of project delivery systems in the last two decades (Hindle and Rwelamila, 1993; Dennis, 1993; The Aqua Group, 1992), the methodologies and procedures for bid evaluation, selecting contractors and awarding contracts have remained relatively unchanged since the 1940's (Merna and Smith, 1990;

Martinelli, 1986; Moore, 1985; Diekmann, 1981). In the U.K. these are based on that of public sector clients who use systems of bid evaluation dominated by the principle of acceptance of the lowest price (Holt at al 1993).

Nowadays the majority of the U.K. construction contracts are awarded via one form or another of the selective tendering methods. The various sectors of the industry are guided by their own Codes of procedure on the subject, e.g. the NJCC (1985,89) Codes for building, the ICE (1983) Standing Joint Committee Guides for civil engineering, and the federation Internationale des Ingenieurs-Conseils (FIDIC, 1982) Procedure for the international scene.

In this chapter, the current methods and practices for tendering, contractor selection and contract awards are reviewed. A series of interviews with client representatives in the North West of England are described where it was found that both public and private clients concerned use methods with similar characteristics and generally select the contractor tendering the lowest bid.

Two basic types of procedures are identified. One is where bids are invited for a contract from a standing list of potential bidders who wish to bid for contract projects of that type - termed *standing list tendering*, another is where bids are invited from a set of potential bidders who wish to bid for that specific contract - termed *project tendering*. A model is proposed in which the five elements of *project package*, *invitation*, *prequalification*, *short list* and *bid evaluation* are common to both standing list and project tendering procedures. It is suggested that these elements occur in all types of procurement arrangements.

2.2 LITERATURE REVIEW

The literature items (Russell and Skibniewski 1988, Merna and Smith 1990, Holt et al 1994) revealed that the contractor selection is divided in to two stages: prequalification and bid evaluation.

2.2.1 Prequalification

The contractor prequalification process is the first step in the project development and bidding process cycle. It involves the selecting or screening and classifying of contractors by project clients and/or their representatives according to a given set of requirements or criteria. Contractor prequalification is a decision-making process that involves a wide set of tangible and intangible criteria and which currently demands much subjective judgment, based on the prequalifier's experience (Thomas and Skitmore 1995).

The aim of prequalification is to identify a number of contractors who would be capable of performing the work satisfactorily if awarded a construction contract of a particular type (Russell and Skibniewski, 1987) and also to ensure competitive, reasonable and easy evaluation of bids submitted by the contractors of the same classification (Merna and Smith, 1990). The result of this procedure is that contractors become formally eligible and are invited to bid for this type of contract.

There is a number of reasons why prequalification is performed (Holt et al, 1994; Severson et al, 1993; Russell and Skibniewski, 1987-88; Merna and Smith, 1988; Samelson and Levitt, 1982; Hunt et al, 1966). These can be summarised as follows:

For owners:

- To identify and exclude contractors who will not have sufficient financial resources or technical experience to undertake the contract.
- To identify and include contractors who will be willing to work with the client and submit bids.
- To minimise the probability of contractor default or delays in executing the work.
- To allow clients to save time and expense in bid evaluation by reducing the number of eligible bidders.
- To improve safety performance. It is known that the prequalification process significantly lowers accident rates, reducing the effort, money, and time needed to maintain high safety performance on the job (Samelson and Levitt 1982)

For contractors:

- Contractors are assured that bids will maintain a realistic relationship to sound construction practices and economic conditions. Thus, preventing unqualified contractors from introducing unrealism into the bidding process.
- To save expense in preparing bids or proposals.
- Prequalification identifies the capabilities of each contactor, thus it reduces the risk of being awarded projects they are incapable of performing.
- To reduce competition in the bidding process, by restricting the number of competing contractors for a specific project. Consequently, the probability of winning the contract is increased.

For surety bonding firms:

- To minimise potential financial losses due to contractors' failure.

Contractor prequalification is also associated with some problems however for both owners and contractors:

For Owners:

- There may be some considerable cost and time involved both in developing and evaluating qualitative prequalification criteria and in evaluating the contractors.
- It is difficult to develop quantifiable criteria that allow accurate and consistent decisions to be made for given project circumstances.
- The decision-making process depends largely on subjective judgment which may introduce bias and possibly unfair practices.
- The reduced number of bidders involved can result in restricted competition leading to higher project costs.

For contractors:

- The extra costs for promotion and public relations involved in securing an opportunity to participate in the bidding process.

2.2.2 Evaluation of Bids

Tender evaluation is "...the process of selecting a contractor from a number of tenderers, given that the client has received the bids or tenders from these tenderers for a specified project" (Nguyen, 1985).

The competitive bidding concept is rooted very deeply in the American tradition. Harp (1988) shows that competitive bidding has been in practice in New York state since 1847, the idea behind this concept is the lower bidder system. It is a system which was established early in the 19th century in the U.K. and which has continued for more than a century and a half (Franks 1990). Recognizing the inadequacy of the system many countries have introduced some changes and modification to the system (Moselhi and Martinelli, 1990). Thus, there are basically two types of bid systems in operation - the lowest-bid and non-lowest-bid system.

2.2.2.1. ***Lowest bid system***

The original function of the competitive bidding arrangement was to ensure that the public received the full benefit of the free and fair competition between the contractors to public construction at the lowest price (Herbsman and Ellis, 1992, referring to Cohen, 1961, and Netherton, 1959). Bid evaluation for the public sector in the UK is currently dominated by the principle of acceptance of the lowest price (Merna and Smith, 1988; Holt et al, 1993). This is in contrast to the USA and Canada, for instance, where construction contracts are generally awarded to the lowest bidder, but contractors are generally required to accompany their proposal with a certified or bid bond in an amount equal to 10% of their total bid price (Moselhi and Martinelli, 1990). Public sector clients in the UK use systems of bid evaluation which conform to general guidelines of the National Joint Consultive Committee (1983,85,89) or Institution of Civil Engineers (1983).

The low bid system was evolved to provide specific public objectives.

- To guard against mismanagement by public officials.
- The clients are publicly accountable and must prove that the money was spent as a result of free and fair competition.
- The lower bidder system protects the public from corruption and other important anti-social practices by public officials.

Today, the policy objectives of the low bid system and the methods of awarding contracts have remained relatively unchanged and still depend largely on the lowest bid price, in spite of a large number of reports and investigations identifying problems within the system.

Merna and Smith (1988) found three main drawbacks: firstly, that low bid prices do not always result in low out-turn prices; secondly, the lowest price might be based on a suicidally low or misconceived bid; and thirdly the lowest bid might not be the most realistic bid.

According to Herbsman and Ellis (1992) there is a trend towards looking for new innovations in contract administration mainly due to the many failures in past projects, especially in the public sector. "The major disappointments in project performance are: extensive delays in the planned schedule, cost overruns, very serious problems in quality, and an increased number of claims and litigation" (Herbsman and Ellis 1992).

Bower (1989), Harp (1990), Ellis and Herbsman (1991) are convinced that one of the major factors behind those failures is the current bidding system used in the public sector. Ellis and Herbsman (1991) suggest using a cost-time bidding concept and advocate an innovative approach in which they consider quality, time and cost in the bidding system.

Hardy (1978) argues that the low bid does not always give the client best value for money, as the bid price effectively represents a cumulative series of payments over time, and he gives particular consideration to the use of discounted cash flow techniques to produce present values.

2.2.2.2 *Non-lowest bid system*

Many countries have introduced some modifications to the initial concept of "lowest bidder" criterion and established procedures for the bids evaluation process (Hegazy and Moselhi, 1994; Herbsman and Ellis 1992; Moselhi, 1990; Merna and Smith, 1990; Martinelli, 1986; Hardy, 1978). The variations in these procedures, however, still serve the common objective of selecting a qualified contractor on competition basis.

In Denmark, for example, the two highest and the two lowest tenders are excluded and the closest to the average of the remaining bids is selected. A similar procedure is used in Italy, Portugal, Peru, and south Korea, but only the lowest and highest are disqualified (Herbsman and Ellis 1992). In Saudi Arabia, the lowest bidder is selected provided that his bid is not less than 70% of the owner's cost estimate (Martinelli 1986). The "lowest bidder" criterion is used for contractor selection by public clients in Canada and the U.S.A. with a bid bond in an amount equal to 10% of their total bid price must be provided (Moslehi and Martinelli 1990; Ioannou 1993). France excludes low bids which appear abnormally low and consequently may cause implementation problems (Henriod and Lanteran 1988).

It is maintained, however, that despite the merits of these modified methods, the bid price criterion is still the sole basis of contractors selection and competition.

2.2.2.3 *Bid evaluation*

Evaluating bids can be time consuming and result in an abnormal expenditure of manhours. To avoid this problem, the economic procedure or approach has to be chosen carefully and some procedures have been recommended as guidelines for bids evaluation (Dennis, 1993).

According to Merna and Smith (1988), the current methods and evaluation procedures for civil engineering works in the UK broadly adopt the concepts outlined in the guidance of the Institution of Civil Engineers (1983), which are essentially concerned with the acceptance of the lowest priced bid.

For admeasurement civil engineering works, the assessment and evaluation of bids is based largely on the BoQ, although non-contractual information is requested by the clients, and the clients also make use of pre-award meeting as the final part of the evaluation (Merna and Smith, 1990).

Dennis (1993), acknowledges that bid analysis is not a straightforward commercial/pricing analysis, accepts that a technical comparison is in some degree difficult to quantify, and suggests that many of the necessary judgments delivered during technical comparisons are therefore subjective. Since the engineer is fully aware of the ultimate requirements of his bid comparison and he produces the technical scope and engineering specifications in the first instance, he suggests that the Engineer should therefore be able to undertake an evaluation by adopting a form of rating (suitably weighted) dependent upon such factors as quality of final product, contractors' past performance, maintenance, time, managerial and financial capabilities.

According to Herbsman and Ellis (1992), a substantial majority of construction contracts are evaluated using the low-bid system, in which price is the sole basis for determining the successful bidder. To accommodate its drawbacks, they propose a multiparameter bid award system in which various parameters, such as cost, time, and quality are weighted for importance according to the owner's preference.

As a result of the study conducted by Merna and Smith (1988), they recommend a number of procedures to be followed for the evaluation of bids, they suggest the three lowest bidders could be chosen as a first stage, then a pre-award meeting with the contractor's team would finalize the best bid.

For highway construction, Ellis and Herbsman (1991) propose that each bidder submits his price bid coupled with a proposed time for completion. In this case, the successful bidder is judged to be the one whose proposal provides the lowest combination of bid cost and total road user cost (bid proposal time being converted to a road user cost).

Martinelli (1986) found from a case study that the bid amount, managerial capabilities, financial capabilities, time of execution were the criteria used in the evaluation of bids, with different weights being assigned to each criterion.

Hardy (1978) views the bid price as effectively representing a cumulative series of payments over time, giving particular consideration to the use of discounted cash flow techniques to produce present values of the bids. He also considers inviting competition on the duration of construction and on the magnitude of advance payments.

The weaknesses in current evaluation techniques, have led the researchers surveyed to develop an alternative techniques for the prequalification and bid evaluation, some of these developed techniques are given in chapter 4.

2.3 DATA COLLECTION

In order to investigate the findings and views of these earlier studies, a series of interviews were undertaken with professionals with relevant construction industry experience. These were selected from a list obtained either from the RICS list of the 1993 directory or based on personnel contacts.

The interviews were conducted at the offices of different public and private client representatives throughout the North West of England. The interviews were ranged from 1 to 2 hrs, with each interview being tape-recorded.

Table 2.1 lists the types of personnel interviewed and other information on the types of firms that participated in the interview.

In order to save the time of the interviewees, the purpose of the interview and the need of the research were identified before the interview either through: (1) a simple list of questions developed and sent to the interviewees (Appendix 2A), or (2) a telephone conversation.

The list of questions covered the main issues identified in the literature review. Interviewees were asked to explain and discuss the current nature of the firm, methods considered during prequalification process, contractor selection and bid analysis system, methods used for selecting the successful contractor for the specific project and problems of the current system.

Interview date	Position	Type of firm	Sector
01-13-94	Select list co-ordinator	Technical and consultancy division (client representive)	Direct works Civil Engineering Building Engineering
01-14-94	Office Administrator	City Architect department.	Building Engineering
01-19-94	Practice Manager	Architect Division	Building Engineering
01-21-94	Quantity Surveyor	Technical and Consultancy division	Building Engineering
01-22-94	Architect Engineer & owner representatives	Consultant	Building
01-24-94	Chief Assistant Engineer	Civil Engineering division	Civil Engineering
01-26-94	Chief Engineer	Architect Department, landscape division	Building
02-08-94	Director of Accountants	Finance Department	Building, and civil Engineering works
02-10-94	Health and Safety Officer	Health and Safety Section	Building, andcivil Engineering works
02-24-94	Architect Engineer	Consultant	Building

Table 2.1: Types of firms interviewed

2.4 ANALYSIS

The responses were easily categorised into eight issues:

1. **Advertisements** for standing lists
2. **Applications** for standing lists
3. **Health and Safety** policy requirements
4. **Financial assessments**
5. **Technical assessments**
6. **Invitation** or advertising for particular schemes
7. Preliminary **screening and bid evaluation**
8. Checking and **pre-award meetings**

Issues 1-5 comprise the prequalification process, and issues 7 and 8 relate to bid evaluation.

2.4.1 Prequalification

The public clients interviewed used essentially the same procedure with only minor variations. The steps that they follow are:

1. **Development** of prequalification criteria.
2. **Collection** of data through application forms.
3. **Evaluation** of data against the criteria.
4. Collection of **supplementary** data if necessary, by contacting the referees.
5. **Acceptance/rejection** of application.
6. **Categorisation** of applicants.

It is important to note that a client may reject a contractor at any stage during the process. As Fig 2.1 shows, a typical prequalification procedure comprises several identifiable steps:

1. The initial step is to advertise openly in the local press. The advertisement invites interested contractors to apply for inclusion on a standing list for a particular type of contract. The advantage of open advertising is to avoid complaints from contractors who otherwise may not be considered by the clients, and also attract only genuinely interested contractors.

2. Interested contractors are invited to fill an application form which include categories of work and company details such as financial standing, technical and organisational ability, general experience and performance record. An outline contents of a typical application form are given in Appendix 2B.

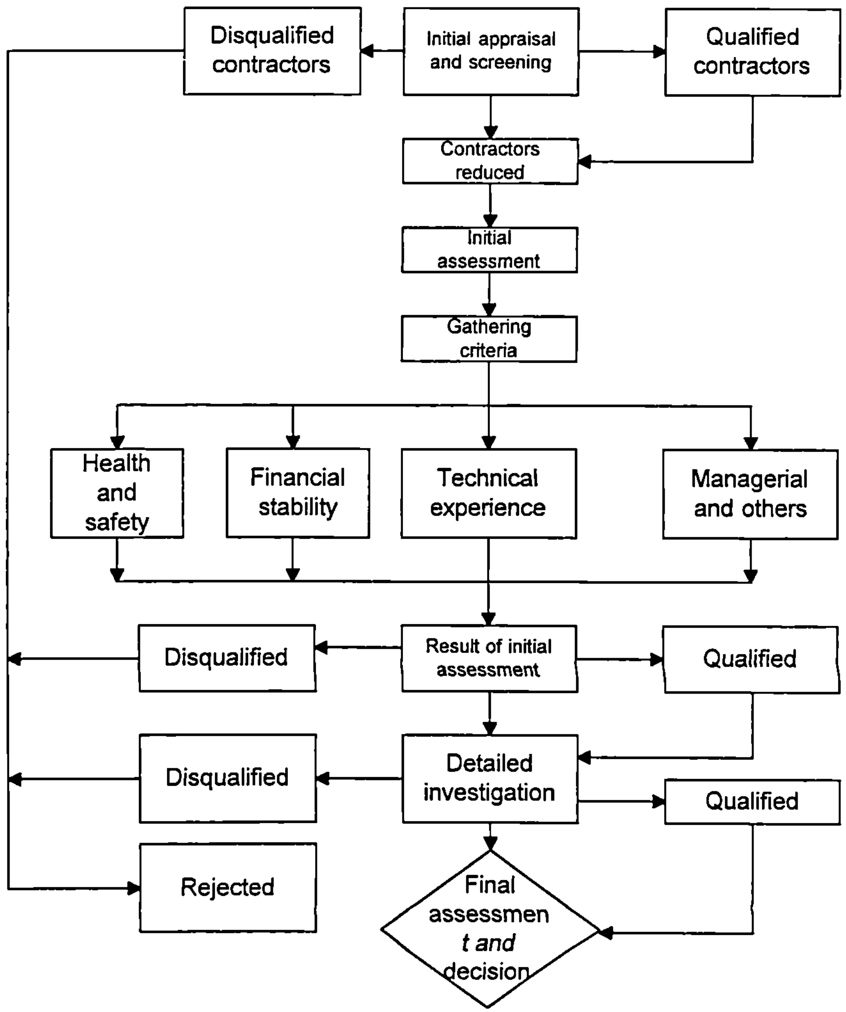

Fig 2.1 prequalification process

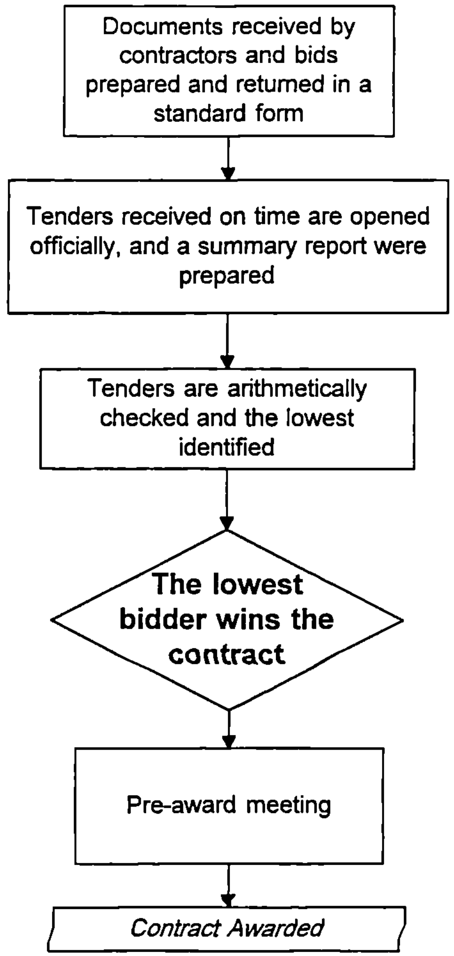

Fig 2.2 Bid evaluation process

3. The volume of applications is often such that it is necessary to conduct an initial appraisal using criteria such as regional and physical location, technical and managerial expertise, and type and size of contracts undertaken.

4. The resulting applications are then assessed on the grounds of the contractors' financial standing, health and safety policies, managerial and organizational capabilities, technical expertise and the past performance. Supplementary data may have to be obtained at this stage from external sources, such as Dun and Bradstreet (an independent agency which provides information on the financial status of contractors), referees and interviews with company personnel. The contractors are then subject to a detailed investigation to assess the current state of their financial, technical and managerial abilities. This financial investigation involves considering information on turnover, gross profit, trading profit, total asset's current liabilities, stock and work in progress, typically over the previous three years trading. Technical assessments are concerned principally with the current commitment of labour and plant resources, the ability to handle the type, quality, size of work, and the ability to perform on site, planning, programming and general progress, site organization and supervision, quality of workmanship, responsibility and consideration for the general public. These are assessed by referee, visits to contractors sites and by meetings with the contractors themselves.

5. The ensuing data is carefully weighted and successful applicants are then categorised on the basis of type and size of the work.

6. Approved lists are independently maintained and whenever necessary updated. The method of updating records of the contractors differs across organisations.

2.4.2 Evaluation of bids

The responses to the prepared questions were categorized into:

1. **Tenders** returned
2. Bid **assessment**
3. Award **decision**
4. Pre-award **meeting**
5. **Award**

Tenders returned

The clients request all bidders to return their tenders in a standard form prepared by the client. The form is only a few pages which include the important items for evaluating the bids.

Bid assessment

The returned bids are opened by an individual, usually the chief executive, sometimes in the presence of a panel. A summary report is prepared commenting on the compliance with bid format and the bid price of each bidder. A typical bid evaluation process is illustrated in Fig 2.2.

Typically, prices submitted and bidders may then be called to return priced bills of quantities and a detailed check is made based on this document only. This process begins with an arithmetical check on a rate by rate basis, identifying the difference between each bid and the client's estimated rates. Any rates that are considered to be unrealistic are noted and a request is made to the contractor to clarify and reallocate those rates.

Pre-award meeting

One of the objectives of this stage is to gather information regarding the problems that may occur during the project execution.

A pre-award meeting is held with the lowest bidder and the client's technical, health and financial representatives. A detailed discussion takes place about the proposed project and the contractor's likely performance, sequence of working, timing of particular activities, and particulars of safety requirements on the site. Finally the contract is awarded.

Award decision

The lowest bidder is specified and, in most primarily cases, the contract is awarded to the bidder tendering the lowest bid price. The unsuccessful bidders are informed of the lowest bid .

2.5 ELEMENTS OF TENDERING SYSTEMS

The eight issues identified in the analysis which comprise the tendering system can be categorized into five major 'elements':

- **Project packaging**
- **Invitations**
- **Prequalification**
- **Short listing**
- **Bid evaluation**

There are two types of tendering system and both include all these five elements. The first is the standing list tendering system and the second is the project tendering system.

2.5.1 *Standing list tendering system*

The prequalification process described earlier results in a standing list of approved contractors. This process is done every 1-3-5 years depending on client policy.

The procedure of this tendering system is illustrated in Fig 2.3, and can be summarized into the following steps:

1 **Invitations.** Applications are invited by open advertisement for entry to the **prequalified standing list** of contractors.

2 **Prequalification.** Responses to the invitation procedure are checked for status by the procedure outlined in Fig 2.1 and those deemed to be suitably prequalified are entered onto the 'approved list' of contractors.

Steps 1 and 2 are carried out at 1, 3 or 5 year intervals depending on the client's normal procedures.

3 **Project package.** This consists of specifications, drawings, bills of quantities, contract conditions etc for the traditional types of contracts.

4 **Invitation.** A group of around 4 to 6 prequalified contractors are selected and invited to bid for the contract.

5 **Short list.** The positive responses to this invitation form a short list of bidders for the contract. If this is too small further invitations may be issued to enable the list to be topped up.

6 **Bid evaluation.** Once the bids have been received, the bid evaluation procedure is carried out as outlined in Fig 2.2

Steps 3 to 6 are carried out for each contract.

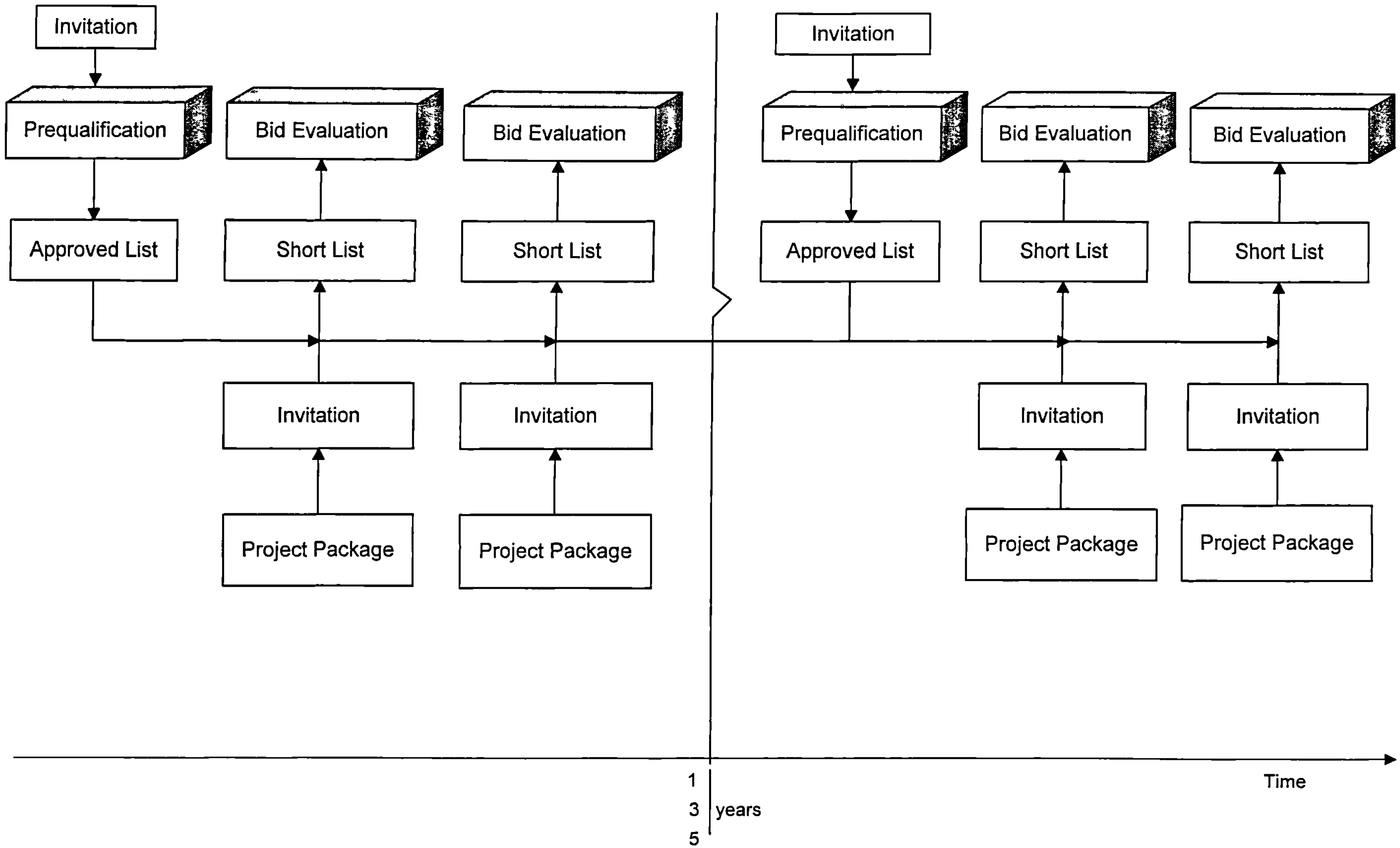

Fig 2.3. Standing list tendering system

2.5.2 *Project list tendering system*

As Fig 2.4 shows, a typical project tendering system procedure comprises five steps:

1 **Project package.** This consists of specifications as before.

2 **Invitations.** Applications are invited by open advertisement or selected for inclusion on the select list for the specific contract. Advertisements may be placed in the local or national press depending on the size of the project. A typical format for the advertisement is:

" Tenders are shortly to be invited from a select list of building contractors for the construction of a 300 sq.m. extension comprising 2 classrooms, w.c.'s, classroom and hall extension at the above school. The extension will be of cavity wall construction on strip footing, with profiled metal deck and will include all associated electrical and mechanical services. The estimated value of the works is in the £80,000 to £100,000 range. Contractors wishing to be considered for the inclusion on a select list to tender, should apply in writing to the Contractor Administrator, Department of........., address, not later than Noon on Wednesday, 4 March 1992."

3 **Prequalification.** Responses to the invitation procedure are checked for status by the procedure outlined in Fig 2.1.

4 **Short list.** A group of around 4 to 6 prequalified contractors are placed on the select list for the contract who will then receive the full project package.

5 **Bid evaluation.** The bid evaluation procedure is carried out for the specific contract as before

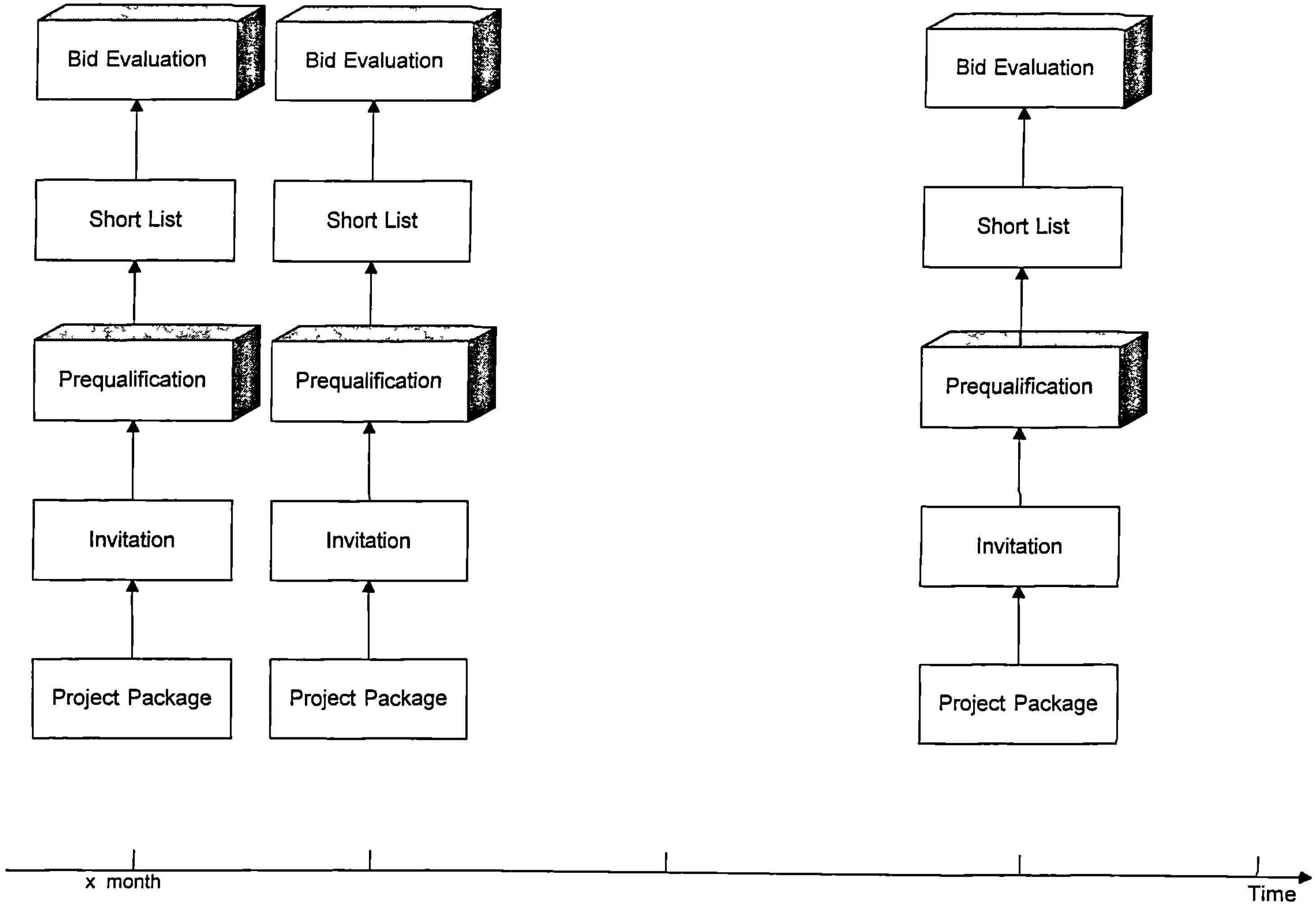

Fig 2.4 Project Tendering system

2.5.3 *Discussion*

The major difference between the standing list and project list tendering system is the timing of the assessment of the contractors for the purpose of the prequalification.

- In the standing list system the complete process of the prequalification is done once every 1,3 or 5 years.
- The standing list tendering system saves the time of clients by restricting the full cycle of prequalification to at least an annual event with periodic updating due to changing circumstances.
- In the standing list system, the client loses some time in the invitation stage. The response to the invitation to submit bids is not always positive and the client has to invite other contractors on most occasions.
- In the standing list system, contractors are sometimes invited when their order books are full or the contract is not quite of interest to them.
- In the project tendering system, part of the prequalification, i.e the preliminary screening, may be done first with detailed investigation being carried out when the contractors are invited to bid for a specific contract.
- In the project tendering system, the client can save time in the invitation stage as only those contractors interested respond positively to the advertisement.
- On the other hand, the client loses time in the project tendering system as he has to repeat the prequalification process for every project.

The tendering elements and procedures of both systems are shown in Fig 2.5. It can be clearly seen from the figure that the two systems are common in the major elements of tendering, the only differences being in the invitation and prequalification process. As Fig 2.5 also indicates, these systems are independent of type of contractual arrangement used.

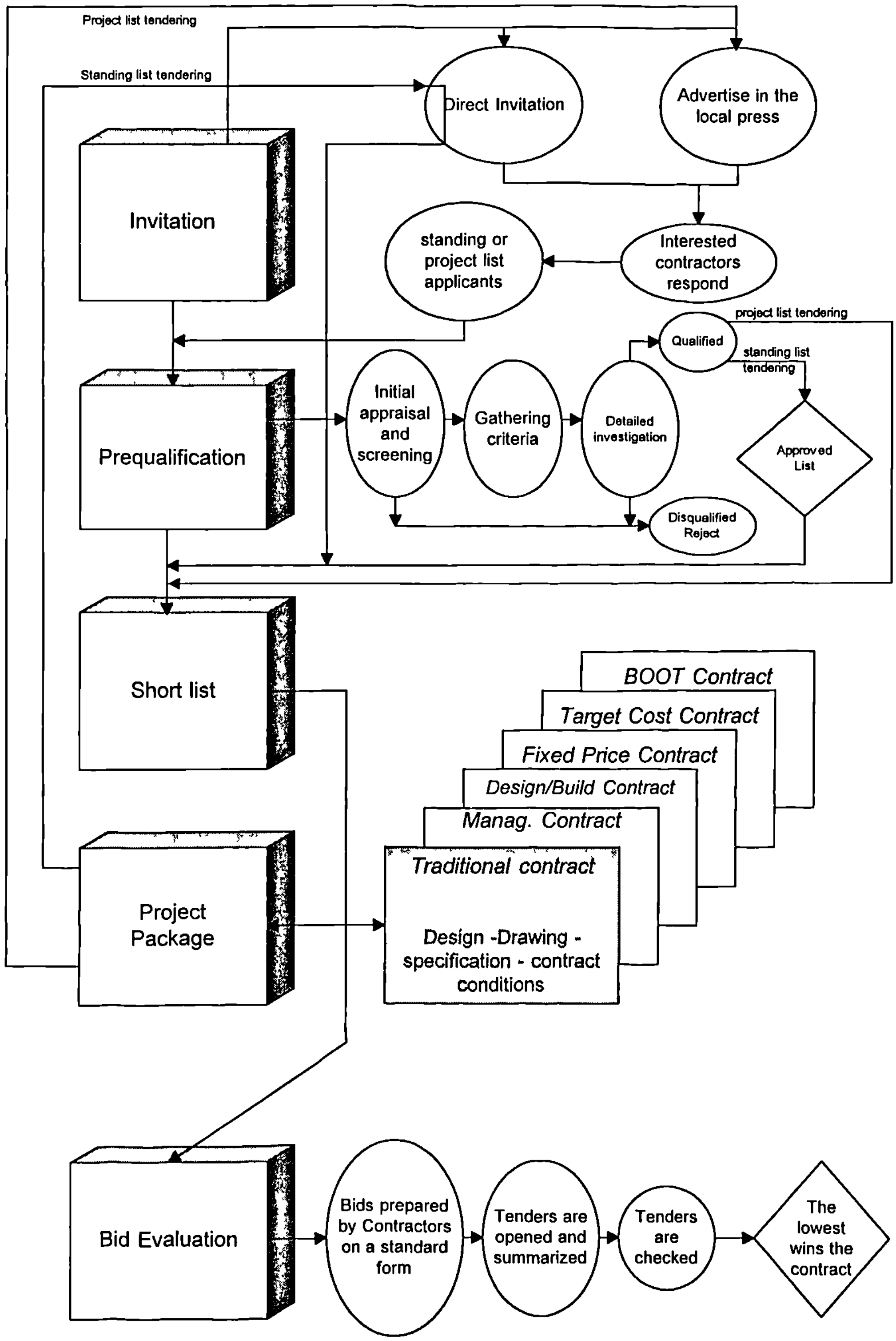

Fig 2.5 Elements and procedures of tendering systems

2.6 CONCLUSION

In the tendering process, contractor prequalification and bid evaluation are as important to clients as bidding strategy is to contractors. This chapter presented the findings of the current practice in prequalification and bid evaluation. Prequalification and bid evaluation were reviewed through an extensive literature search and interviews with construction industrial professionals in the North West of England.

It was found that all the public clients concerned use methods with similar characteristics and generally select the contractor tendering the lowest bid.

Two basic types of tendering procedures were identified. One is where bids are invited for a contract from a standing list of potential bidders who wish to bid for contract projects of that type -termed *standing list tendering*, another is where bids are invited from a set of potential bidders who wish to bid for that specific contract - termed *project tendering*. A model was proposed in which the five elements of *project package*, *invitation*, *prequalification*, *short list* and *bid evaluation* are common to both standing list and project tendering procedures. It is suggested that these elements occur to some extent in all types of procurement arrangements.

The constancy of these practitioners both in the selection of the lowest bid and the general approach to tendering, in corroboration of the general literature on the subject indicate that the model proposed here is appropriate in the general field.

The model proposed may serve as a systematic approach to tendering and bid evaluation for novice owner organisations. Also, the proposal that this model may apply beyond the purely traditional procurement arrangements offers a much needed breakthrough in the conceptual understanding of the relationship between, and separation of, contractor selection and the general construction procurement process. With the continued proliferation of new, novel and increasingly complex approaches to construction procurement, such an understanding is of vital importance both for practitioners and students of the subject. Also, as with all good descriptive models, it is possible that the insights afforded by the model may provide inspiration for the further development of such systems perhaps in more coherent and systematic manner than hitherto.

The following chapter (3) is a continuation of this chapter. It covers reviews of the contractor selection criteria (CSC) considered during prequalification and bid evaluation. It consists of literature survey and interviews which were conducted for this chapter (2).

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3. COMMON CRITERIA FOR CONTRACTOR SELECTION

CHAPTER 3

Common Criteria for Contractor Selection

3.1 INTRODUCTION

The survey of current procurement practice carried out in chapter 2 conclude that all types of arrangements comprise five common process 'elements', or sub-systems. These are *project packaging*, *invitation*, *prequalification*, *short listing* and *bid evaluation*. For each of these sub-systems there are a variety of actual and possible alternatives available - different types of project packages, invitational forms, prequalification systems, short listing methods and bid evaluation procedures - which offer clients differing combinations of expertise, risk, flexibility and costs (Nahapiet, 1985).

This raises a major question. For a given project, is there some **'best'** combination of sub-system alternatives or does **any** such combination produce roughly the same outcome? In theory, the answer lies in the opportunity costs involved - would the extra benefits of using a better system have outweighed the extra costs in finding (or designing) and implementing it? Unfortunately, if the alternative system is new to the procurer, it is only possible for the procurer to know such costs **after** rather than **before** the system is chosen, and even then only if accurate records are kept. In response to these difficulties, the approach in practice is to make some subjective assessment but, as Holt et al (1993) has found, subjective approaches in these areas do not necessarily serve the best interests of the options available. This seems certainly to be the case in the public sector where, according to Latham Report (NJCC, 1994), "[there is] no means of ensuring that all housing associations, trust hospitals, grant maintained schools, private Government agencies, utilities companies, etc., are aware of the best current practice and changes in the construction industry".

One solution is for procurers to share experiences and data so that good **estimates** of likely costs and benefits can be made. It is not common practice for procurers to share experiences and data in this field however. Latham (1994) reported a lack of communication between the procurers, a feature that is symptomatic of the construction industry as a whole[1]. The reasons for this are not known but it seems reasonable to assume that the isolated and *ad hoc* development of systems by procurers has resulted in the lack of a common basis for comparison. Whilst, it cannot be shown to be sufficient (ie., the existence of a common basis for comparison will result in the sharing of experiences and data between procurers[2]), it is highly likely to be a necessary precursor to such sharing (or at least reduce the opportunity costs of sharing). Furthermore, even if such a sharing still fails to take place, for commercial reasons for instance, the existence of

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[1] The Banwell Report (Banwell, 1964) observed that the construction industry does not appear to move forward with the same speed and purpose of its active members which are lively and full of new ideas. In Banwell's view, this is due to the fact that the various sections of the industry have long acted independently of each other. As a result, the Banwell committee consider the most urgent problem confronting the construction industry to be the necessity to think and act as a whole. In fact, there is widespread agreement that even the Simon Report (1944), the report by Sir Harold Emmerson (1962) and the Banwell Report themselves have resulted in little action or implementation of their proposals. This is a situation in need of attention and "unless an effective communication network is established ... more and more cases of bad practice will come to light"(NJCC, 1994).

[2] According to Latham (1994:50), both the DOE and the DOT ask applicants to submit similar documents. Most local authorities and other public sector clients also keep separate lists. Such duplication of effort, it is argued, is wasteful of money and adds costs to the clients because of the resource implications of maintaining separate lists.

a common basis for comparison would at least allow research to take place on an experimental basis.

Is a common basis for comparison possible? The signs are favourable. All procurers have the same goals. They all want a project more or less at a reasonable cost, to a reasonable quality, within a reasonable time and with reasonable security (Masterman 1994, Bent 1984; Curtis *et al*, 1991). The tendering system aims to achieve this goal by ensuring the simultaneous selection of an appropriate contractor to deliver the project, mechanism for delivery, price to pay and legal framework. The only difference then between procurers is in the strategic choice of sub-system 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 (Russell and Skibniewski, 1988).

In this chapter, the author is concerned with identifying such universal criteria for *prequalification* and the means by which different emphases can be accommodated to suit the requirements of clients and projects. The information, assessment and evaluation strategies currently used by procurers for screening contractors are considered and the results are reported of an extensive literature review and an interview study with a sample of construction professionals who have an extensive experience in prequalification and bid evaluation processes. The findings indicate the most common criteria considered by procurers during the prequalification and bid process are those pertaining to financial soundness, technical ability, management capability, and the health and safety performance of contractors.

3.2 LITERATURE REVIEW

Chapter 2 concludes that the contractor selection process comprises five common process 'elements', or sub-systems, for all types of procurement arrangements. These are *project packaging*, *invitation*, *prequalification*, *short listing* and *bid evaluation.* Prequalification is a *pre*-tender process used to investigate and assess the capabilities of contractors to satisfactorily carry out a contract if it is awarded to them and has been examined by several researchers (eg., Hunt *et al*, 1966; Helmer and Taylor, 1977; Russell and Skibniewski, 1987,88; Merna and Smith, 1990; Ng, 1992; Holt et al, 1994; Potter and Sanvido 1994). It provides a client with a *standing list* of potential contractors to invite to tender for similar types of projects on a regular basis, or just a *project list* of contractors to be invited to tender for a specific project. Bid evaluation, on the other hand, involves similar processes but occurs at the *post*-tender stage and involves the consideration of the bid amount in addition to the contractors' capabilities.

Contractor prequalification and bid evaluation are therefore decision-making processes that occur within the overall procurement strategy. They involve the development and consideration of a wide range of necessary and sufficient decision criteria as well as the participation of many decision-making parties (Russell and Skibniewski, 1988). However, despite a huge increase in the complexity of projects and clients' needs in the last two decades together with an associated increase in alternative forms of project delivery systems, the methods of quantification and assessment of criteria for prequalification and bid evaluation have hardly changed.

The review of the literature revealed the existence of various criteria, types of information and methods of assessment.

3.2.1 Prequalification and bid evaluation criteria

Prequalification and bid evaluation procedures are currently used in many countries and involve many different types of criteria to evaluate the overall suitability of contractors. These are said to include general, technical, managerial and financial criteria (Hunt *et al*, 1966), financial stability, managerial capability and organisational strength, technical expertise and experience of comparable construction (Merna and Smith, 1990) and relevancy of experience, size of firm and safety record (Moselhi and Martinelli, 1990).

To this Dennis (1993) added the criterion of previous prequalification. A review of prequalification records, he maintains, should satisfy both the engineer and the client in that each bidder should have: the financial strength to sustain the cash flows likely to arise during the project; experience of projects of a similar nature, competence and plant capacity to complete the project within the constraints imposed by the contract; technical capability (including human resources) sufficient to satisfy the requirements of the contract; a complete understanding of similar project scopes and ability to absorb subsequent changes; the facilities (testing, quality control, etc.) necessary to endorse assurance of quality; and to be able to comply in all respects with health and safety regulations.

Criteria may vary in emphasis according to the characteristics of the project. For planning and tendering the parallel runway for Kingsford Smith Airport, for example, where a design and build contract was the method assigned for the project delivery, several criteria were investigated for selecting a suitable contactor for the job (Herbert and Biggart, 1993). These were management capability (project management structure, human resources and quality management), delivery capability and experience (proposed construction methods and plant ownership, current and completed contracts), relationships (industrial relations, occupational health and safety, and claims and dispute history) and financial status (based on an investigation of measures such as net assets, earnings and several financial ratios including debt to equity, current ratio and ability to carry construction losses).

Another case is a contract auction for a multi-storey office building, estimated at US$10.4 million for construction and US$1.57 million per year for the operation, where Moselhi and Martinelli (1990), in consultation with industry, found the selection criteria considered for bid evaluation to be: bid amount; annual life cycle cost; number of years in business/bid amount; volume business/bid amount; financial credit/bid amount; previous performance; project management organization; technical expertise; time of execution; and relation with subcontractors.

Another case (Diekmann, 1981), when faced with the problem of selecting a contractor for a hybrid unit/price cost-plus contract, higher level criteria were proposed comprising cost exposure, company stability, quality of produce, and management capability, each of which were then broken down into second, third, and (in some cases) fourth levels of sub-criteria.

The criteria are also used in the process of short-listing, ie., where the number of applicants for prequalification is so great that the number of contractors have to be reduced to a short list. Here Merna and Smith (1990) found that the type and size of contract together with regional and physical location were used as criteria in addition to the quality and quantity of technical and managerial expertise available.

3.2.2 Information

It is necessary to collect and analyze information in order to quantify objectively the criteria for prequalification and bid evaluation. This information includes that relating to the contractor's permanent place of business, adequacy of plant and equipment to do the work properly and expeditiously, suitability of financial capability to meet obligations required by the work, appropriateness of technical ability and experience, performance of work of the same general type and on a scale not less than 50% of the amount of the proposed contract, the frequency of previous failures to perform contracts properly or fail to complete them on time, the current position of the contractor to perform the contract well, and the contractor's relationship with subcontractors, or employees (Hunt *et al*, 1966). The assessment of contractors who have previously prequalified can, of course, be assisted by reference to previous prequalification records.

In total, the information used for the assessment of criteria for prequalification and bid evaluation falls into five groups - general information which is used mainly for administrative purposes, financial information, technical information, managerial information and safety information.

3.2.2.1 General information

This concerns the administrative information relating to contractors wishing to be considered for inclusion in clients' standing lists. There is very little literature on this subject. Ng (1992) has mentioned only the name of the contractor in his list for gathering data about each contractor for the prequalification process. Seeley (1986), referring to Silva (1982), covers more information about the contractors including the legal status of the company, particulars of holding, subsidiary or associated companies, membership of trade association and name of directors, whilst Holt et al (1994) found litigation tendency, size, age, and image of the contractor to be popular information collected from contractors although ranking 24,27,29 and 31 in importance among the 31 variables in their study.

3.2.2.2 Financial information

This involves financial statements and other information to check on the financial exposure of the company for both domestic and overseas contracts. Financial status is most often assessed by ratio analysis, examination of bank references, credit reference and turnover history (Holt et al, 1994). Financial stability, on the other hand, requires the consideration of credit ratings, bank arrangements, bonding capacity and financial statements (Russell et al, 1992). Furthermore, studies by Severson et al(1993, 1994) on predicting the likelihood of experiencing a claim, investigated trends in contractor financial data in the form of the assets, liabilities and stockholders' equity portion of the contractor's balance sheet, together with the contractor's income statement.

3.2.2.3 Technical information

This is concerned principally with the current commitment of the contractor's labour and plant resources, ability to handle the type, quality and size of work, and the ability to perform on site. 'Past experience', which includes the type and size of projects completed, is the technical information most used (Holt et al, 1994) and is assessed by visits to existing sites and by meetings to discuss, in general terms, the nature of the construction work, the programme dates and the client's requirements.

3.2.2.4 Managerial information

Managerial organization and expertise are considered by identifying the contractor's managerial approach to risk, contract strategy, claims and variations. Here Ng (1992) has listed four sources of managerial information comprising: (1) management and organisation of work, (2) resources, (3) coordination-control-response, and (4) documentation. Helmer and Taylor (1977) have classified these management variables into three fundamental areas: (1) planning (management perspective, qualification of key management personnel, use of planning tools), (2) organization (integration of activities, communication, human relations); and (3) controlling (control system, adaptability, risk assessment, subcontract management). Finally, Diekmann (1981) has grouped the management source of information into site organization, project manager, corporate management, experienced procurement, project control, and historical performance.

3.2.2.5 Safety information

Samelson et all (1981,1982) has focused on construction cost reduction by means of accident cost control through owner selection of safe contractors. A survey of construction site safety in Honduras (Jaselskis and Suazo, 1994) indicated a substantial lack of awareness of the importance of safety at all levels of construction industry. Questions on experience modification rating (EMR) and the Occupational Safety and Housing Administration (OSHA) incidence rate can however generate the required information about the safety performance of the contractors (Samelson and Levitt 1982).

3.2.3 Assessment and evaluation

3.2.3.1 Assessment

The information relating to the criteria can be assessed in various ways. Moore (1985), for example, has proposed a quantitative system for selecting contractors for fast track projects in which an evaluation team initially visits the contractor's home office to collect the required information and assign preliminary scores to the criteria used. Table 3.1 shows how this is done. A maximum point value is assigned for each aspect of construction project execution. These values are then weighted according to their relative importance on the overall project delivery strategy. When a category is made up of subcategories, the weighted value scores of the subcategories are added to calculate the total value for the category. To avoid individual biases, it is recommended that a minimum of three evaluators is required for each scoring activity.

Maximum points	Category or criteria
5	* Craftsmen availability
5	* Training or skill level of craftsmen
	* Supervision
	80 percent-interviews and reference checks on 8 to 10 key people
25	10 percent-foreman quality and training
	10 percent-foreman availability
10	* Productivity improvement programme
25	* Systems and procedures
	Cost, schedule, material control, personnel, accounting,
	subcontracts, purchasing, safety
5	* Field organization, work rules, work policies
3	* Safety record
2	* Geographical experience
3	* Experience with the specific type of facility
5	* Quality control
2	* Home office support
2	* Executive involvement-leadership
5	* Small tools and construction equipment
3	* Engineering coordination
100	

Source: Moore (1985)

Table 3.1: Relative importance of project execution factors

Holt et al (1993) has proposed a modification of the present system (prequalify/select) with quantifiable indices. This comprises a three-stage process requiring the calculation of what is called a P1 scale index to investigate the more general areas surrounding potential tenderers. A P2 scale index is calculated for the second stage to further assess the contractor in the light of specific factors. Finally a P3 scale index is calculated to compare the bid prices of the invited tenderers

3.2.3.2 Evaluation

The term "evaluation" is used to denote the procedure for the strategic assessment of tender bids submitted by prequalified contractors. It is said that the strategy used for bid evaluation should reflect the client's objectives (Hardy, 1978). These, according to Herbsman and Ellis (1992), amount to the 'major' criteria of cost, time and quality as measured by the bid amount, time of execution and quality of previous work respectively. This implies that the winning bid is fully responsive to the contract in addition to the bidder being sufficiently well qualified to undertake the contract (Hardy, 1978). In addition, Herbsman and Ellis (1992) has also proposed further project specific criteria including safety, durability, security and maintenance.

The UK public sector of Civil Engineering however is thought to follow the concepts outlined in guidance notes of The Institution of Civil Engineers (1983) and the NJCC (1983,85,89) Codes for building, which are concerned with the justification of the lowest priced bid (Merna and Smith , 1990).

Another procedure for bid evaluation in use in the UK public sector is that by clients who require a tender submission of only an initial lump sum price without a prequalifying process. These clients sometimes request further information from tenderers for a more process. These clients sometimes request further information from tenderers for a more detailed evaluation of the three lowest bids (Merna and Smith, 1987). In this case, clients request a complete package of information from tenderers checked initially for qualification, alternatives and errors in the tenders before proceeding to a more detailed technical, financial or contractual evaluation to identify the winning bidder.

Any bid evaluation practice that goes beyond that of selection of lowest bidder is currently largely subjective (Merna and Smith, 1990). More objective methods have been proposed by Moselhi and Martinelli (1990) and Diekmann (1981) by means of multiattribute utility techniques for combining the bid price and contactor selection criteria. The evaluation of bids by multiattribute methods can encounter some difficulties when comparing different criteria measured on different scales and various ways have been suggested for combining criteria values into a single scale. Hardy's (1978) criterion for example is the bid which maximises the return on the client's investment. Thus he proposes that bidders should submit a schedule of the payments they expect to fall due to them during the contract. Both the client and contractor may use this to determine the Present Value of bids. Ellis and Herbsman (1991) on the other hand proposes a time/cost approach to determine the winning bidder in highway construction contracts by which a road user cost is applied to the contract time proposed by each bidder. Therefore in this case it is suggested that the criteria to be considered are bid prices and contract time (the road user cost being applied to the contract time). By converting the contract time to a cost to the client, a straight forward comparison can be made on a single criterion. Finally, Holt et al (1993) combines his P2 and P3 scores into a simple index by assigning a 60% weighting for the P3 score (representing the bid price) and a 40% weighting to the P2 score (representing the scores of the information collected).

3.2.4 Conclusion

The conclusion from these disparate studies is that there is no consensus as yet on a common set of criteria for contractor selection. However, several recurrent factors emerge. The lowest bid is clearly the most dominant criterion as this involves no subjective judgement and satisfies most of the requirements of public accountability. Most sources mention the need to consider financial and technical criteria on the grounds that contractors have to have a minimal level of resources to complete the work. On the whole, the quality of resources and managerial capability seem to be secondary issues.

3.3 INTERVIEW FINDINGS

In order to corroborate the findings and views of these earlier studies, an interview survey with sample of nine professionals with relevant construction industry experience was undertaken (note: these are the same interviews conducted in chapter 2). The list of interviewees, comprising client representatives, was compiled by reference to the Royal Institution of Chartered Surveyors list of the 1993 directory (RICS, 1993) and personnel contacts in the North West of England. The interviews were conducted at the offices of clients' representatives and comprised one civil engineering, three building engineering, one landscape, one financial, one safety and health policy, and two list coordinators. Table 3.2 lists the types of personnel interviewed and other information on the types of firms that participated in the interview. The interviews ranged from 1 to 2 hours, with each interview being tape-recorded.

Interview date	Position	Type of firm	Sector
01-13-94	Select list coordinator	Technical ann consultancy division (client representative)	Direct works Civil Engineering Building Engineering
01-14-94	Office Administrator	City Architect Department.	Building Engineering
01-19-94	Practice Manager	Architect Division	Building Engineering
01-21-94	Quantity Surveyor	Technical and Consultancy division (area office)	Building Engineering
01-22-94	Architect Engineer & owner representatives	Consultant	Building
01-24-94	Chief Assistant Engineer	Civil Engineering Division	Civil Engineering
01-26-94	Chief Engineer	Architect Department, landscape division	Building
02-08-94	Director of Accountants	Finance Department	Building, civil, and direct Engineering works
02-10-94	Health and Safety Officer	Health and Safety Section	Building, civil, and direct Engineering works
02-24-94	Architect Engineer	Consultant	Building

Table 3.2: Types of firms interviewed

In order to make the interviewing more effective and to save the time of the interviewees, the purpose of interview and the need of the research was communicated to the interviewees the interview through either: (1) a simple list of questions developed and sent to the interviewees (Appendix 3); or (2) a telephone conversion. The interviews were conducted in an open semi-structured manner, allowing the respondent to introduce whatever information was felt to be relevant but with the topics identified from the literature survey being introduced by the interviewer at convenient points.

The interview responses were all found to fall into one of the following three categories: (1) what information is considered **for selecting contractors**, (2) how the information is used to assess the four criteria, and (3) the strategies that are employed to evaluate the criteria.

3.3.1 Information considered

3.3.1.1 Information from contractors

Information is obtained from firms wishing to be included on a standing list of approved contractors or project tendering list, usually via a detailed questionnaire from the client. Firms already included on a standing list must also provide all the information required. The information is always treated as a matter of utmost confidentiality and is used only in compiling and monitoring approved lists of contractors. The information requested from applicants comprises both general and specific information. Application forms often request information relating to:

- Categories of work offered by the client
- Company details
- Scope of work offered by the firm
- Technical resources and references
- Particulars of existing insurances
- Taxation details
- Financial information
- Sub-contracting
- Race relations
- Plant and equipment
- Health and safety

Typical company details required are given in Table 3.3.

Full name and status of company	
Local address Telephone number	
Registered office Address if different from above	
Date company established	
Company registered number(indicate Public, Private or co-operative	
Co-operative companies must comply with ICOM Model rules	
Date when last company accounts were registered and the financial year to which they relate	
Parent company (if applicable)	
Nominal and paid up share capital	
Managing Director	name and tel No.
Person dealing with the application on behalf of the company	Name and Tel No.
Description of the company/firms business activities. Please confirm that the objects of the company stated in its memorandum of association cover the purposes for which this list is being compiled	
SOLE TRADER/PARTNERSHIP	
Full names of Proprietor or every partner	
Date of formation or commencement of trading	
Person dealing with this application	Name and Tel No.
Description of the business activities	
FOR ALL FIRMS	
List the names of every Director, Partner, Associates and company secretary	
Have any of the directors, partners or association been involved in any firm which has been liquidated or gone into receivership?(give details)	
Has any Director, Partner or Associates been employed by the client?details required	
Is any director, Partner or Associates relative to any of client employee	

Table 3.3: General information about the contractors

The following is a list of information requested from the contractors by one of the clients.

- Types of work the firm wishes to, and could, carry out
- Financial penalties previously levied in respect of failures to perform to the terms of a contract
- Contracts the firm has had terminated or employment determined under the terms of contract
- Contracts not renewed due to failure to perform in accordance with the terms of contract
- Competence of potential employees. This may include job descriptions, application forms, references, qualifications, inspections of previous work,

trial periods before confirmation of employment and personal recommendations.

- Skills including professional, managerial, and technical expertise, that are available to the company, e.g. qualifications and relevant experience
- Staffing levels in the company including management, professional/technical, administrative/clerical, manual supervisor, etc.
- Currency of records of employees
- Names, addresses and details of work carried out recently for public sector clients other than this authority, including supervising officer, contract title, tender price and type of work.
- Contracts carried out for the client in the last 3 years
- Main plant and equipment owned by the company.

3.3.1.2 Other information

An initial assessment leads to a reduced number of contractors followed by a detailed investigation involving requests for information from referees. Different clients use different ways of requesting information from the referees and there are distinct differences in the type of detailed information requested.

The finance personnel interviewed use information collected from mainly two sources of information:

1 the Standard Business report from Dun & Bradstreet, including payment profile, liquidity and equity.

2 3 years published accounts from the contractor which include
    - Balance sheet statement. - Income statement (Profit and Loss account).

In addition, financial assessments may also include

- Confirmation that the company is still trading.
- A statement of turnover since the last set of published accounts.
- Details of any outstanding claims or litigation against the company.

Applicants also have to provide security information in the form of a health and safety policy. This covers the names of personnel responsible for implementation of the policy, number of employees, procedures to convey the safety polices to the employees, procedures for reporting and recording the accidents, first aid provision and details of prosecutions served on the firm by health and safety executives. Further information includes particulars of existing insurances, taxation, sub-contracting and race relations record.

3.3.2 Criteria assessment

Contractors may be rejected at any stage of the prequalification process ie., during preliminary screening or after a detailed investigation. For the larger client organisations, the application forms are received by a list coordinator. The provision of incomplete information, or failure to enclose the relevant documents, usually excludes any further assessment of criteria. Valid forms are then passed to different sections and departments for assessment against the selection criteria.

3.3.2.1 Assessment of general information

Some of the general information is used for administrative purposes, the remainder being used for technical and financial assessment of the contractors. General details of the company, such as the date of establishment, whether a contractor is a cooperative or has a parent company, are usually requested for administrative purposes although they might be used as an indication of the firm's general status. All those interviewed were found to use subjective judgment in assessing general information.

3.3.2.2 Assessment against technical criteria

Most of the clients, with minor variations related to the general policy of the client (such as ability to attract local labour), use the same type of information for assessing the technical ability of the contractors.

80% of the clients' interviewed use dichotomous (yes/no, rejected/accepted) or trichotomous (bad/good/excellent) variables for assessment, with the remaining 20% using a point system (1,2,3,....). Table 3.4 shows a points' system used by one of the clients interviewed. Another client uses a cardinal system for assessing technical information requested (Table 3.5). All interviewees use value judgments based on the experience of the assessor and the information available.

		Points out of 20
1	* Planning, Programming and General Progress.	
2	* Site organisation and Supervision.	
3	* Quality of Workmanship.	
4	* Adequacy of labour force and plant.	
5	* Responsibility and consideration for the general public.	
6	* Responsibility and consideration for the adjoining owners affected by the work.	
7	* Signing, lambing off and watching.	
8	* Taking of adequate safety precautions on the work.	
9	* Willing to effect remedial works which were required during the defects liability period.	
	Interim and Final Accounts:-	
10	*Presentation	
11	* Settlement	
	What was the contractor's attitude with regard to claims?	
12	* Justification	
13	* Documentation	
14	* Settlement	
	Any other comments regarding claims	
15	* Relations with Statutory Undertakers	
16	* Working relations between members of the referee staff and the staff of the firm .	
	Total score out of 320	
17	* Percentage of work sub-let	
	Details..	
18	* Standard of Sub-contractors work: Points out of 20	

20 points=outstanding, 15 points=good, 10 points=satisfactory, 5 points=poor, 0 points=unsatisfactory

Table 3.4: The point system used for requesting technical criteria

1. Type of work has the firm carried out for the referee	
2. Value of work has the firm carried out for the referee	
3. The quality of workmanship was:	Poor/Average/Good.
4. The referee relationships with their management were:	Poor/Average/Good.
5. Their site organisation and programming were:	Poor/Average/Good.
6. Compliance with specification was:	Poor/Average/Good.
7. Did the firm have difficulty providing adequate labour?	YES/NO.
8. Was the contract completion date achieved?	YES/NO.
9. Has the firm completed defects to the referees satisfaction	YES/NO.
10. Were damages for non-completion ever applied?	YES/NO.
11. Relationship with sub-contractors and suppliers generally	Good/Avg/Por.
12. Were nominated sub-contractors paid promptly?	YES/NO.
13. Was the final account settled amicably without undue claims	YES/NO.
14. Did the contractor have a tendency to make excessive claims?	YES/NO.
15. Do the referee consider this firm capable of undertaking the work assigned to him?	YES/NO.
16. Would the referee employ this firm again if the occasion arose?	YES/NO.
17. Any further comments which would be helpful	

Table 3.5: Technical information requested for cardinal system

The following are some of the reasons used by client's representatives for rejecting applications on technical grounds

- Unsatisfactory work or performance on a contract for the client within the last 5 years
- Unsatisfactory work or performance on a contract for any other Authority.
- No previous experience in the category of work applied for.
- Habitually submits excessive claims.
- Declined invitations, or did not submit a tender on at least three occasions in the previous 12 months.
- Inadequately staffed reception arrangements for telephone at Head Office.
- Inadequate plant resources.
- Likely to cause additional cost to the client in supervising contracts because of inadequate arrangements for Head Office or site management.
- Disregard for the Conditions of Contract or instructions given by, or on behalf of, the supervisor.

3.3.2.3 Assessment against financial criteria

The detailed measurement and financial analysis of contractors carried out by clients involves the assessment of the contractors' past, present, and anticipated future financial condition. The request form used for the financial assessment of contractors takes the form shown in Fig 3.1. The objective is to identify any weaknesses in contractors' financial health that could lead to future problems and to determine any strengths the firm might capitalize upon. Clients or list coordinators pass the completed application forms to their finance departments for financial analysis/assessment.

FINANCIAL REFERENCE FOR CONTRACTORS

FAO Peter Harrington   Date..............
Finance Department
Town Hall

Please carry out a financial vetting of the following contractor:-

Contractor:..   Address .... Tel:................

Contracts Applied For: £ ....   Reg. No. ....

Information by Finance Department

Company Turnover:..................................   Date of Company Accounts: ....

Contractors financially suitable for contracts:-

	Please Tick
£ 0 to £50,000	....
£50,000 to 100,000	....
£100,000 to 500,000	....
over 500,000	....
The contractor is not financially suitable to work for Bury MBC	....

Comments..................................
Please return form ASAP TO: Neil S Long, Department of development Services

Fig 3.1: Financial reference for contractors

Assets			
Current assets:			
Cash		£ 1,400	
Accounts receivable		10,000	
Inventories		12,000	
Prepaid expenses		300	
Total current assets		--------	£ 23,700
Fixed assets:			
Land		2,000	
Plant and equipment	£ 12,300		
Less: Accumulated depreciation	7,300		
Net plant and equipment		5,000	

Total fixed assets			7,000
Total assets			30,700
Liabilities and Owner's Equity			
Current liabilities:			
Accounts payable		£ 3,000	
Notes payable		3,400	
Accrued salaries, wages		3,100	
Current portion of long-term debt		500	

Total current liabilities			£ 10,000
Long-term liabilities:			
Deferred income taxes		1,500	
First mortgage bonds		6,000	
Debentures		2,900	
Total long-term liabilities		-------	10,700
Owner's equity:			
Common stock		100	
Additional paid-in capital		2,000	
Retained earnings		8,200	
Total owner's equity		-------	10,300

Total liabilities and owner's equity			30,700

Table 3.6: Balance Sheet of x contractor

Clients use these statements for the purpose of financial ratio analysis for each contractor. These ratios are then compared with the average industry ratios. The average industry ratio is derived from a financial analysis for all firms and is usually carried out by government or national agency. The financial ratios provide the basis for answering very important questions about the financial standing of the contractor.

1. How liquid is the firm? Liquidity refers to the firm's ability to meet maturing obligations and to convert assets into cash.

2. Is management generating sufficient profits from the firm's asset? Since the primary purpose for purchasing an asset is to produce profits, the analyst often seeks an indication of the adequacy of the profits being realized.

3. How does the firm's management finance its investments? These decisions have a direct impact upon the returns provided to the common stockholders.

4. Are the common stockholders receiving sufficient returns on their investment?

Categories of financial ratios and what each ratio will indicate on the financial standing of the contractor are provided in financial management standard texts. Table 3.7 summarises the different ratios corresponding to the industry norms.

Trend analysis is sometimes performed to determine how different variables changed over time for contractors. A Firm's financial ratios can be compared with two types of standards: (1) industry norms, as the basis for comparison between the financial status of the firm with respect to the average of the industry; and (2) trend comparisons, for the firm itself over a minimum period of three years. An example of trend analysis is shown in Table 3.8.

Ratio	Formula	Calculation	Industry average	Evaluation
Liquidity ratios				
1.Current ratio	Current assets/current liabilities	23,700/10,000=2.37	1.7	Satisfactory
2.Quick ratio	(current assets-inventories)/ current liabilities			
Efficiency ratios				
3. Average collection period	Average accounts receivable/ (annual credit sales/360)			
4.Inventory turnover	Cost of gods sold/ending inventory			
5. Fixed asset turnover	Sales/fixed assets			
6. Total asset turnover	Sales/total assets			
Leverage ratios				
7. Debt ratio	Total liabilities/total assets	20,700/30,700=67%	58.9%	Poor
8. Long-term debt to total capitalization	Long-term debt/total capitalization			
9. Times interest earned	Net operating income/annual interest expense			
10.Cash flow overall coverage ratio	(NOI+lease expense+depreciation/interest+leas expense+principal payments/(1-tax rates)			
Prfitability ratios				
11.Gross profit margin	Gross profit/sales			
12.Operating profit margin	Net operating income/sales			
13.Net profit margin	Net income/sales			
14.Operating income retrun on investment	Net operating incom/total assets			
15.Return on total assets	Net income/total assets			
16.Return on common equity	Net income available to common/common equity			

Table 3.7: Summary of financial ratios

Narrative	YEAR 3	YEAR 2	YEAR 1
Date	31/3/92	31/3/91	31/3/90
Turnover	£2743511	£2115532	£1512652
Gross Profit	312561	234379	192962
Trading Profit\ Operating Profit	18536	14353	4943
Totals Assets Less Current Liabilities	73546	65392	48516
Stock & Works in Progress	2756	2000	4631
Current assets	735981	524601	336953
Current Liabilities	575689	516349	331122
Current Assets less stk & wrks in Prog	733225	522601	332322
Debtors	309456	271903	215572
Creditors	546987	516349	331122
Contract size	200000	200000	200000
RATIOS:-			
Return on capital employed	24.98	21.95	10.19
Gross profit as a percentage Turnover	11.39	11.08	12.76
Trading profit as a percentage turnover	0.67	0.68	0.33
Work per £ of capital employed	34.87	32.35	31.18
Current ratio	101.56	101.6	101.76
Quick ratio	101.65	101.21	100.36
Debtors: Creditors	47.66	52.66	65.1
Contract size to turnover %	7.28	9.45	13.22
Comments:-			
Ratios			
Turnover			

Table 3.8: Example spreadsheet of the analysis of financial trends

3.3.2.4 Assessment against managerial criteria

These criteria are used to assess elements such as the

- Capability to execute the work in an appropriate manner.
- Existence and application of quality control programs.
- Ability to coordinate the work.
- Previous performance of the company in projects of similar type and size.
- Percentage of the work previously performed by the company that was completed within budget and schedule.
- Quality of work achieved in the last projects.
- Quality programmes of the company.
- Identifying the managerial approach to risk specially at a pre-award meeting.

As with the technical criteria, most of the clients interviewed use subjective methods, although a few do use quantitative methods in assessing the information.

3.3.2.5 Assessment against security criteria

This information is not always taken seriously by clients and it is rare to find a contractor rejected on this criteria, especially if a contractor is already on a standing list. Several points are checked by the safety officer during the pre-award meeting however, including company safety policy, Method Statement, F10 notices used in the UK for the contracts over 6 weeks duration, job flow charts, welfare provisions, electricity regulations, IE ELCB or 110 V Transformers, Health and Safety Information charts for employees, accident books, excavations weekly examinations, reports of tests (sites), lifting appliances, weekly inspections and test reports, scaffolding weekly examinations, cranes, eye bolts certificates of test and examination, underground services and drainage connections. Again, all the information is assessed subjectively.

3.3.3 Criteria evaluation

The strategies for short-listing contractors for invitation to tender are different from one client to another.

1) For the **standing list** tendering system some clients select contractors at random from the list for invitation to bid whilst most clients select contractors using the rotation system. Still others use a points' system in which those on the list are invited to tender through an advertisement in a press. In this case, selection is made from those applying who are willing to tender and receive the full package on the basis of a points' score, with the highest six scorers given the chance to tender. Table 3.9 provides an example of this system and the criteria that are considered in selection.

Project .... Estimated Value £ ....

1. Location: within the client region, 4 points; up to 20 miles, 3 points; 20-40 miles, 1 point
2. Annual turnover: 2-3 times estimated value, 1 point; 3-6 times estimated value, 2 points; over 6 times estimated value, 3 points.
3. Trades Employed: which identifies the specific categories of the contractor, no record found in point system.
4. Experience: at least £... 1 point for each similar project, with a maximum of 8 points. Note that some aggregation of smaller projects is permissible but only when firm has only done projects of similar value
5. Work in public sector: a maximum of 2 points for comparable projects in public sector
6. Safety: If safety policy was reviewed within 1 year of form date - 1 point.
7. Performance with this authority: assessment of quality, attitude, time, etc, max 3 points.

FIRM	1	2	3	4	5	6	7	TOTAL	DECISION
A									
B									
C									
D									

Table 3.9: Example of project advert system and the criteria considered

2) For **project list** tendering, a quantitative system is used in which contractors are invited to tender through an advertisement in a press or by direct invitation. In this case, selection is made from those applying who are willing to tender and receive the full package on the basis of a points score, with the highest five to six scorers given the chance to tender.

At bid evaluation stage, it is the practice of all the respondents to select the contractor tendering the lowest bid irrespective of the technical, financial, managerial and security information available. Thus the lowest bid is currently used to decide the winner of all contracts, even if the contractors tendering for the contract had received lower assessments compared to the other tenderers for other criteria.

After the winning contractor is identified by the client, final checks and a pre-award meeting are normally carried out to clarify the technical points, safety aspects, and risks associated with the construction.

3.4 DISCUSSION

The most notable aspect of this survey is the increasing subjectivity in our interviewees' practices in moving from information collection, through criteria assessment to final evaluation phases. Although only ten practitioners were interviewed, all are clear about the information to be collected and the general reasons for its collection, there is some variance in the coherence of views on the criteria for which the information was to assess, and complete perversity in the abandonment of the criteria in the bid evaluation phase. The following are the main points drawn from the investigation.

- The application forms used to collect information about the contractor differ in structure and in the detailed information requested for most of the clients interviewed.
- Financial soundness is the most important criterion considered during the prequalification stage.
- There is little awareness to the importance of safety criteria, which are treated as of secondary importance. It is enough for the contractor to submit a two pages safety policy to be accepted for a standing or a project list.
- Attitudes of contractors towards claims is an essential issue.
- Ability to complete on time is also an essential criterion considered during the detailed investigation phase.
- Approach to dealing with third parties (eg., gas and electric suppliers) is important for civil engineering works and relationship with subcontractors and suppliers are considered important for building and civil engineering works.
- Different methods are used to assess the information collected.
- Bid price is the only criterion considered by all clients in the bid evaluation phase.

In fact the distinct impression gained is that of the cart being put before the horse in a situation reminiscent of Buckminster Fuller's *Operating Manual of Spaceship Earth* where it is conjectured that our major institutional systems were put in place for the amusement of some whimsical, and long since departed, extra terrestrial 'Pirates'! Whilst the logic is clearly appropriate - the 'ends' of contractor selection justify the 'means' of evaluation through criteria development and assessment through information collection - the formal procedures necessary to collect the information seem to have taken on a life of their own at the expense of the more difficult phases of assessment and evaluation which, in the absence of any formal procedures, appear to take place in a largely subjective and *ad hoc* manner.

The central issue in this are the criteria to be used in contractor selection. These are determined by the client or project objectives and determine the information needed for their assessment. Although it was not possible to make direct comparisons between criteria used by different clients and due to the often implicit nature of these criteria, I had little difficulty interpreting their actions in terms of the four criteria identified in the literature. This strengthens my belief that, although there is little sharing of knowledge between clients, the similarity of their goals tends to result in the use of similar criteria.

The results of this study indicate that there is some variation in the measures and methods of assessment used. Each client uses a different scale for categorizing the contractors. Furthermore, although clients apply all the criteria to some extent, there is no systematic way of developing and differentiating between methods of assessment.
Also, an important and surprising omission for all those interviewed is that there is no investigation of the contractors' workload outside the client's environment at the time of contract awarding.

3.5 A COMMON SET OF CRITERIA

As discussed earlier, most of the clients involved in the study use the same type of criteria with some variation, but all of them use a mixture of criteria to collect information about the contractors. Also, there was no definite differentiation and classification of these different types, which makes the assessment more difficult. This confirms the findings of the literature surveyed. Thus, this survey, in conjunction with the litertaure, allows the author to summarize the five main criteria currently used, arranged in a way to assess the method of collection for information about contractors, and also for assessment later in the selection of contractors in the prequalification and bid evaluation stages. Table 3.10 identifies these five main criteria **(Financial soundness, Technical ability, Management capability, Safety, and Reputation)** along with the information necessary to assess these criteria.

Financial Soundness	1. Financial stability 2. Credit rating 3. Banking arrangements and bonding 4. Financial status
Technical Ability	1. Experience 2. Plant and Equipment 3. Personnel 4. Ability
Management Capability	1. Past performance and quality 2. Project management organization 3. Experience of technical personnel 4. Management Knowledge
Health and Safety	1. Safety 2. Experience Modification Rating (EMR) 3. Occupational Safety and Housing Adminstration OSHA Incidence rate 4. Management safety accountability
Reputation	1. Past failures 2. Length of time in business. 3. Past client/contractor relationship 4. Other Relationships

Table 3.10: The main and source of criteria for contractor prequalification

Table 3.11 summarises the financial soundness criteria. Table 3.12 covers the technical criteria and the method of measurement of contractors' technical ability. The technical criteria are divided into four sources of information: experience; plant equipment; personnel; and ability of contractors. The measure of this criterion is shown for each type of source of information, for example plant and equipment is measured by the availability of owned construction equipment, testing equipment, small tools, etc. Tables 3.13,3.14, and 3.15 cover Management, Health and Safety, and Reputation criteria respectively. The criteria identified in Tables 3.10-3.15 were used for preparing a questionnaire survey in chapter 5 to validate and support the findings of this chapter.

It is important to note that the degree of emphasis and the weights assigned to each criterion is different and largely depends on the circumstances and specifics of the project as well as the preferences of the decision makers and their different experiences.

Financial soundness			
Financial Stability	**Credit rating**	**Banking arrangements and bonding**	**Financial status**
* Current and fixed assets * liquidity * Annual turnover	* Subcontractors * Suppliers	* Short term borrowing * Long term borrowing * Bonds	* Balance sheet statement * Income statement

Table 3.11: Measures of financial criteria

Technical ability			
Experience	**Plant and Equipment**	**Personnel**	**Ability**
* Experience over last five years in construction. * Current and completed contracts. * Past experience on owner's major projects. * Experience and capability of technical field personnel. * Complexity of work executed. * level of technology. * Types of projects executed in the past five years. * Performed work of the same general type and scale and ability to absorb subsequent changes.	* Availability of owned construction equipment * Adequate plant and equipment to do the work properly and expeditionary * Small tools and construction equipment. * The testing equipment as quality assurance.	* Availability of first level supervisors and number presently employed * Availability of skilled crafts * Expertise in design * Skills including professional, and technical expertise, that are available to the company, e.g. qualifications and relevant experience * Craftsmen availability (Training or skill level of craftsmen Supervision.	* Ability to handle the offered type and size of work. * Ability to perform on site. * Ability to control and organise contracts and efficiently integrate labour resources. * Ability to meet target dates.

Table 3.12: Measures of technical criteria

Management Capability			
Past Performance and quality	**Project Management Organization**	**Experience of Technical personnel**	**Management knowledge.**
* Past performance * Quality-control program and quality of work on past projects * Quality assurance certificate * Quality level, including aesthetics, confidence in design, and flexibility in accommodating design inputs by the client * Quality of Workmanship.	* Experience in completion of project on schedule. * Planning, Programming and General Progress. Site organisation and Supervision. * Engineering coordination * Present workload and capability to support the current projects * Capability to manage subcontractors. * Drawing control procedure * Capability to perform material control * Methods of procurement adopted * Certainty, including the reliability of the original price, reliability of the estimated construction time. * Field organization, work rules, work policies	* Present workload and capability of contractor key site-management personnel * Availability of first-line supervisors * Staffing levels in the company including management, professional/technical, administrative/clerical * Executive involvement-leadership	* Scheduling and cost control system and how it is utilized * Material control, personnel, accounting, subcontracts, purchasing. * Level of research and development * Risk avoidance and responsibility, including client involvement and design liability. * Productivity improvement programme * Time performance * Predicted outturn costs

Table 3.13: Measures of management criteria

Health and Safety			
Safety	**ExperienceModification Rating (EMR)**	**OSHA Incidence rate**	**Management safety accountability**
* Experience in handling dangerous substances * Experience in noise controlling * Accident Book * Complied in all respects with health and safety regulations. * Health and Safety Information chart for employees * Safety record * Company safety policy	* Financially rewarding or penalizing employers according to their accident claims.	* OSHA is the Occupational Safety and Housing Adminstration which is the average numbers of injures and illness.	* Who in the organization receives and reviews accident reports, and what is the frequency of distribution of these reports. * Frequency of safety meetings for field supervisors. * Compilation of accident records by foremen and superintendents and the frequency of reporting. * Frequency of project safety inspection and the degree to which they involve project mangers and field superintendents. * Use of an accident cost system measuring individual foremen and superintendents as well as project managers.

Table 3.14: Measures of Health and Safety criteria

Reputation			
Past failures	**Length of time in business.**	**Past client /contractor relationship**	**Other relationships**
* Past and present experience regarding legal suits or claims. * Reasons for recent debarment (if any). * Reasons for failed contract(if any). * Previous failures to perform contracts properly or fail to complete them on time. * Financial penalties previously levied in respect of failures to perform to the terms of a contract. * Contracts the firm has had terminated or employment determined under the terms of contract. * Contracts not renewed due to failure to perform in accordance with the terms of contract.	* Amount of projects executed in the past five years. * Capacity of work. * Company's stability * Permanent place of business. * Depth of organization.	* Proximity of contractor's home office to project * Responsibility and consideration for the client staff and general public . * The performance of contractors over a number of previous invitations * Responsibility and consideration for the adjoining owners affected by the work. * Experience of working with the owner, i.e., understanding of the owner's procedures in meetings and for ayments. * Responsible attitude towards the work.	* relationships with subcontractors, industrial. * Maximum percentage of subletting * Relationship with employees. * Relations with Statutory Undertakers. * Working relations between members of the referee staff and the staff of the firm including head Office staff. * Race relations. * Standard of Sub-contractors work.

Table 3.15: Measures of the contractor reputation criteria

3.6 CONCLUSION

The increasing needs in shorter project periods, making earlier occupation possible and allowing the client to obtain an earlier return on his investment in the 70's, has led to the use of alternative forms of project delivery systems, but the tendering and awarding systems are still largely in their original form. One of the most difficult decisions taken by the client is selecting the contractor. The inappropriateness of the selected contractor leads to sub-standard work, delays, disputes, or even bankruptcy.

In order to invite suitable bidders it is necessary to clarify and develop pre-determined selection criteria, improve and organise the assessment of information relating to these criteria, and develop methods for evaluating the criteria against the client's goals in the prequalification and bids evaluation stages of the procurement process. This chapter is concerned with identifying such criteria and the means by which different emphases can be accommodated to suit the requirements of clients and projects.

The information, assessment and evaluation strategies currently used by procurers for screening contractors have been considered and the results are reported of an extensive literature review and interview study with a sample of construction professionals with extensive experience in prequalification and bid evaluation processes. The findings indicated the most common criteria considered by procurers during the prequalification and bid processes pertaining to financial soundness, technical ability, management capability, health and safety performance of contractors and the reputation.

There is constancy between these practitioners both in the selection of the lowest bid and the using in general approach to tendering, and in the common criteria being used. There is however sufficient corroboration with the general literature on the subject to indicate that the model proposed for collecting different types of criteria may well be appropriate in the general field.

The research on which this thesis is based, rests on the premise that there is a possible common set of contractor selection criteria. If these criteria are identified and their levels of importance determined, the development of an objective quantitative selection framework could be facilitated. Construction clients may then apply more objective contractor selection methods as a means of identifying the most suitable contractor for a project. This alternative approach could avoid duplication of effort (with a commensurate reduction in individual clients' resource costs).

The next stage should now be to conduct a larger and more focused survey covering a wider range of clients. This wider survey is covered in chapter 5 in which I used the common set of criteria identified from this study as a basis for comparison in terms of identity of contractor selection criteria used by different clients in the construction industry.

Once this has been realised, there is a real prospect of developing a prescriptive, or even normative Code, for selection criteria to provide a consistent, logical, objective and therefore a comparable and communicable basis for useful information exchange between procurers of construction work for more accurate, reliable and efficient decision making.

The following chapter (4) is part of the literature survey. It concentrates on previous decision analysis techniques for modelling prequalification. At the end it presents the principles of utility theory, its advantages as a decision tool for selecting contractors.

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4. DECISION MODELS FOR SELECTING CONTRACTORS

CHAPTER 4

Decision models for selecting contractors

4.1 INTRODUCTION

This chapter is also part of the literature survey. It concentrates on previous decision analysis techniques for modelling prequalification. At the end it presents the principles of utility theory, its advantages as a decision tool for selecting contractors.

Several decision tools for modelling engineering management problems exist. Such tools range from qualitative to quantitative in their treatment of available data relevant in decision-making. The adoption of any tool to a given engineering management decision domain has both advantages and disadvantages or tradeoffs in obtaining an optimum or best possible solution to the problem.

One decision domain involves prequalification of construction contractors prior to allowing them to participate in the bidding process. Prequalification decision-making typically involves criteria for which data are qualitative, subjective, and imprecise. Several decision analysis techniques exist for modelling prequalification decision-making. Previous decision support systems are described below.

4.2 FINANCIAL MODEL

Mathematical formulae for prequalification purposes are utilized by many state departments of transportation(DOTs) in the U.S.A. The evaluation process is typically performed on an annual basis (Russell 1992).

The formula typically utilises parameters from a financial statement (balance sheet) to establish the maximum aggregate amount of uncompleted work a contractor can have under construction at any one time. A judgemental reduction of this calculated value to reflect items such as contractor safety, past performance, and co-operation is usually applied (Russell and Skibniewski 1987).

For example, in Ohio, to determine the maximum allowable work volume for a given contractor during prequalification process, the applicant's net current assets(NCA) are multiplied by a coefficient C (e.g 10). The volume of work obtained in this manner is also regarded as the maximum financial capacity. Then, final ratings are determined by modification coefficient (M) of the financial capacity using the following factors: organization and key personnel 20%; planning and equipment 20%; construction experience 20%; credit 15%; and past performance 25%(Ohio 1963)

Whether a contractor is prequalified for a given project or not is dependent upon the size of the project compared to the difference between the contractor's maximum financial capacity and the amount of current uncompleted work. If the project cost exceeds the difference described above, the contractor is not allowed to bid on the project.

These formulae do not make the maximum utilisation of available contractor data. Their ability to adequately ascertain a contractor's performance capabilities and capacity were found to be inaccurate (Nittany Engineers and Management Consultants 1985).

In many instances, the contracting officer makes a prequalification decision based on subjective judgement. This judgement may be based on the comparison of such factors as previous experience with the contractor, how a contractor's field staff operate, how well a contractor has adapted to the owner's construction operations and procedures and other data (Russell and Skibniewski 1987).

4.3 LINEAR MODEL

A linear model is frequently used in the prequalification process. In this model, each decision parameter (contractor selection criteria) and its relative weight of importance is determined based on the characteristics of the decision maker. Once the decision parameters are established, the contractor can be rated with respect to the decision parameters. A contractor's score is calculated as a weighted sum of ratings over all decision parameters. The rank order of the scores can be used to perform contractor selection. An example application of this model can be found in (Bent 1984) and (Russell and Skibniewski 1988).

A computerised algorithm, QUALIFIER-1, has been developed according to the above concept(see Russell and Skibniewski 1990). The model's structure, decision parameters, and corresponding weights embedded within the program are based on statistically analyzed questionnaire data. Details regarding questionnaire survey are presented in Russell and Skibniewski (1988).

This program calculates an aggregate weighted rating for candidate contractors. The ratings are then rank-ordered.

One of the drawbacks of this program is that it requires a user to be knowledgeable on what and how the evaluation is to be performed. A deterministic rating is given by a decision maker after a subjective analysis and synthesis of the available contractor data are completed. Various items can impact the obtained results, which are human-dependent, including information overload, incompetent personnel, personal biases, and lack of experience and knowledge within this domain.

The assumption of additivity of the model's decision parameters has been made. Furthermore, the model does not account for imprecision and/or uncertainty associated with data submitted by the contractor or judgement applied in evaluating these data by the client.

4.4 FUZZY SET MODEL

Another approach to modelling the contractor prequalification decision-making process is fuzzy set. Fuzzy sets were first introduced by Zadeh (1965). Nguyen(1985) applied this methodology to the evaluation and selection of contractors based on three criteria, cost which is the sum total offer made by each contractor, past experience, and predictive judgement on the contractor's likely performance for the present job.

Decision makers are typically faced with qualitative variables such as contractor experience. Varying degrees of contractor experience exist. However, under classical set theory, a contractor is either experienced or not. Fuzzy sets theory enables these varying degree to be expressed by linguistic variables such as 'poor', 'good', and 'very experienced'. The degrees of experience can, therefore, be measured accurately.

Since fuzzy sets permit information to be treated based on varying degrees of confidence, it is particularly suitable to model uncertainty associated with human perception or subjective probability judgement as in the case of evaluating tenders.

Several mathematical operations of fuzzy set theory exist. An illustration which includes the aggregation of the three criteria previously mentioned using fuzzy sets is presented in Nguyen (1985)

4.5 KNOWLEDGE-BASED EXPERT SYSTEM MODEL

The idea of knowledge-based expert system is to establish a more structured approach to the process. A prototype knowledge-based expert system, QUALIFIER-2, has been developed by Russell et al (1990) for contractor prequalification.

The decision model presents a procedure to be followed by prequalification officials as a means to formalise the contractor analysis process. This is achieved by representing the prequalification problem by a hierarchy of decision parameters. A decision tree of each parameter contained in the hierarchy is employed.

The developed decision model separates the contractor prequalification problem into a number of sub-problems. These sub-problems consist of five distinct linear levels within the model hierarchy. Each level can be characterised by numerous other lower-level decision parameters pertinent to evaluating a given level. At each level, inferences are based on a set of 'if... then' production rules (Russell 1992). The model comprises the following levels(or modules):

1- References/reputation/past performance - preliminary screening criterion

2- Financial stability - to evaluate the financial condition of each contractor.

3- Status of current work programme - to evaluate contractor's current workload and determine any severe difficulties with ongoing projects.

4- Technical expertise - to evaluate technical characteristics of contractor.

5- Project - specific criteria - to evaluate if candidate contractor can provide unusual expertise or specified facilities required by the project.

The system has four possible decision responses which can be rendered at each decision point:

1. Qualify (continue to the next level)
2. Disqualify (terminate the analysis)
3. Unsure(prior to making the decision, the judgement of the user must be exercised; e.g more data collection and analysis may be required)
4. Unknown (based on the variable responses input, the system's knowledge base does not contain rules which incorporate these variable responses to draw a conclusion)

A more complete description of the system can be found in (Russell et al 1990).

4.6 COMPETITIVENESS MODEL

Drew and Skitmore (1993) believe that "*the objectives of prequalifying bidders is to obtain an optimal level of competition, that is obtaining the lowest bid at a minimum cost of bidding*". They suggest a model by systematically recording, in terms of competitiveness, previous bidding performances of contractors. A measure of competitiveness is the percentage of each bid above the baseline, or C-competitiveness,

i.e. $\mathbf{C_i=100(x_i-y)/y}$

where x represents the bid value of individual bidder i, and y is the lowest bid. Lower percentage values indicate greater competitiveness.

By aggregating the C values for an individual bidder over a series of auctions it is then possible to examine the bidder's performance in terms of the frequency distribution of the aggregated C values. Two summary statistics were considered to describe the frequency distribution, the arithmetic mean C', and standard deviation C". Low values of C' are taken to denote high competitiveness and low values of C" are taken to denote a high level of consistency of competitiveness.

Then, by comparing C' and C" of their competitiveness, it may be possible to find out which contractor is *"Sensible, "Suicidal", "Non Serious" or "Harmless"*. They conclude that, from the client's point of view, *"Sensible, and "Non Serious"* are essentially low risk contractors, whilst *"Suicidal", and "Harmless"* are essentially high risk contractors, and which type of contractor to be prequalified ultimately depends on client's attitude to risk and cost trade-off.

4.7 MULTIATTRIBUTE TECHNIQUES

Holt et al (1993) has proposed a system with quantifiable indices. This comprises a three-stage process requiring the calculation of what is called a P1 scale index to investigate the more general areas surrounding potential tenderers. A P2 scale index is calculated for the second stage to further assess the contractor in the light of specific factors. Finally a P3 scale index is calculated to compare the bid prices of the invited tenderers. Finally, Holt et al (1993) combines the P2 and P3 scores into a simple index by assigning a 60% weighting for the P3 score (representing the bid price) and a 40% weighting to the P2 score (representing the scores of the information collected).

Herbsman and Ellis (1992) proposed a system which is based on the idea that the selection process of the contractor will be based on more parameters than just bid price (cost). The successful bidder will be selected according to the lower combined bidding value. Most logically, this number will be represented by a pound value, but it can be represented using points, percentage, etc.

The major parameters will be Cost, C; Time, T; and Quality, Q. Secondary parameters can also be incorporated into the system, such as: Safety, S; Durability, D; Security, S; Maintenance, M; and a few more. Quantification of these parameters and an example application of this model can be found in Herbsman and Ellis (1992).

Ellis and Herbsman (1991) on the other hand proposes a time/cost approach to determine the winning bidder in highway construction contracts by which a road user cost is applied to the contract time proposed by each bidder. Therefore in this case it is suggested that the criteria to be considered are bid prices and contract time (the road user cost being applied to the contract time). By converting the contract time to a cost to the client, a straight forward comparison can be made on a single criterion.

Hardy's (1978) criterion for bid evaluation is the bid which maximises the return on the client's investment. Thus he proposes that bidders should submit a schedule of the payments they expect to fall due to them during the contract. Both the client and contractor may use this to determine the Present Value of bids. Hardy (1978) views the bid price as effectively representing a cumulative series of payments over time, giving particular consideration to the use of discounted cash flow techniques to produce present values of the bids. Here he also considers inviting competition on the duration of construction and on the magnitude of advance payments.

4.8 DISCUSSION

A common inadequacy of the above modelling techniques is, none of them actually maximise the usage of data available for prequalification decision making. Varying types of data are presented; quantitative, qualitative but artificially quantified. This is a result of the restricted capabilities and flexibility that each modelling technique has adequately to model each aspect of the problem domain.

Certain models require a deterministic rating from the decision makers which is contrary to the basic principle of the objectivity in the prequalification process. Furthermore, they do not account for imprecision and/or uncertainty associated with data submitted by the contractor.

Some of these models, such as knowledge-based expert system, may not be an ideal model for rank ordering the contractors. As a result, some of these models could not produce a short list of the tenderers.

The Financial model was found not accurate about the contractor's performance capabilities and capacity. In many instances, the contracting officer makes a prequalification decision based on subjective judgement.

In terms of ease of implementation, some models, such as fuzzy set model and statistical models seem to be too sophisticated to be operated by the decision makers. What seems to be needed is a more effective system for prequalifying contractors.

A system that should be able to make use of the available data, account for uncertainty, prequalify the contractors in terms of the client goals time, cost and quality, and which type of contractor to be prequalified ultimately depends on decision maker attitude to risk and trade-off. Literature review revealed that the best technique for measuring the decision maker attitude towards risk and tradeoffs is the utility (preference) theory (Corner and Kirkwood 1990).

4.9 UTILITY THEORY TECHNIQUE

In an uncertain world the responsible decision maker must balance judgements about uncertainties with his or her preferences for possible consequences or outcomes. It's not easy to do. Utility techniques concentrate on formalizing the preference or value side of the problem. The technique is about how a decision maker should think systematically about identifying and structuring objectives, about making vexing value tradeoffs, and about balancing various risks (Keeney and Raiffa 1993).

Different sets of axioms that imply the existence of utilities with the property that expected utility is an appropriate guide for consistent decision-making, are presented in (von Neumann and Morgenstern 1947), (Savage 1954), (Luce and Raiffa 1957), (Hammond 1967), (Fishburn 1970) and (Keeney 1982).

4.9.1 Terminology

To facilitate the understanding of the utility decision analysis technique, a brief explanation of how terms as objective, attribute, utility are utilized, is given below.

Objectives: Objective generally indicates the direction where to concentrate the efforts to do better (Keeney and Raiffa 1993). In the way it is used it may imply conflicting interests, since the achievement of one can only be accomplished at the expense of another.

Attributes: Attributes are the scales in which the level of achievement of objectives are measured (Moselhi and Martinelli 1990). The attribute may be well defined as quantities such as pounds or other more vague units such as safety, quality, etc.

Utility: Utility may be defined as a measure of desirability of an alternative (Ang and Tang 1984). The utility concept was introduced to provide a uniform scale to compare tangible and intangible attributes. It is noteworthy to point out that since utility is a measure of value of an attribute for the decision maker, it may have different values depending on his assessment.

By suitable questioning we can determine for each individual a relationship between his utility and pounds which is called his utility function.

Utility function: Utility function is a complete summary of the decision maker's attitude toward risk (Swalm 1966, Hammond 1967). It is a device to quantify the preferences of a decision-maker by assigning a numerical index to the various levels of satisfaction of an objective or an attribute (Mustafa and Ryan 1990).

In any decision involving risk, a man will choose that alternative which maximizes his utility. Once we know his utility function, the odds he assigns to events in a decision-making situation, and the consequences of each possible outcome, we should be able to predict his choice in this situation, since he will attempt to maximize his utility.

4.9.2 Procedure to apply utility analysis technique

In the application of this technique for decision making, several elements must be identified in the process. The way to develop the process are described briefly below. More information about this topic is available in references (Swalm 1966; Hammond 1967; Schlaifer 1969; Keeney 1974, 77, 82; Hertz and Thomas 1984; Keeney and Raiffa 1993). The process consists of the following steps:

- Statement of the problem: In this stage a feasible set of alternatives must be established in order to build a decision model.
- Definition of attributes. The attributes selected must be comprehensive enough to account for the most relevant characteristics of the alternatives.

The most common way to identify a list of relevant attributes is through consultation with experienced persons in the field related to the case being considered. In some cases, the consultation process should be extended to other groups that might be affected by the final output; for instance, users of the facility under consideration should be consulted when a decision concerning a public utility is to be made.

- Identification of the Decision-making group. In general, the determination of the Decision making group is very important since they will be questioned in order to determine the utility functions. In some cases, within the decision making group there could be persons reflecting conflicting interests. Obviously the utility values of these individuals will be totally different affecting the total utility function for a determined attribute.

- Determination of the utility functions. These functions are the most important input of the multiattribute decision analysis. The utility function represents the quantification of the order of preferences of the decision-maker, and it must be determined for each one of the attributes.

The procedure to obtain utility function(s) consists in determining the decision maker equivalence between preference gambles. Some of the techniques to assess utility functions have been explained in detail by (Keeney 1977, 82 ; Spetzler and von Holstein 1975; Ang and Tang 1984).

- Assessment of the weighing factors or scaling constants: The scaling constants represent the relative importance that the decision maker(s) assign to each one of the attributes. It show how much the decision maker is willing to give up in one attribute to gain on the other attribute.

- Calculation of the overall relative utility. Once the utility functions have been determined and scaling constants have been assigned, the calculation of the overall utility is performed using the formulae of one of the four models (Additive model, multiplicative model, multilinear model and general model) described by (keeney and Raiffa 1993). Each of these four models are described in Chapter 9, an illustrative example of additive model is given in chapter 6.

The reason for using utility theory is because in the majority of engineering problems, attributes with different units of measurement, such as cost, time, quality could be combined. Utility theory provides the tools to construct a scale (usually from 0 to 1) which will permit a uniform evaluation of the attributes under consideration (Martinelli 1986). Nevertheless, the determination of the utility functions may indeed be a difficult process, since it depends to some degree on the personal perceptions of situations and its consequences from the part of the decision maker. A comprehensive review of utility theory is presented in (Keeney and Raiffa 1993).

The art of applying multiattribute utility theory has expanded in many applications, Corner and Kirkwood (1990) in their survey of the applications of the decision analysis that appeared in a major operation research journals(1970 - 1989), counted twenty eight applications for the utility analysis technique. A list of applications used as references is shown in appendix 4. Only one of these application by "Dyer and Lorber 1982" is used in bidding.

4.10 CONCLUSION

As outlined in this chapter, there is currently no decision model which uses available data to its full extent, they do not account for uncertainty associated with data submitted by the contractor. Consequently, each decision model has some limitations in arriving at a solution.

A multiattribute utility decision system which will be presented in this thesis is expected to be a feasible tool to aid in decision-making regarding contractor prequalification. A system that should be able to make use of the available data, account for uncertainty, prequalify the contractors in terms of the client goals or project success factors such as time, cost and quality, and which type of contractor to be prequalified ultimately depends on decision- maker attitude to risk and trade-off.

This chapter is part of the literature survey. It concentrates on previous decision analysis techniques for modelling prequalification. It presents the principles of utility theory, its advantages as a decision tool for selecting contractor. Chapter 3 investigated the contractor selection criteria, while chapter 2 investigated the tendering procedures. Chapters 2, 3, and 4 concluded the literature survey and some initial interviews on the issues of preqalification. In the following chapter 5, a wider questionnaire survey will investigate the findings of chapters 2, 3 and 4.

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5. A SURVEY OF TENDERING PROCEDURES AND CONTRACTOR SELECTION CRITERIA

CHAPTER 5

A Survey of tendering procedures and contractor selection criteria

5.1 INTRODUCTION

In order to cover a wide range of professionals involved in prequalification in the construction industry, and also to substantiate the findings of the literature survey and the interviews conducted earlier in chapters 2 and 3, a questionnaire survey was prepared and sent to the public and private clients. The format, structure, contractor selection criteria and their measures used in this questionnaire were based upon the findings of chapters 2 and 3.

5.2 OBJECTIVES

The aim of the survey was to maximise the response rate from the sample frame. The survey was carried out in an effort to investigate the common characteristics of tendering procedures and the common criteria used by clients of the construction industry to select the contractor.

It was also intended to collect information about the number, value and types of contracts in use, the criteria considered by clients to evaluate bids submitted by tenderers, and to establish the clients' level of satisfaction with the performance of completed projects in terms of time, cost and quality.

5.3 METHOD OF DATA COLLECTION

It has been established by Hoinville and Jowell (1978:124) that postal surveys can retrieve data from a wider geographical area than interviews, particularly if there is a need to minimise expenditure, while at the same time giving a level and quality of response at least equal to interview survey.

This view has been supported by Oppenheim (1986:37) who also confirmed that this method was preferable if the information had to be obtained from records.

The need to collect detailed information from clients based in different geographical locations therefore led to the decision to use the postal survey method of information gathering, utilising self-administered questionnaire.

The questionnaires were distributed to 300 clients who were selected randomly from Municipal year book 1995 and RICS 1994 directory.

5.4 QUESTIONNAIRE DESIGN

The design of the questionnaire form was given particular attention. In order to maximise the response rate, it was determined that the length of the questionnaire should be restricted to permit completion within a fifteen to twenty minute time period which is believed to be reasonable (Fortune and Lees 1993).

5.4.1 Format

The layout and format of the questionnaire reflected the advice given by Hoinville & Jowell (1978:125-130) with the majority of the questions being closed in nature (Appendix 5)

On the basis of Bradburn's(1980:19) work in this field, open, familiarly worded, longer questions were usually used for threatening items, i.e those asking "why" and "how" in order to enhance the possibility of obtaining truthful replies from respondents. These types of questions are not included in this questionnaire. The respondents are not influenced by question length and by wording familiarity in making a "yes" or "no" answer which is the majority of questions in this questionnaire.

The following techniques were also used to examine the response:-

a) The title of the questionnaire and the covering letter incorporated an undertaking of strict confidentiality in respect of all the information provided by the respondents (Moser and Kalton 1971).

b) The questions were ordered in such a way as to enable the respondent to gain confidence by initially having to answer a few simple questions before moving on to those requiring more complex responses.

c) The majority of the questions only required a tick to be placed in the appropriate space in order to provide an answer.

d) In order to reduce the apparent number of questions, sub-letters, e.g. Q11.1a. 11.1b, etc were used wherever possible.

e) The questionnaire was presented in as an attractive way as possible.

5.4.2 Contents.

- The questionnaire contained sixteen questions divided into four sections A, B, C, and D (appendix 5), the first four comprising section A, sought to classify the type of respondents' organisations i.e public or private, the qualification and function of the respondent, and the number, value and types of contracts implemented by the firm.

- The next five questions in section B asked for details related to tendering procedure, which includes the methods used to solicit tenders, the major elements in tendering system, the major steps to prequalify contractors, and the major steps for evaluation of bids. These questions were sought to investigate the findings of Chapter 2.

- Questions 10 to 14 in section C related to the type of criteria used by clients for contractor selection. These questions were sought to investigate the findings of Chapter 3.

- Question 15 relates to the criteria considered by the firm in evaluating bids submitted by tenderers.

- The final question in section D asked whether the respondent was satisfied generally with the performance of completed projects in terms of time, cost and quality. The result of this section will be used as a base for chapter seven forward.

5.5 DISTRIBUTION AND RESPONSE TO THE QUESTIONNAIRE

To ensure that the objectives of the questionnaire were achieved it was necessary to undertake a pilot exercise. Such exercise was highlighted by Panten (1950) who emphasised the importance of "piloting" as a technique which could provide guidance on sampling frame, suitability of the data collection method, adequacy of the questionnaire form itself and the non-return rate expected. Accordingly, a pilot survey was conducted with a group of Ph.D. students in management in Salford university and UMIST, and a member of staff in the department of surveying at Salford University to test the questionnaire before an industry-wide survey was launched. This was done to ensure that the data collected would be comprehensible and established the most productive form of data analysis. This pilot study allowed useful modification to be made to the questionnaire style and minor cosmetic refinements berfore the main survey was initiated.

300 questionnaires were distributed to public and private clients' organisation selected randomly from Municipal year book 1995 and RICS 1994 directory. The prime aim in the composition of the sample, was to achieve a reasonably balanced blend of public and private sector contractor selection.

Out of the 300 questionnaires distributed, 162 questionnaires were returned, i.e nearly 54 %, of this 6 was invalid. 156 useful replies were therefore received (88 of which represents 56.5% public and 68 representing 43.5%, private). A response rate of 52% was obtained; whilst this is below the lower level of the response rate for postal surveys i.e 60% as quoted by Hoinville & Jowell (1978:6), it is well above the 30-40% cited by Moser and Kalton (1971) and above the 15% rate cited by Harper (1971:21) and is thus considered to be valid base for further examination and analysis.

5.6 QUESTIONNAIRE ANALYSIS

The analysis of the results were carried using a spreadsheet supercalc SC5 (1989). The analysis concentrated only on the response rate for each question.

Table 5.1 provides the number and value of contracts awarded by the respondents. The value of the total amount of work awarded is £ 5,450,000 million. This figure equates to 10,284 contracts worth an average of £ 529,000 awarded by each respondent.

It is also worth noting, that while 56.5% of sample population were public sector clients, they were responsible for only 40 % of the value of work done. This is because the private sector projects were much larger. However, the public sector awarded 5,260 of the work in terms of the number of contracts. Thus, the survey encompassed a broad sample of contractor selection practitioners, i.e those awarding many low value jobs and those awarding fewer but higher value projects.

Type of client	Total £M	Total number of contracts	Mean value each contract £M
Public sector	2203	5260	0.418
Private sector	3247	5024	0.646
All respondent	5450	10284	0.529

Table 5.1 Work awarded by respondents

5.7 ANALYSIS OF RESPONSES

Question 1 asked for the type of firm, all 156 respondents provided this information. Table 5.2 shows the number of respondents from both public and private sectors.

Types of firms	No of respondents	%
Public	88	56.5
Private	68	43.5

Table 5.2 Types of firms in the survey

Question 2 asked for the qualification of the respondents. Table 5.3 shows the numbers and percentage of qualification of the respondents; this information was requested to make sure that the respondent is a qualified person and familiar with the subject.

Qualification of the respondent	Public (88)		Private (68)	
	No.	%	No.	%
Quantity surveyor	40	45.4	37	54.4
Architect	4	4.5	5	7.3
Building engineer	16	18	0	0
Building surveyor	18	20.5	10	14.7
Others	10	11.6	16	23.6

Table 5.3 Qualification of the respondents

All respondents are qualified persons (quantity surveyors, Architects,...) for both public and private sectors, even those which are not listed in the Table i.e "others" which represent 11.6% and 23.6% from both public and private sectors respectively, are qualified persons.

Question 3 asked the respondents to describe the function they perform. This was requested to make sure that the respondent was practising the tendering procedure and selection of contractor.

Function of the respondent	Public (88)		Private (68)	
	No.	%	No.	%
Prequalification	83	94.3	63	92.6
Bid evaluation	79	89.7	68	100
Others	12	13.6	7	10.29

Table 5.4 Function of the respondents

Nearly 95% of the respondents perform prequalification in public and private sectors. About 90% practice bid evaluation for public sector and 100% for private sector. In addition to prequalify and evaluate bids of contractors some of the respondents practice some other jobs.

Question 4 asked the respondents to provide the approximate number, value and types of contracts they were involved in over the last three years; this information was requested to investigate the type of contracts in use, and to establish a basis for the analysis of questions 5 to 14. The survey has covered a wide range in terms of number and amounts of contracts.

From Table 5.5 about 59.6% of contracts in use from this survey were traditional contracts amounting to 23.8% of the total . Term contracts represent 14.1% of contracts in use with a value 32.1%. Design and build contracts represent 26% and has a value of 42.5%.

Type of contract	Public		Private	
	Number	amount £M	Number	amount£M
Traditional contract	3848	490	2288	806.8
Term contract	1368	1690.6	84	60.16
Design and build	40	16.4	2636	2300
Target cost contract	0	0	0	0
Others	4	6	16	80

Table 5.5 Number, value and types of contracts

In order to make comparison between different procurement systems, it was requested from the respondents to answer questions 5 to 9 according to the large number of contracts they were involved in. According to this, three types of contracts were found to be valid for this study and they were traditional contracts, term contracts, and design and build contracts, the details of the number of respondents from each type of clients were shown in Table 5.6.

Question 5 asked for the methods of soliciting tenders; this information and those in questions 6 to 9 were requested to investigate the common characteristics of contractor selection procedures in different procurement systems, the subject of chapter 2.

For traditional contracts 96% of contracts are awarded via standing or project list tendering system in public sector, while it reaches 100% in private sector. In term contracts 100% of the respondent use standing list tendering system for soliciting tenders, 25% of them also use project list tendering system. For design and build contracts 87.5% of the respondents use either standing or project list. These findings substantiate the findings of chapter 2 (2.5) in the systems of soliciting tenders.

Traditional contract				
Method of soliciting tenders	Public (76)		Private (52)	
	No.	%	No.	%
Standing list	49	64.5	11	21.2
Project list	24	31.5	46	78.8
Others	3	4	0	0
Term contracts				
Method of soliciting tenders	Public (12)		Private (0)	
	No.	%	No.	%
Standing list	12	100	-	-
Project list	4	25	-	-
Others	0	0	-	-
Design and build				
Method of soliciting tenders	Public (0)		Private (16)	
	No.	%	No.	%
Standing list	-	-	3	18.75
Project list	-	-	11	68.75
Others	-	-	2	12.5

Table 5.6 Methods of soliciting tenders

Question 6. asked for the definition of the five major elements in the tendering system. This question was asked to check whether the definition of these different elements of tendering systems are different from one type of contract to another, or not.

For traditional contracts 85.5% of the respondent agree to the definition of project package, while it is 67% for term contracts and 62.5% for design and build contracts. For the Invitation, Prequalification, short list and bid evaluation elements, almost 100% of the respondents for the three types of contracts agreed to the offered definition.

Traditional contract

elements of tendering system	Public (76)						Private (52)					
	Y	%	N	%	DN	%	Y	%	N	%	DN	%
Project package	65	85.5	7	9.2	4	5.2	36	69	12	23	4	7.6
Invitation	73	96	3	4	0	0	49	94	3	6	0	0
Prequalification	76	100	0	0	0	0	50	96	2	4	0	0
Short list	76	100	0	0	0	0	43	82	9	18	0	0
Bid evaluation	72	95	4	5	0	0	48	92	4	8	0	0

Term contract

elements of tendering system	Public (12)					
	Y	%	N	%	DN	%
Project package	8	67	0	0	0	0
Invitation	12	100	0	0	0	0
Prequalification	12	100	0	0	0	0
Short list	12	100	0	0	0	0
Bid evaluation	12	100	0	0	0	0

Design and build

elements of tendering system	Private (16)					
	Y	%	N	%	DN	%
Project package	10	62.5	4	25	0	0
Invitation	16	100	0	0	0	0
Prequalification	16	100	0	0	0	0
Short list	16	100	0	0	0	0
Bid evaluation	16	100	0	0	0	0

Table 5.7 Definition of the five major elements of tendering system

Question 7. asked whether the five major elements were present in their tendering system

For traditional contracts over 90% of the respondents used the major five elements in their tendering systems except the short list element in private sector where only 83% responded by yes to the question. For term as well as design and build contracts, 100% of the respondents used these elements in their tendering systems.

Traditional contract												
elements of tendering system	Public (76)						Private (52)					
	Y	%	N	%	DN	%	Y	%	N	%	DN	%
Project package	71	93	5	7	0	0	52	100	0	0	0	0
Invitation	76	100	0	0	0	0	52	100	0	0	0	0
Prequalification	72	95	0	0	4	5	48	92	4	8	0	0
Short list	72	95	4	5	0	0	43	83	9	17	0	0
Bid evaluation	69	91	7	9	0	0	48	92	4	8	0	0

Term contract						
elements of tendering system	Public (12)					
	Y	%	N	%	DN	%
Project package	12	100	0	0	0	0
Invitation	12	100	0	0	0	0
Prequalification	12	100	0	0	0	0
Short list	12	100	0	0	0	0
Bid evaluation	12	100	0	0	0	0

Design and build						
elements of tendering system	Private (16)					
	Y	%	N	%	DN	%
Project package	16	100	0	0	0	0
Invitation	14	87.5	2	12.5	0	0
Prequalification	16	100	0	0	0	0
Short list	16	100	0	0	0	0
Bid evaluation	16	100	0	0	0	0

Table 5.8 Elements of tendering system

Question 8. asked for the major steps to prequalify contractors

Traditional contract												
Steps of prequalifying contractor	Public (76)						Private (52)					
	Y	%	N	%	DN	%	Y	%	N	%	DN	%
Development of criteria	69	91	7	9	0	0	43	83	9	17	0	0
Collection of data	72	95	4	5	0	0	32	61	20	39	0	0
Evaluation of data	76	100	0	0	0	0	42	81	10	19	0	0
Collection of supplementary data	72	95	4	5	0	0	47	90	5	10	0	0
Acceptance/rejection of application	76	100	0	0	0	0	44	85	8	15	0	0
Categorisation of application	61	80	13	17	2	3	44	85	8	15	0	

Term contract						
Steps of prequalifying contractor	Public (12)					
	Y	%	N	%	DN	%
Development of criteria	12	100	0	0	0	0
Collection of data	12	100	0	0	0	0
Evaluation of data	12	100	0	0	0	0
Collection of supplementary data	12	100	0	0	0	0
Acceptance/rejection of application	12	100	0	0	0	0
Categorisation of application	8	66	0	0	4	34

Design and build						
Steps of prequalifying contractor	Private (16)					
	Y	%	N	%	DN	%
Development of criteria	12	75	4	25	0	0
Collection of data	11	68.75	5	31.25	0	0
Evaluation of data	16	100	0	0	0	0
Collection of supplementary data	16	100	0	0	0	0
Acceptance/rejection of application	16	100	0	0	0	0
Categorisation of application	8	50	8	50	0	

Table 5.9 Major steps to prequalify contractor

For term contracts, 100% of the respondents used the major steps (8a to 8f) specified in the questionnaire to prequalify the contractors.

For traditional contracts over 80% of private clients and over 90% of the public clients developed criteria for prequalification, 95% of the public collected the data through application forms, while only 61% of private sector used this method, 81% of private sector evaluated the data collected against criteria, in public sector 100% evaluated the data against criteria, over 90% of public and private collected supplementary data, 100% of public accepted or rejected the application, about 80% of the respondents of public and private categorised the applicants.

For design and build 75% developed criteria for prequalification, 69% collected the data through application forms, 100% evaluated the data, collected supplementary data, and accepted or rejected the application, only 50% of the respondents categorised the applicants.

Question 9. asked for the major steps for evaluation of bids, Table 5.10.

For traditional contracts, 90% to 100% of the respondents from the public sector used the major steps a, b, c and e while only 47% held a pre-award meeting with a contractor. Over 90% of private sector used the steps a, b, c and f but 80% of the respondents held a meeting with the contractor. In term contracts, 100% of the respondents used all the steps except pre-award meeting which was never used i.e 0% responded yes. For design and build contracts 100% of the respondents answered yes for the all steps for evaluation of bids.

Traditional contract												
steps for evaluation of bids	Public (76)						Private (52)					
	Y	%	N	%	DN	%	Y	%	N	%	DN	%
Tenders returned	76	100	0	0	0	0	50	96	2	4	0	0
Bid assessment	76	100	0	0	0	0	49	94	0	0	3	6
Award decision	70	92	6	8	0	0	48	92	0	0	4	8
Preaward meeting	36	47	32	53	0	0	42	81	8	16	2	3
Award	76	100	0	0	0	0	47	90	5	10	0	0
Term contract												
steps for evaluation of bids	Public (12)						Private (0)					
	Y	%	N	%	DN	%	Y	%	N	%	DN	%
Tenders returned	12	100	0	0	0	0	-	-	-	-	-	-
Bid assessment	12	100	0	0	0	0	-	-	-	-	-	-
Award decision	12	100	0	0	0	0	-	-	-	-	-	-
Preaward meeting	0	0	12	100	0	0	-	-	-	-	-	-
Award	12	100	0	0	0	0	-	-	-	-	-	-
Design and build												
steps for evaluation of bids	Public (0)						Private (16)					
	Y	%	N	%	DN	%	Y	%	N	%	DN	%
Tenders returned	-	-	-	-	-	-	16	100	0	0	0	0
Bid assessment	-	-	-	-	-	-	16	100	0	0	0	0
Award decision	-	-	-	-	-	-	16	100	0	0	0	0
Preaward meeting	-	-	-	-	-	-	16	100	0	0	0	0
Award	-	-	-	-	-	-	16	100	0	0	0	0

Table 5.10 Major steps for evaluation of bids

Questions 10 to 14. asked for the criteria and/or their measures used for contractor selection discussed in chapter 3. The following Table 5.11 shows the number and percentage of respondent for different types of contracts for public and private clients. This information was requested to investigate the type of criteria used in contractor selection in different procurement systems. Since the aim is to investigate the criteria used for contractor selection, therefore the discussion of question 10 to 14 will concentrate on the criteria rather than the measures.

Type of contract	Traditional contract								Term contract				Design and Build			
Type of client	Public (76)				private (52)				public (12)				private (16)			
Criteria	Y	%	N	%	Y	%	N	%	Y	%	N	%	Y	%	N	%
10.1 Financial stability	71	93	0	0	28	54	8	15	9	75	0	0	12	75	0	0
a	68	89	0	0	17	33	27	52	12	100	0	0	5	31.2	7	43
b	63	83	0	0	20	38	24	46	12	100	0	0	4	25	8	50
c	68	89	4	5	37	71	8	15	8	67	0	0	11	68.7	4	25
10.2 Credit rating	36	47	20	26	17	33	20	38	3	25	0	0	4	25	8	50
a	17	22	35	46	12	23	27	52	5	41.6	0	0	5	31.2	8	50
b	28	37	28	37	9	17	28	54	4	33	0	0	4	25	8	50
10.3 Bank arrangements	35	46	12	16	21	40	12	23	4	33	0	0	9	56	4	25
a	32	42	20	26	16	31	24	46	8	67	0	0	4	25	9	56
b	24	31	22	29	16	31	23	44	9	67	0	0	4	25	8	50
c	67	88	8	10	29	56	11	21	8	67	4	33	13	81	0	0
10.4 Financial status	56	74	0	0	21	40	15	29	4	33	0	0	5	31	8	50
a	72	95	0	0	28	54	12	23	9	75	0	0	4	25	7	43
b	48	63	11	14	20	38	24	46	12	100	0	0	10	62	3	18
11.1 Experience	55	72	4	5	36	69	4	7	8	67	0	0	16	100	0	0
a	68	89	8	10	52	100	0	0	12	100	0	0	16	100	0	0
b	76	100	0	0	52	100	0	0	12	100	0	0	16	100	0	0
c	76	100	0	0	45	87	7	13	12	100	0	0	12	75	4	25
d	53	69	23	30	44	85	8	15	12	100	0	0	16	100	0	0
e	36	47	36	47	41	79	12	23	12	100	0	0	13	81	3	18
f	32	42	41	54	28	54	23	44	12	100	0	0	12	75	4	25
g	64	84	12	16	49	94	4	7	12	100	0	0	16	100	0	0
h	65	85	8	10	48	92	4	7	8	67	0	0	12	75	4	25
11.2 Plant and equipment	12	16	36	47	28	54	24	46	8	67	4	33	0	0	12	75
a	14	18	62	81	8	15	43	83	4	33	8	67	0	0	12	75
b	21	27	48	63	17	33	35	67	9	75	3	25	0	0	12	75
c	13	17	63	83	13	25	40	77	8	67	4	33	0	0	12	75
d	12	16	60	79	12	23	39	75	8	67	4	33	0	0	12	75
11.3 Personnel	44	58	12	16	20	38	8	15	5	41.6	4	33	16	100	0	0
a	64	84	12	16	41	79	11	21	8	67	3	25	16	100	0	0
b	40	53	29	38	33	64	20	38	4	33	4	33	16	100	0	0
c	20	26	43	56	20	38	31	60	8	67	4	33	16	100	0	0
d	48	63	28	37	28	54	24	46	8	67	4	33	16	100	0	0
e	48	63	27	35	29	56	23	44	8	67	4	33	10	62.5	6	37.5
f	64	84	12	16	52	100	0	0	9	75	3	25	16	100	0	0

11.4 Ability		43	56	0	0	24	46	4	7	5	42	0	0	16	100	0	0
	a	72	95	4	5	49	94	4	7	12	100	0	0	16	100	0	0
	b	70	92	4	5	48	92	3	5	12	100	0	0	16	100	0	0
	c	64	84	8	10	50	96	2	4	12	100	0	0	16	100	0	0
	d	69	91	0	0	48	92	0	0	12	100	0	0	16	100	0	0
12.1 Past performance		56	74	4	5	29	56	0	0	12	100	0	0	16	100	0	0
	a	76	100	0	0	48	92	4	7	12	100	0	0	16	100	0	0
	b	56	74	15	20	41	78	11	21	12	100	0	0	16	100	0	0
	c	15	19.7	52	68	24	46	28	54	10	83	2	17	4	25	8	50
	d	35	46	33	43	25	48	23	45	4	33	8	67	16	100	0	0
	e	72	95	4	5	52	100	0	0	12	100	0	0	16	100	0	0
12.2 Project management organization		56	74	8	10	37	71	0	0	12	100	0	0	16	100	0	0
	a	68	89	8	10	48	92	4	7	8	67	0	0	16	100	0	0
	b	49	64	19	25	52	100	0	0	9	75	3	25	16	100	0	0
	c	52	68	20	26	48	92	4	7	8	67	4	33	12	75	4	25
	d	28	37	43	57	33	63	15	29	9	75	3	25	13	81	4	25
	e	40	53	32	42	52	100	0	0	12	100	0	0	16	100	0	0
	f	37	48	36	47	32	62	19	36	8	67	4	33	16	100	0	0
	g	15	20	56	74	13	25	40	77	5	42	7	58	12	75	3	18
	h	23	30	47	62	12	23	35	67	8	67	4	33	12	75	4	25
	i	16	21	56	74	9	17	32	62	10	83	2	17	5	31	11	68
	j	36	47	36	47	49	94	4	7	8	67	4	33	8	50	0	0
	k	44	58	24	31	28	54	23	44	8	67	4	33	4	25	4	25
12.3 Experience of technical personnel		36	47	20	26	28	54	0	0	9	75	3	25	16	100	0	0
	a	40	53	27	36	41	79	12	23	6	50	6	50	16	100	0	0
	b	44	58	24	31	36	69	15	29	9	83	3	25	13	81	3	18
	c	36	47	27	36	37	71	16	31	9	83	3	25	12	75	4	25
	d	28	37	40	53	40	77	12	23	8	67	4	33	16	100	0	0
12.4 Management knowledge		28	37	27	36	12	23	16	31	7	58	4	33	14	87	0	0
	a	24	31	44	58	28	54	20	38	5	42	6	50	4	25	8	50
	b	15	20	52	68	21	40	27	52	6	50	6	50	4	25	8	50
	c	7	9	55	73	16	31	32	62	7	58	4	33	0	0	12	75
	d	29	38	40	53	25	48	24	46	8	67	4	33	9	56	4	25
	e	24	31	44	58	20	38	28	54	8	67	4	33	8	50	6	37
	f	28	37	39	52	37	71	11	21	7	58	5	42	8	50	8	50
	g	30	39	31	41	32	62	16	31	5	42	4	33	13	81	3	18
13.1 Safety		52	68	8	10	25	48	8	15	12	100	0	0	12	75	4	25
	a	46	60	27	36	20	38	31	60	12	100	0	0	4	25	8	50
	b	44	58	28	37	24	46	28	54	12	100	0	0	9	56	5	31
	c	57	75	15	20	25	48	28	54	12	100	0	0	8	50	5	31
	d	72	95	0	0	33	64	19	36	12	100	0	0	12	75	4	25
	e	50	65	23	30	21	40	32	62	12	100	0	0	8	50	6	37
	f	68	89	4	5	28	54	15	29	12	100	0	0	11	68	4	25

	g	76	100	0	0	40	77	12	23	12	100	0	0	12	75	4	25
13.2 EMR		8	5	60	79	0	0	52	100	3	25	8	67	0	0	12	75
13.3 OSHA		8	5	60	79	0	0	52	100	4	33	8	67	0	0	12	75
13.4 Management safety accountability		28	37	16	21	8	15	23	44	8	67	4	33	4	25	8	50
	a	40	53	28	37	17	33	28	54	9	75	2	17	5	31	10	62
	b	28	37	39	52	16	31	32	62	8	67	3	25	5	31	9	56
	c	27	35	40	53	21	40	27	52	9	75	4	33	4	25	9	56
	d	23	30	47	62	28	54	20	38	8	67	4	33	5	31	8	50
	e	16	21	51	67	12	23	35	67	7	58	5	42	4	25	12	75
14.1 Past failures		53	69	13	17	17	33	16	31	12	100	0	0	8	50	8	50
	a	41	54	32	42	29	56	15	29	12	100	0	0	9	56	7	43
	b	37	49	40	53	12	23	32	62	12	100	0	0	4	25	8	50
	c	36	47	36	47	20	38	23	44	12	100	0	0	9	56	7	43
	d	44	58	27	36	33	64	12	23	12	100	0	0	8	50	4	25
	e	28	37	43	57	16	31	27	52	12	100	0	0	5	31	8	50
	f	42	55	32	42	13	25	32	62	12	100	0	0	4	25	8	50
	g	40	53	31	41	20	38	24	46	12	100	0	0	3	18	8	50
14.2 Length of time in business		56	74	8	10	37	71	4	7	12	100	0	0	16	100	0	0
	a	60	79	11	15	44	85	7	13	12	100	0	0	16	100	0	0
	b	60	79	12	16	49	94	4	7	12	100	0	0	16	100	0	0
	c	65	85	8	10	48	92	4	7	8	67	4	33	16	100	0	0
	d	52	68	19	25	32	62	19	36	12	100	0	0	16	100	0	0
	e	32	42	15	20	41	79	12	23	12	100	0	0	16	100	0	0
14.3 Client/contractor relations		48	63	8	16	32	62	0	0	6	50	6	50	16	100	0	0
	a	35	46	39	52	37	71	16	31	12	100	0	0	12	75	3	18
	b	48	63	23	30	36	69	15	31	9	75	3	25	16	100	0	0
	c	59	77	15	20	52	100	0	0	8	67	4	33	16	100	0	0
	d	40	58	32	42	41	79	4	7	8	67	4	33	12	75	4	25
	e	44	63	28	37	48	92	4	7	9	75	3	25	13	81	3	18
	f	32	42	40	53	45	87	3	5	11	92	0	0	12	75	4	25
	g	57	75	15	20	44	85	8	15	8	67	4	33	16	100	0	0
14.4 Other relations		42	55	10	13	25	48	12	23	8	67	4	33	12	75	4	25
	a	28	37	44	58	28	54	23	44	4	33	8	67	4	25	11	68
	b	22	29	51	67	29	56	24	46	8	67	4	33	4	25	9	56
	c	28	37	44	58	17	33	36	69	4	33	8	67	5	31	8	50
	d	32	42	40	53	25	48	28	54	7	58	4	33	5	31	9	56
	e	34	45	40	53	21	40	31	60	12	100	0	0	4	25	8	50
	f	40	53	31	41	8	15	44	85	11	92	0	0	4	25	10	62
	g	52	68	19	25	29	56	23	44	8	67	4	33	4	25	8	50

Table 5.11 Criteria and measures of contractor selection

Q10 Financial soundness

In traditional contracts, 93% of public sector clients used the financial stability criterion (Q10.1) to select contactor, while 54% of private sector used this criterion, in term contracts, 75% used the financial stability. 75% of design and build contracts also used the financial stability criterion.

In traditional contracts, 47% and 33% of public and private sector clients respectively used credit rating criterion(Q10.2), 25% of term and design and build contracts used the credit rating as a criterion to select contractor.

Bank arrangement with bonding (Q10.3) is an important criterion, 88% of the public clients using the traditional system ask for bonding (Q10.3 c), 67% in term contracts ask for this measure and 81% in design and build contracts ask for bonding.

Financial status (Q10.4) is important to the public using traditional contracts where it is found that 74% of the respondents used this criterion for selection, on the other hand only 40% of private sector used this criterion. In term contracts 100% used the income statement (10.4 b), while 62% of design and build contracts used this measure to investigate the financial status of the contracts during prequlification.

Q11 Technical ability

Experience (Q11.1) is an important criterion for the three types of contracts, it scored about 70% for traditional contracts, 67% for term contracts and 100% for design and build contracts, on the other hand plant and equipment criterion (Q11.2) is considered important in term contracts. About 67% of the respondents use this criterion, it received 54% of private clients using traditional contracts, while this criterion is considered not important (0%) for design and build contracts.

The technical personnel criterion (11.3) and its measures were very important for design and build contracts, 100% of the respondents used this criterion, 58% of public clients in traditional system used this criterion, while in term contracts, 41.6% of the respondents investigated the technical personnel of the contractors. The ability criterion (Q11.4) is also considered very important for design and build contracts, 100% used this criterion. 100% of the term contract users considered that the measures of the ability criterion are very important, these measures scored around 90% in private and public clients in traditionl system.

Question 12 Management capability

Past performance (Q21.1) has scored 100% rate from the respondents for design and building and term contracts, and scored 74% of public clients respondents using traditional system, these figures are applied to project management organization criterion (Q12.2). For the experience of management personnel, 47% of public clients for the traditional system used this criterion, but it is 54% for private clients. 75% for term contracts and 100% for design and build contracts used this criterion for contractor selection. It can be noticed here that the management issues are very important for design and build contracts. Management knowledge has scored 37%, 58%, and 87% for traditional, term, and design and build contracts, respectively.

Q13. Health and Safety

For term contracts 100% of the respondents used the safety criterion (Q13.1), for design and build contracts 75% used this criterion during prequalification. In the case of traditional contracts, 68% of public clients used the safety as a criterion, while it is 48% in private sector, normally the company safety policy is a measure of the safety criterion, this measure has scored 100% for term contracts and for public clients using traditional contracts, while it is 75% for design and build contracts.

Experience Modification Rate (EMR) (Q13.2) as well as Occupational Safety and Housing Administration incidence rate (OSHA) (Q13.3) seem to be not familiar to the construction industry in the U.K, this was noticed during the interviews conducted, while in the USA many publications (Levitt and Parker 1976; Samelson et al 81; Samelson and Levitt 1982; Hinze and Russell 1995) have emphasised the importance of using such criteria for selection. However, this survey resulted in 0% response for the two criteria from traditional and design and build contracts, about 25% of term contract users indicated they are using the (EMR) while 33% of the respondents used (OSHA) incidence rate.

Management safety accountability (Q13.4) was used in the contracts surveyed in this study. For traditional contracts, 37% of public clients and only 15% of private clients used this criterion, while for term contracts, 67% used this criterion and 25% for design and build contracts.

Q14. Reputation

For traditional contracts 69% of public client respondents used past failures of contractors (Q14.1) as a criterion for selection, while only 33% of private clients considered this criterion. On the other hand, 100% of term contract users considered the past failures for contractor selection, 50% of design and build contract clients used the criterion for contractor selection.

Length of time in business criterion (Q14.2) is important for all types of contracts covered in this study. Over 70% of the respondents of the traditional contracts users considered the criterion for selection, 100% of both term and design and build contracts considered the criterion.

About 63% of the traditional contract users considered client/contractor relations criterion (Q14.3) for selection, whilst it is only 50% for the term contracts and 100% for design and building contracts.

The last criterion investigated in this questionnaire survey was the relationship between the main contractors and subcontractors, employees, ...(Q14.4). In Traditional contracts, 55% of the clients that responded used this criterion, in term contracts the response rate was 67%, while for design and build the rate was 75%.

Question 15. asked for the criteria considered for *evaluation of bids.*

Type of contract	Traditional				Term contract		Design and build	
Type of client	Public(76)		Private(52)		public(12)		private(16)	
Criteria for bid evaluation	No.	%	No.	%	No.	%	No.	%
Lowest bid	73	96	47	90	0	0	16	100
Average bid	8	10.5	20	38	0	0	0	0
Lowest NPV	3	3.9	5	9.6	0	0	0	0
Others	12	15.7	4	7.5	12	100	4	25

Table 5.12 Criteria for evaluation of bids

For traditional contracts, 96% of public clients selected the contractor bidding the lowest price, 10.5% used the average system, in addition to the lowest bid, 15.7% used other criteria such as the most financially advantaged, for evaluation of bids. On the other hand, 90% of private clients selected the lowest bidder, 38% used the average bid system, while 7.5% used other criteria for evaluation of bids. For term contracts, the twelve clients (i.e 100%) covered in this survey used the most economically advantaged criterion for evaluation of bids. For design and build contracts, 100% of the respondents used the lowest bid system, in addition to that, 25% of them used some other criteria such as, technical vs price; quality of previous work.

Question 16. asked respondents for the level of satisfaction with the contractors' performance of completed projects in terms of time, cost and quality.

	Type of contract	Traditional contract				Term contract		Design and Build	
	Type of client	Public(76)		Private(52)		Public(12)		Private(16)	
Project performance	Level of satisfaction	No.	%	No.	%	No.	%	No.	%
Time	Not satisfied	7	9.2	4	7.7	1	8.3	0	0
	Moderately satisfied	45	59.2	26	50	2	16.6	11	68.75
	Satisfied	24	31.6	22	42.3	9	75.1	5	31.25
Cost	Not satisfied	9	11.8	5	9.6	2	16.6	0	0
	Moderately satisfied	24	31.5	15	28.7	2	16.6	12	75
	Satisfied	43	56.7	32	61.5	8	66.8	4	25
Quality	Not satisfied	5	6.5	0	0	0	0	3	18.75
	Moderately satisfied	33	43.4	24	46	2	16.6	9	56.25
	Satisfied	38	50.1	28	54	10	83.4	4	25

Table 5.13 Respondents' level of satisfaction with the contractors' performance

For traditional contracts only 31.6% of public clients were satisfied with contractor's performance in terms of time, 68.4% were either not satisfied or moderately satisfied with time. In terms of cost, 43.3% of public clients either not satisfied or moderately satisfied, on the other hand 56.7% were satisfied. In terms of quality, the level of satisfaction was balanced at 50.1% satisfied and 49.9% either not satisfied or moderately satisfied. For private clients only 42.3% were satisfied with time, 61.5% were satisfied with cost and 54% were satisfied with quality. This result shows that the level of satisfaction ranges between 50% to 60% for the three project success factors, time, cost and quality.

For term contracts, 75% of the respondents were satisfied with the time factor, 66.8% were satisfied with the cost, and 83.4% were satisfied with the quality. For term contracts, the level of satisfaction ranges between 67% to 83%. For design and build contracts, 31% of the clients were satisfied with the contractors' performance in terms of time, 25% of them were satisfied with cost and quality. This result shows that the level of satisfaction in D&B contracts are lowest among the three types of contracts and it ranges between 25% to 30%.

5.8 CONCLUSION

In order to cover a wide range of professionals involved in prequalification and also to substantiate the findings of the literature survey and the interviews conducted earlier in chapters 2 and chapter 3, a questionnaire survey was sent to the public and private clients. The survey was carried out in an effort to investigate the common characteristics of tendering procedures, the common criteria used by clients of the construction industry to select the contractor, and to establish the clients' level of satisfaction with the performance of completed projects in terms of time, cost and quality.

Out of 300 questionnaires distributed to public and private clients, 156 useful replies were received, a response rate of 52%. In this survey 56.5% of the sample population were public and 43.5% were private. The survey covered 10284 contracts, 59.6% of these contracts were traditional contracts, 14.1% term contracts, and 26% design and build contracts.

Common characteristics of tendering procedures

For the three types of contracts covered in this survey 85% to 100% of the respondents used either standing or project list tendering system (Q5). For the invitation, prequalification, short list and bid evaluation elements, almost 100% of the respondents for the three types of contracts agreed with the offered definition (Q6).

For traditional contracts, term and design and build contracts, over 90% of the respondents used the major five elements (Q7) in their tendering systems.

For term contracts, 100% of the respondents used the major steps to prequalify the contractors (Q8). For traditional contracts, 80% to 100% of the private clients and 90% to 100% of the public clients used these major steps. For design and build contracts 70% to 100% used these steps to prequalify the contractor while only 50% of the respondents categorised the applicants.

For traditional contracts, 90% to 100% of the respondents of public and private clients used the major steps for evaluation of bids (Q9) except a pre-award meeting. In term contracts, 100% of the respondents used all the steps. For design and build contracts, 100% of the respondents answered yes to all the steps for evaluation of bids.

The result of this survey shows that the clients that are using all the different types of contracts covered in this study used the same methods of soliciting tenders, the five major elements in their tendering system and the major steps to prequalify contractors and evaluation of bids.

Common criteria of contractor selection

For the three types of contracts covered in this survey, all the different types of criteria for contractor selection considered in this questionnaire survey (Q10.1 to Q14.4) were used by the clients with some variance. The only exceptional cases were the experience modification rate (EMR) (Q13.2) and occupational safety and housing administration incidence rate (OSHA) (Q13.3) which were not used by traditional and design and build contracts users. About 25% of term contract users have indicated they are using the (EMR) while 33% of the respondents used (OSHA) incidence rate.

This chapter has widely covered the issues discussed in chapters 2 and 3, and found that the results were consistent with the literature survey as well as the interviews conducted in chapters 2 and 3, and the questionnaire survey covered in this chapter. In the following chapter (6) the research will look into a hypothetical case study to select a contractor. The case study will combine contractor selection criteria identified (chapters 3 and 5) and the simplest form of utility techniques i.e an additive model which is mentioned in chapter 4 see (4.9.2).

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6. CONTRACTOR SELECTION USING MULTIATTRIBUTE UTILITY THEORY-AN ADDITIVE MODEL: HYPOTHETICAL EXAMPLE

CHAPTER 6

Contractor selection using multiattribute utility theory: an additive model hypothetical example

6.1 INTRODUCTION

Researchers such as Raiffa (1969), Fishburn (1970), and Keeney (1971,74) have developed procedures for aggregating the individual utility functions of any number of attributes (criteria) into one global preference function. Keeney and Raiffa (1993:289) consider three mathematical formulations in detail(additive, multiplicative and multilinear models). The main advantage to the additive utility model is its simplicity. The assessment of the n-attribute utility function is reduced to the assessment of n one-attribute utility functions and n-1 independent scaling constants, the additive model is valid regardless of whether the attributes are scalars or vectors attributes. The mathematical formulas of multiplicative and multilinear models are very complicated in the case of n-attributes, in addition there are different types of scaling constants that has to be assessed.

The main aim of this chapter is only to learn and show how to build a utility function for a decision maker by a technique known as a standard gambling and not to revise the theory and restrictive conditions of applying any of the three models, therefore the additive case was proposed in this chapter for its simplicity.

The theoretical basis of the technique is provided together with an example of an additive model to illustrate the technique and for which <u>real</u> interviews with a number of construction professionals were conducted to generate the utility functions needed.

6.2 MULTIPLE OBJECTIVE DECISION MAKING

Traditionally, decision analysis has been concerned with situations in which decision makers must choose among several alternatives A_1, A_2, ..., A_i, ..., A_n each of which will eventually result in a consequence describable in terms of single attribute (X). Profit maximization has long been considered to be the prime objective of contract bidding strategies. In recent years, however, there has been a growing awareness that, whilst most decision-makers are interested in maximising profits, they are also concerned with other objectives such as corporate good will, market share, and future growth .

Selection of a construction contractor is also a decision characterised by multiple objectives. Clients want to minimize the likely cost of projects, but also they want contractors to maintain schedules as well as achieving acceptable quality standards.

6.2.1 Unidimensional Utility Theory

Utility is a measure of desirability or satisfaction and provides a uniform scale to compare and/or combine tangible and intangible attributes. A utility function is a device which quantifies the preferences of a decision maker by assigning a numerical index to varying levels of satisfaction of an attribute. For a single attribute (X), the utility of satisfaction of a consequence x_1 is denoted by $u(x_1)$. Utility functions are so constructed such that $u(x_1)$ is less preferred to $u(x_2)$ i.e $u(x_1) < u(x_2)$, if and only if x_1 is less preferred to x_2 i.e $x_1 < x_2$. In other words, a utility function is a transformation of some level of contractor performance, x_i, measured in its natural units into an equivalent level of decision maker satisfaction, as shown in Fig 6.1.

Theoretically, decision makers comprise three types: risk averse, risk neutral, and risk prone as shown in Fig 6.2a, 6.2b, and 6.2c respectively, the decision maker's risk attitude being reflected in the shape of the utility curve which combines the decision maker's preference attitudes, ie., increasing or decreasing utility with increasing x_i.

6.2.2 Multi-Attribute Additive Utility Function

Most decisions are characterized by a number of attributes (X_1, X_2, ..., X_i, ..., X_n). If x_i designates a specific level of X_i, then the task is to find a utility function.

$$U(X) = U(X_1, X_2, ..., X_n) \text{ over n attributes}$$

The most common formulation of a multiattribute utility function is the additive model (Ahmad and Minkarah 1987, Moselhi and Martinelli 1990, Keeney and Raiffa 1993).

$$U_i = \sum_{j=1}^{n} w_j \times u_{ij} \qquad \textbf{(6.1)}$$

where

U_i = Overall utility value of alternative i
u_{ij} = The utility value of the j^{th} attribute for the i^{th} alternative
n = Number of attributes
w_j = Relative weight of the j^{th} attribute

The advantage of an additive form is its simplicity. In order to determine the overall utility function for any alternative, A decision maker need only determine *n* unidimensional utility functions for that alternative.

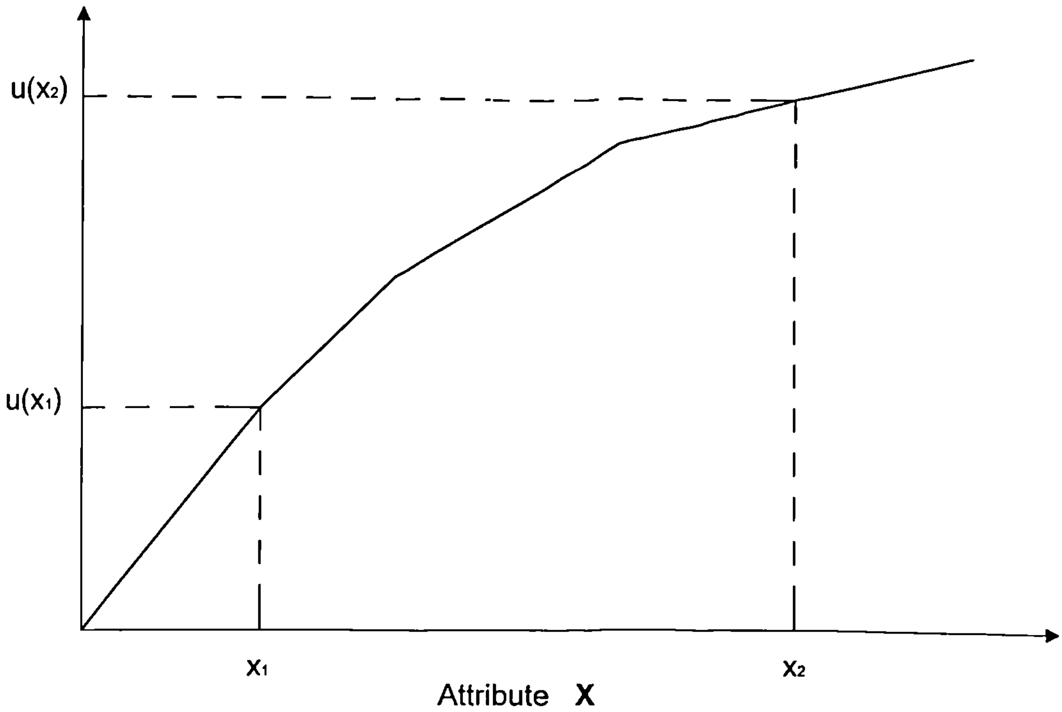

Fig 6.1. An increasing utility function

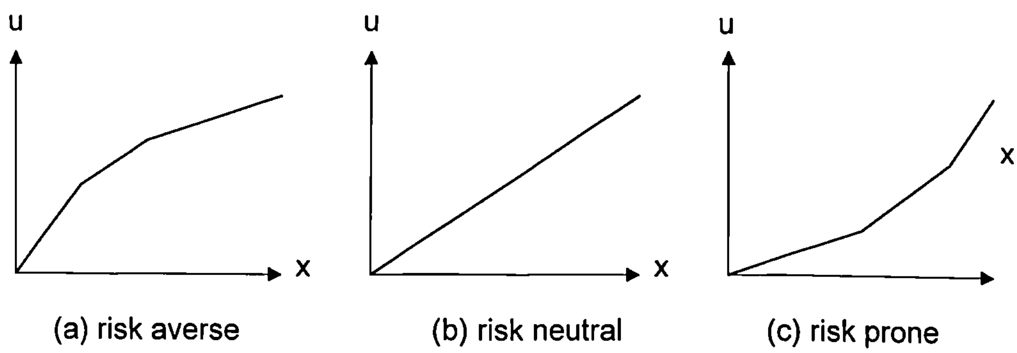

Fig 6. 2. Types of decision makers

In order to apply additive model, some rather restrictive independence requirements among attributes have to be satisfied. In as much as the nature of independence requirements are somewhat beyond the scope of this chapter for simplicity, the satisfaction of independence requirements were given in chapter 9 and the interested reader is directed to Keeney (1971) for further clarification of independence requirements.

Multiattribute utility theory generally combines the main advantages of simple scoring techniques and optimization models. Further, in situations in which satisfaction is uncertain, utility functions have the property that expected utility can be used as a guide to rational decision making.

This chapter now proceeds to demonstrate the development of an additive utility model for the selection of a contractor by an example.

6.3 DESCRIPTION OF THE EXAMPLE

A hypothetical example will be used to illustrate the multiattribute technique. The hypothetical example scheme consists of a multistorey building at the city centre of Manchester area. It consist of 3 floors.

1. First floor is assigned to be a shopping area.
2. Second and third floor to be rented as an offices.
3. The approximate floor area is 4,000 square metres.
4. The client's estimate is 4.5 million pounds.
5. The project duration is 28 weeks which is fixed by the client.

6.4 TENDERING PROCEDURE

A project tendering system is adopted and a notice of call in the local press to the contractors was issued specifying the place where the prospective bidders could apply.

Several potential bidders were subjected to a preliminary investigation by examination of their files, past records with the client, technical referees reports, creditor reports and visits to site. As a result, five contractors (A, B, C, D and E) were pre-qualified.

At the bid due date the five contractors' presented their bids as shown in Table 6.1. at the point, according to the traditional approach, arithmetical checks would be made and the contract would be awarded to contractor E (£4.2 million), the lowest bidder. The type of contract assigned for this project and suits the capabilities of the client is a traditional contract.

Contractor	A	B	C	D	E
Advance payment (million £)	0.1	0.3	0.3	0.3	0.1
Capital bid (million £)	3.9	3.5	3.5	4	3.6
Routine maintenance (million £)	0.3	0.25	0.3	0.25	0.1
Major repairs (million £)	0.4	0.35	0.2	0.4	0.4
Total Bid price (million £)	**4.7**	**4.4**	**4.3**	**4.8**	**4.2**

Table 6.1 Bids Amounts of the five bidders

6.5 ARGUMENT ABOUT THE DECISION

Now it may be argued that, as the bidders have already passed a preliminary screening, they should all be treated as equal and therefore the decision of contract award should be based on the one remaining attribute only i.e project cost (bid price). This does not however account for the other capabilities of the bidders. In addition, the objectives of any project also involve its completion time and level of quality. What is needed is a method of comparing bidders which takes into account these various objectives and permits the selection of the contractor who has the best overall qualification to perform the job, a method that takes into account the financial, technical, management capabilities of the bidders and the difference between them is required.

To consider these additional criteria , of which several can be measured by subjective judgments, a multiattribute utility technique is proposed and illustrated in this example. The technique allows considering more than one attribute and also ensures that the contractor that has the best overall capacity to perform the job is selected.

6.6 OBJECTIVES OF THE CLIENT

To illustrate the multiattribute technique, It is important to set a list of contractor selection criteria that fulfils the clients objectives. Before we set out the list of the criteria it is necessary to identify the objectives of the client for this specific project, also to know the resources required, resources available, and other constraints. The objectives of the client for this multistorey building can be listed into the following:

6.6.1 Global objectives:

1. To provide more services to the public by providing new shops.
2. To create a chance for more jobs for the people.
3. To invest the money and to maximize the firm's profit.

6.6.2 Project objectives

1. To increase quality standard.
2. To increase safety during construction.
3. To minimize the cost of the project.
4. To complete the project within the specified time.

6.6.3 Constraints

In addition to the objectives specified, there are some constraints that should be considered and they may influence the types of criteria for selecting the suitable bidder to construct the project successfully and fulfilling the client's objectives. The constraints that should be considered can be summarized into the following:

1. The requirement for the noise control 2. The need to consider the traffic arrangements
3. Working around a crowded area. 4. Using the local resources

The parameters identified herein will assist the decision makers to identify the relevant criteria and their order of importance and there relative weights for this example. These criteria and their characteristics are essential parameters in the multiattribute technique.

6.7 SELECTION OF CRITERIA FOR EVALUATION

For the selection of criteria a consultation process and extensive interviews (hypothetical) were carried out with construction professionals involved in the evaluation of bids in different construction engineering organizations in the North West of England.

Before the interviews were conducted, a preliminary list of criteria directly related to the example was identified, this preliminary list is based on the findings of chapters 3 and 5 in which a comprehensive list of criteria was listed for general purpose. The list of criteria was finally structured taking into account that the attributes selected for the evaluation must have two basic characteristics:

1. Comprehensive. 2. Measurable.

The first characteristics refers to the fact that the criteria must be comprehensive enough, so that it will provide a clear understanding of the decision-maker's objectives. However, an excessive number of criteria would lead to an unpractical model to manage. Therefore a state of equilibrium must be reached.

The second characteristic means that the criteria must allow measurement (a) to obtain a probability distribution for each alternative over the possible level of attribute (b) to assess the decision-maker's preferences for different possible outcomes of the criteria in terms of utility values or rank ordering without taking an unreasonable amount of time and effort.

Keeping these characteristics in mind, the interviews were conducted and a comprehensive list of criteria were arranged in a systematic form and then evaluated. Taking into consideration the recommendations and responses of those interviewed, a set of six main criteria (the same as those identified in chapter 3 and 5 plus the bid price) was chosen as representative of the example, each one of these criteria is measured through four different sources of parameters which also considered as a subcriteria.

The six criteria and their means of measurement or in other words their subs are shown in Table 6.2.

(1) **Bid amount**				(2) **Financial soundness**			
Advance payment	Capital bid	Routine maintenance	Major repairs	Financial stability	Credit rating	Bank arrangement and bonding	Financial status
(3) **Technical ability**				(4) **Management capability**			
Experience	Plant and equipment	Personnel	Ability	Past performance and quality	Project management organization	Experience of technical personnel	Manageme nt knowledge
(5) **Health and safety**				(6) **Reputation**			
Safety	Experience modification rating EMR	Occupational safety OSHA	Management safety accountability	Past failures	Length of time in business	Past client/contrctor relationship	Other relations

Table 6.2. Main criteria and their subs for this example

These criteria or attributes intend to cover not only bid price , but also the technical, management, safety records, reputation, and financial capabilities of the bidders. The attributes are also divided in two levels of hierarchy as shown in Fig 6.3. These levels of hierarchy are according to the degree of detail required to describe a certain aspect in the evaluation. The attributes selected for the evaluation are described as follows:

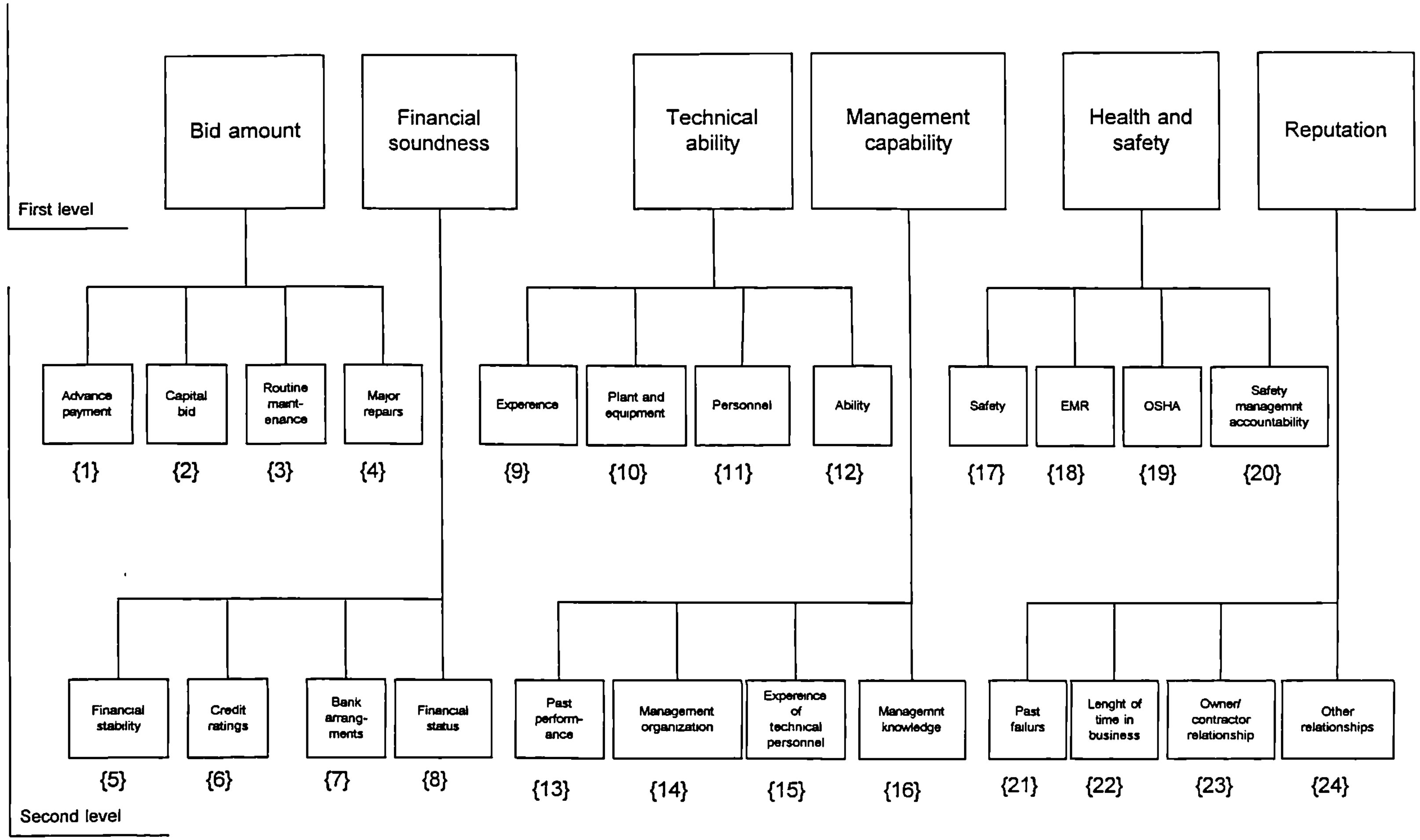

Fig 6.3 Selection criteria and its level of hierarchy

6.7.1 Bid amount

This is the criterion that received the highest attention among the interviewee with the highest relative weight. The criterion was divided into four subcriteria (advance payment, capital bid, routine maintenance, major repairs), their combination also considered as the source of measure of the total bid price of each bidder. The bidders were asked to submit their bids according to these four parameters.

6.7.1.1 Advance payment cost

The bidders were asked to submit their separate amount for the advance payment they need (this is usually done in some countries, Hardy 1978), this amount is usually requested by the bidders for the purpose of mobilization and preparation of the site. The difference in the advance payments submitted by the bidders will give a client an indication of the capacity of each bidder and their capability of starting the project with or without the assistance of an advance payment.

6.7.1.2 Capital cost of bid

This is the price that the bidder submits to perform the work, which is basically based on bill of quantities and the bidders submitted their total sums accordingly without taking into account the time value of money. It was considered that the size of this project and the time span of its duration (28 weeks) did not justify the inclusion in the analysis of interest rate and escalation factors. However, this might not be the case in projects of larger duration.

6.7.1.3 Routine maintenance cost

It is possible in many cases that, some differences may arise in operating and maintenance (O&M) routine costs of the equipments proposed by each of the bidders even for a fixed level of performance required. For this reason bidders were requested to submit their proposals for routine maintenance cost as a separate figure in the total bid amount, in order for the client to make an appropriate decision to choose among the alternatives such as the choice between heating systems (electrical, natural gas) or enclosure systems.

6.7.1.4 Major repairs cost

The repairing costs are related to the costs of repairs of the major parts of the building that the client has to do from time to time in order to prevent excessive deterioration of the building, therefore bidders were asked to submit their bids for repairing the elements of the building that are expected to be deteriorated due to different causes. Since an annual maintenance and repair cost increases as the life expectancy of the structure increases, therefore these two criteria are included for the evaluation purposes.

The offers submitted by the contractors are shown in Table 6.3 .

Contractor	A	B	C	D	E
Advanced payment cost(Million £)	0.1	0.3	0.3	0.15	0.1
Capital bid (m £)	3.9	3.5	3.5	4	3.6
Routine maintenance (m£)	0.3	0.25	0.3	0.25	0.1
Major repairs cost (m£)	0.4	0.35	0.2	0.4	0.4
Total bid amount (m £)	4.7	4.4	4.3	4.8	4.2

Table 6.3 Detailed offers submitted by the five bidders

The subcriteria of bid amount is described in money terms, this makes the assessment of alternatives and building the utility curves more easily to the decision makers.

6.7.2 Financial soundness

The financial analysis of the firm's involves the assessment of a firm's past, present, and anticipated future financial condition. The inclusion of this criterion is to identify any weaknesses in the firm's financial health that could lead to future problems, it included to cover aspects such as the financial stability, liquidity and financial capacity to perform the work. This criterion can be measured in terms of four criteria described below:

6.7.2.1 Financial stability

By this criterion it is intended to follow-up the financial history of the company. That is why it considers not only the period of time since the legal formation of the company will give an indication of the financial stability but also the trend of its volume of business, results of trend analysis aver a wide range of period. This is done to find out if the company is following an ascendant, stable or descendent trend in its volume of business, its previous current and fixed assets, its liquidity, its annual turnover are all means of measure of the financial stability of the firm.

6.7.2.2 Credit ratings

The managerial abilities and activities of the general contractor are a major variable in the fortunes of subcontractors, suppliers, banks and thus are major variables in the whole realm of construction management. This criterion is included to investigate the management abilities of the mains towards their subs and suppliers.

This criterion can be identified and measured through the credits from these parties which have an experience in dealing with the general contractor. Many parameters can be looked at in the evaluation of this criterion, such as the assessment of honesty, trustworthy and fair dealing, financial stability for this type of job, payment to his subs, schedule to coordinate work of all trades.

6.7.2.3 Bank arrangements and bonding

The reason for the inclusion of this criterion is to verify if the companies have the financial strength to perform the job. This criterion is closely related to the capacity of the company to obtain bid and performance bonds, which generally are conditions for a bid to be accepted; but also refers to the capacity of the company to finance its operations between payments and its ability to guarantee a source of fund in case of cash difficulties between the payments. Its borrowing whether is it for short term borrowing or long term borrowing indicate its financial management and its use of fund for the investment.

6.7.2.4 Financial status

This is an important criterion as it depicts the financial status of the firm, published accounts will consist mainly of two main statements; balance sheet statement and income statement.

These statements provide the raw material for the financial ratios which are the principal tool of financial analysis. The financial ratios provide the basis for the financial well-being of the firm, such as the liquidity of the firm which is referred to the ability of the contractor to meet obligation and to convert assets into cash. Financial ratios also indicates whether the firm's finance management generates sufficient profits from the firm's asset. These parameters can measured by means of liquidity ratios, efficiency ratios, leverage ratios and profitability ratios.

The normal procedure by the finance personnel to assess the financial capacity of the firm is by looking to the firm own figures and make a comparison over a period of time within a firm itself to check if there is any trend of improvements. The other comparison is made with the average of the industry and how the firm performed financially with the other firms.

A subjective judgment based on the experience of the personnel and if the firm has passed some requirements, is usually adopted to accept or reject the firm. In this example it is recommended to use a point scaling system from (1 to 20) to differentiate between the firms in their level of achievements in the financial criteria.

A point score system is used here as a similar system used by some clients in prequalification and it gives more flexibility to differentiate between different levels of likely performance between the bidders and can be used to construct utility curves. In this system **0-4=very poor; 5-8= poor; 9-12=good; 13-16=very good; 17-20=excellent.**

The utility curves for these criteria are adopted a normal procedure of considering the best and the worst scores are having the best and worst utility values.

6.7.3. Technical ability

The inclusion of this criterion is to identify any weaknesses in the firm's technical ability that could lead to future problems, it included to cover aspects such as the availability of equipments, plants, personnel and ability to handle and perform the work to a standard level. This criterion can be measured in terms of four criteria described below:

6.7.3.1 Experience

The inclusion of this criterion is to ensure that the bidders have experience in similar type of projects, especially as this project is to be of a high quality standard. This criterion is measured by means of the, experience over the last five years in construction, past experience on client's major projects, experience and capability of technical field personnel, complexity of work executed, level of technology, types of projects executed in the past five years, performed work of the same general type and scale and ability to absorb subsequent changes.

6.7.3.2 Plant and equipment

This criterion is included to verify that the various equipments required for the execution is available at any time during the construction process. The measurement of this criterion can be traced by the availability of construction equipment at any time, adequate plant and equipment to do the work properly and expedientially, small tools and, the testing equipment.

6.7.3.3 Personnel

The personnel represent the main parameter in the success of any project as they will implement the planned programme for the project management and construction, for this reason this criterion is considered essential and included in the evaluation of bidders. This criterion can be measured by the availability of first level supervisors and number presently employed, availability of skilled crafts , expertise in design, skills including professional, and technical expertise, that are available to the company, e.g. qualifications and relevant experience, craftsmen availability.

6.7.3.4 Ability

This is included to be sure that the bidders can handle this kind of job with a high efficiency performance. This can measured by the ability to handle the offered type and size of work, ability to perform on site, ability to control and organise contracts and efficiently integrate labour resources, ability to meet target dates. All these parameters can be extracted form the previous measures such as the credit ratings from the subs and suppliers, contacting referees, visiting their sites.

For the assessment of technical ability of the firms, usually the client's want to be sure that the firm has adequate type of resources for the period of the project.

The firms have different polices and therefore they purchase or hire different type of equipment or employ different level of key personnel, which in turn has lead to different abilities of the firms to handle projects. Due to the difference in the firms achievement and due to the nature of this criterion a scale point system (**1-20**) was also assigned to measure this criterion.

6.7.4 Management capabilities

This criterion was included in the evaluation to assess elements such as the capability to execute the work in an appropriate manner, the existence and application of quality control programs, ability to coordinate the work and capability and competence of the contractor's staff. The criteria considered in the evaluation are:

6.7.4.1 Past performance and quality

This criterion was included to account for the previous performance of the company in projects of similar size and technical characteristics. In the evaluation it was considered which percentage of the works previously performed by the company were completed within budget and schedule, the quality of work achieved in the last projects, the success of quality programmes of the company. Only the performance of the last five years in these issues was considered for the evaluation.

6.7.4.2 Project Management Organization

The purpose of the inclusion of this criterion is to determine the existence of procedure and systems that would ensure a proper development of the work. Adequate programs in aspects such as quality assurance, quality control and safety control certainly are a good indication of good management capability, these are means of evaluating the capability of the bidder in terms of the project management organization.

6.7.4.3 Experience of technical personnel

This criterion is included to cover the capabilities and experience of the "key" personnel considered for the job (foremen, construction superintendents, engineers), these personnel are the key to the project success. For this the experience, curricula vitae, personnel attitude, honesty and any other relevant information about the academic preparation and working experience of the key personnel must be analyzed carefully. It is also understood that the personnel evaluated will be those in charge of the job.

6.7.4.4 Management Knowledge

This criterion can be measured by investigating the contractor's scheduling and cost control system and how it is utilized, material control, personnel, subcontracts, purchasing, level of research and development, risk avoidance and responsibility, productivity improvement programme, time performance and predicted outturn costs.

6.7.5 Health and safety

Increasing different type of accidents in the last decade has tightened the regulation to consider a safer contractor for future works. For this reason this criterion is becoming an essential to include in the evaluation of the bidders. Four sources of measure or criteria can be traced for the measurement of this criterion.

6.7.5.1 Safety

This criterion is included to be sure that the bidder has complied with the health and safety regulation, it is also included to assess the capability of bidder to work in dangerous areas. This criterion can be measured by experience in handling dangerous substances, experience in noise control, accident book, health and safety information chart for employees, safety record, weekly testing programme for the equipment, and company safety policy. Most of this information could be collected either through the referees, bidder files, visits and so on.

6.7.5.2 Experience modification rating (EMR)

This is included as a measure of the safety performance of the company, which provides an objective indicator of a contractor's performance to the average accident claim performance in his mix of work classification. EMR, has been developed by the insurance industry as an equitable means for financially rewarding or penalizing employers according to their accident claims over the last 3- years. It, therefore discriminates between contractors with varying safety performance.

6.7.5.3 Occupational safety OSHA

OSHA is the Occupational Safety and Housing Adminstration incidence rate which gives the average numbers of injures and illness per 100 man-year for a construction firm. bidders can compile this rate from the accidents rate, this rate can be used to compare different project managers or supervisors. Since there is no third party involved in assessing this rate, therefore the client didn't put high weight for this criterion.

6.7.5.4 Management safety accountability

This is the criterion which describe the level of management in the firm. This can be recognized by checking who in the organization receives and reviews accident reports, and what is the frequency of distribution of these reports, frequency of safety meetings for field supervisors, compilation of accident records by foremen and superintendents and the frequency of reporting, frequency of project safety inspection and the degree to which they involve project mangers and field superintendents, use of an accident cost system measuring individual foremen and superintendents as well as project managers.

6.7.6 Reputation

This criterion will summarize the firm's past success or failure, and its mainly based on the overall contractor's past attitude, capability, management. Four measure considered for describing this criterion to investigate the contractor reputation.

6.7.6.1 Past failures

The following is used to measure this criterion; past and present experience regarding legal suits or claims; reasons for recent debarment (if any), reasons for failed contract(if any); previous failures to perform contracts properly or fail to complete them on time; financial penalties previously levied in respect of failures to perform to the terms of a contract; contracts the firm has had terminated or employment determined under the terms of contract; contracts not renewed due to failure to perform in accordance with the terms of contract.

6.7.6.2 Length of time in business

This is included to check the ability of the contractor to compete and get a chance to increase his volume of work from the time of establishment. The following could be considered as the indication of this criterion: amount of projects executed in the past five years; capacity of work, company's stability; permanent place of business; depth of organization; number and size of contracts signed every year.

6.7.6.3 Past client/contractor relationship

This can be measured by the following: proximity of contractor's home office to project; responsibility and consideration for the client staff and general public; the performance of contractors over a number of previous invitations; responsibility and consideration for the adjoining clients affected by the work; experience of working with the client, i.e., understanding of the client's procedures in meetings and for payments in other words public clients are quite different in this respect to private clients; local knowledge; responsible attitude towards the work. These are all means of which the reputation of the contractor can be judged.

6.7.6.4 Other relationships

The management abilities and activities of the general contractor are a major variable in the fortunes of subcontractors, and the suppliers, and thus are major variables in the whole realm of construction management. The inclusion of this criterion is basically to investigate the responsibilities of the main contractors towards his subs and suppliers, as these two parties sometimes can cause a delay or failures to the project plan. Many parameters in this respect could be used to judge the management ability of the bidder, this might be put in a form of questionnaire passed to the subcontractors and suppliers, these questions may include.

1. Does the general contractor push his subs to do their work?
2. Is he honest, trustworthy and fair dealing?
3. Does he "shop" bids?
4. Does he have enough financial stability for this type of job?
5. Does he pay his subs on time?
6. Does he set up a schedule to coordinate work of all trades?
7. Does he pays his suppliers on time?
8. Does he appear an honest firm to deal with in trading ?

In addition to that the client has to investigate the bidders relation with employees, relations with statutory authorities, working relations between members of the referee staff and the staff of the firm including head office staff, race relations, standard of sub-contractors work.

6.8 SCORES OF INTANGIBLE CRITERIA

The management capabilities, health and Safety and Reputations and their subs are all intangible and subjective criteria. As far as the preliminary investigation has revealed there is no standard methods to measure these criteria. For this reason a scoring point system (1-20) was also taken as a measure to distinguish between the level of achievements between the firms for these kind of attributes and to construct the utility curves.

Each bidder has passed a preliminary and detailed investigation by looking at his files, past records with the client, contacting the technical referees, contacting the creditors, visits to site. After these investigation each bidder has scored certain value from (1 to 20) for different type of criteria considered for this example.

The decision maker has to bear in mind that some of the attributes are negatively oriented, for example past failure, will automatically means that a higher score will clearly indicate that the bidder has many failures in past projects. However, to overcome this problem in order to make the scoring consistent for all attributes for the easiness comparison, the following procedure has been followed in this case.

> The scoring system followed in such type of criteria is to subtract the real score of the bidder from 20, this will change the attribute to a positive oriented scale, for example bidder A has scored 5 points on a real count which indicate the bidder has less past failures. The score of the bidder A for the purpose of consistency was counted as (20 - 5 = 15), therefore this score was assigned to the bidder. By this organization the higher the score indicate the better the bidder.

Note also that the bid price criterion is also negatively oriented, but in this criterion there is no change made to the values submitted by the bidders, but in this case the decision maker has to be very careful when assigning values for the utility function. In this case the lowest bid amount represent the best option and therefore must receive the higher utility value and the highest bid price is the worst option and must be assigned a lower utility value.

Table 6.4 shows the score of the twenty criteria identified for this case for each bidder along with their offers for the bid amount which was figured in millions of pounds.

Contractor	A	B	C	D	E
{1} Advance payment(Million £)	0.1	0.3	0.3	0.15	0.1
{2} Capital bid (m £)	3.9	3.5	3.5	4	3.6
{3} Routine maintenance(m£)	0.3	0.25	0.3	0.25	0.1
{4} Major repairs (m£)	0.4	0.35	0.2	0.4	0.4
{5} Financial stability (points)	12	11	13	10	10
{6} Credit rating (points)	14	15	14	9	11
{7} Bank arrangements (points)	15	13	15	10	13
{8} Financial status (points)	17	17	16	11	14
{9} Experience (points)	11	15	9	16	6
{10} Plant and equipment (points)	13	14	10	18	16
{11} Personnel (points)	9	14	14	15	6
{12} Ability (points)	11	11	15	13	6
{13} Past performance (points)	15	10	16	10	10
{14} Management organisation (points)	10	17	13	10	11
{15} Experience of technical personnel (points	12	16	11	9	14
{16} Management Knowledge (points)	15	15	14	19	15
{17} Safety (points)	9	17	16	10	17
{18} EMR (points)	15	8	17	6	20
{19} OSHA (points)	8	13	9	10	16
{20} Management safety accountability (points)	7	11	12	8	11
{21} Past failures (points)	15	16	11	10	11
{22} Length of time in business (points)	14	15	14	11	6
{23} Client/contractors relationship (points)	10	13	14	10	10
{24} Other relationships	9	12	17	9	13

Table 6.4 Scores of the five bidders for the complete set of criteria

In order to see the general profile of each bidder, the average score has been used to check the score of the five bidders in the main six criteria. For example the average score for the financial soundness attribute for bidder A will be:

Attribute {5} +{6}+{7}+{8} divide by four

$$(12 + 14 + 15 + 17) / 4 = 14.5$$

Table 6.5 shows the average score of all bidders together with their total bid amount. The profile of the scores of the five bidders (A,B,C,D,E) is shown in Fig 6.4, it is clearly seen that bidder E has scored the best one for the attribute 1 (4.2 Million). A closer look at the scores for the other attributes, however, indicates that bidder E is generally inferior to the other bidders. This provides a first indication that bidder E may not be the best contractor for the project and suggests the need for the other attributes to be also taken into account.

Contractor	A	B	C	D	E
(1) Bid amount (Million £)	4.7	4.4	4.3	4.8	4.2
(2) Financial soundness (Points)	14.5	14.5	14.5	10	12
(3) Technical ability (Points)	11	12	12	15.5	8.5
(4) Management capability (Points)	13	13.5	13.5	12	12.5
(5) Health and safety (Points)	10	13	13	8.5	16
(6) Reputation (Points)	12	14	14	10	10

Table 6.5 Average scores of the five bidders for the main criteria

6.9 ASSESSMENT OF SCALING FACTORS

During the interviews, the individuals were consulted about the ranking and relative importance that should be given to a list of attributes previously identified. These individuals were asked to select from the main criteria those which they consider the most important for the present example. Consequently, they were asked to rank them in order

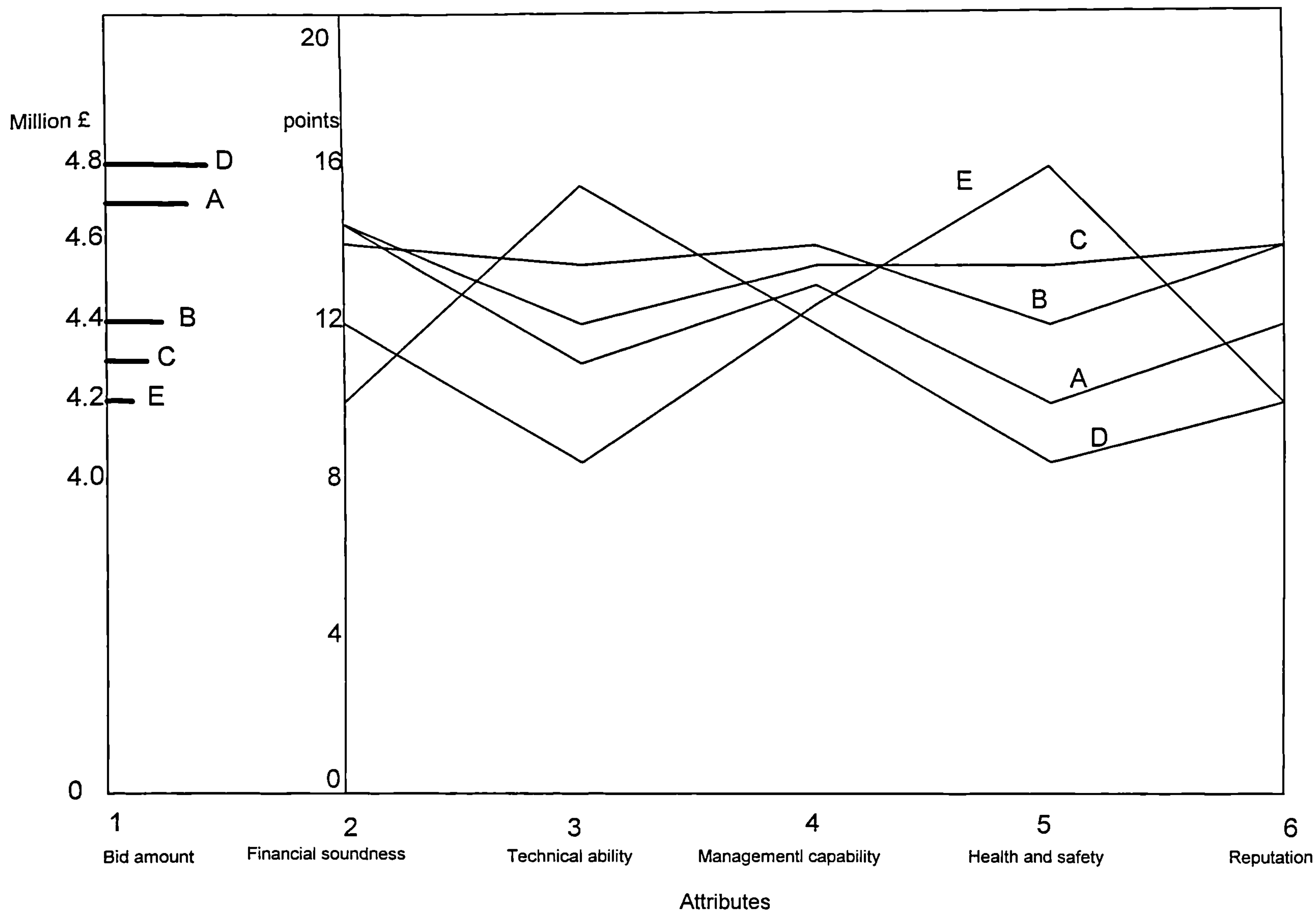

Fig 6.4. Profile of the scores for the five bidders A,B,C,D andE

of importance and to give relative weights to each attribute in a scale from 0 to 1, these are shown in Table 6.6. The sum of the total weights must be equal 1.

Criteria	Bid amount	Financial soundness	Technical ability	Management organization	Health and safety	Reputation
Weight	0.55	0.15	0.1	0.1	0.05	0.05

Table 6.6. Weights of the attributes for this example

Relative weights of the sub-criteria already defined were obtained using the procedure described above and the results are shown in Table 6.7.

(1) Bid amount (0.55)				(2) Financial soundness (0.15)			
Advance payment	Capital bid	Routine maintenance	Major repairs	Financial stability	Credit rating	Bank arrangements and bonding	Financial status
.05	.75	.1	.1	.3	.2	.15	.35
(3) Technical ability (0.1)				**(4) Management capability (0.1)**			
Experience	Plant and equipment	Personnel	Ability	Past performance and quality	Project management organization	Experience of technical personnel	Management knowledge
.2	.45	.3	.05	.4	.2	.2	.2
(5) Health and safety records (0.05)				**(6) Reputation (0.05)**			
Safety	Experience modificat-ion rating	Occupation-al safety OSHA	Managem-ent safety accountabi-lity	Past failures	Length of time in business	Past client/contrctor relationship	Other relations
.2	.3	.3	.2	.3	.1	.4	.2

Table 6.7 Relative weights of subcriteria for this example

Finally, the total weight or the scaling factor of all criteria considered is presented in Table 6.8. The relative weights of the attributes in a hierarchical structure are shown in Fig 6.5.

(1) Bid amount				(2) Financial soundness			
Advance payment	Capital bid	Routine maintenance	Major repairs	Financial stability	Credit rating	Bank arrangements and bonding	Financial status
0.0275	0.4125	0.055	0.055	0.045	0.03	0.0225	0.0525
(3) Technical ability				**(4) Management capability**			
Experience	Plant and equipment	Personnel	Ability	Past performance and quality	Project managemen t organizatio n	Experience of technical personnel	Management knowledge
0.02	0.045	0.03	0.005	0.04	0.02	0.02	0.02
(5) Health and safety records				**(6) Reputation**			
Safety	Experience modification rating	Occupational safety OSHA	Management safety accountability	Past failure	Length of time in business	Past client/cont tor relationship	Other relations
0.01	0.015	0.015	0.01	0.015	0.005	0.02	0.01

Table 6.8. Scaling factors for the criteria in this example

6.10 CONTRACTOR SELECTION PROBLEM

The decision maker representing the client must decide which one of the five bidders is the most suitable to fulfil the client objectives, especially now the bidders have scored different levels for different attribute which make the decision to choose more complicated. The decision maker has decided not to consider the bid price only as a criterion to identify the best bidder, but he has considered the full list of the criteria relevant to this case.

Each bidder has different levels of scores in different types of tangible and intangible criteria, therefore the decision maker has to use a method that is able to include mixed type of attribute. In this aspect the multiattribute utility theory which has an application in other fields has a promising solution for the problems of this kind in this example and was chosen for use in selecting the best bidder for this example.

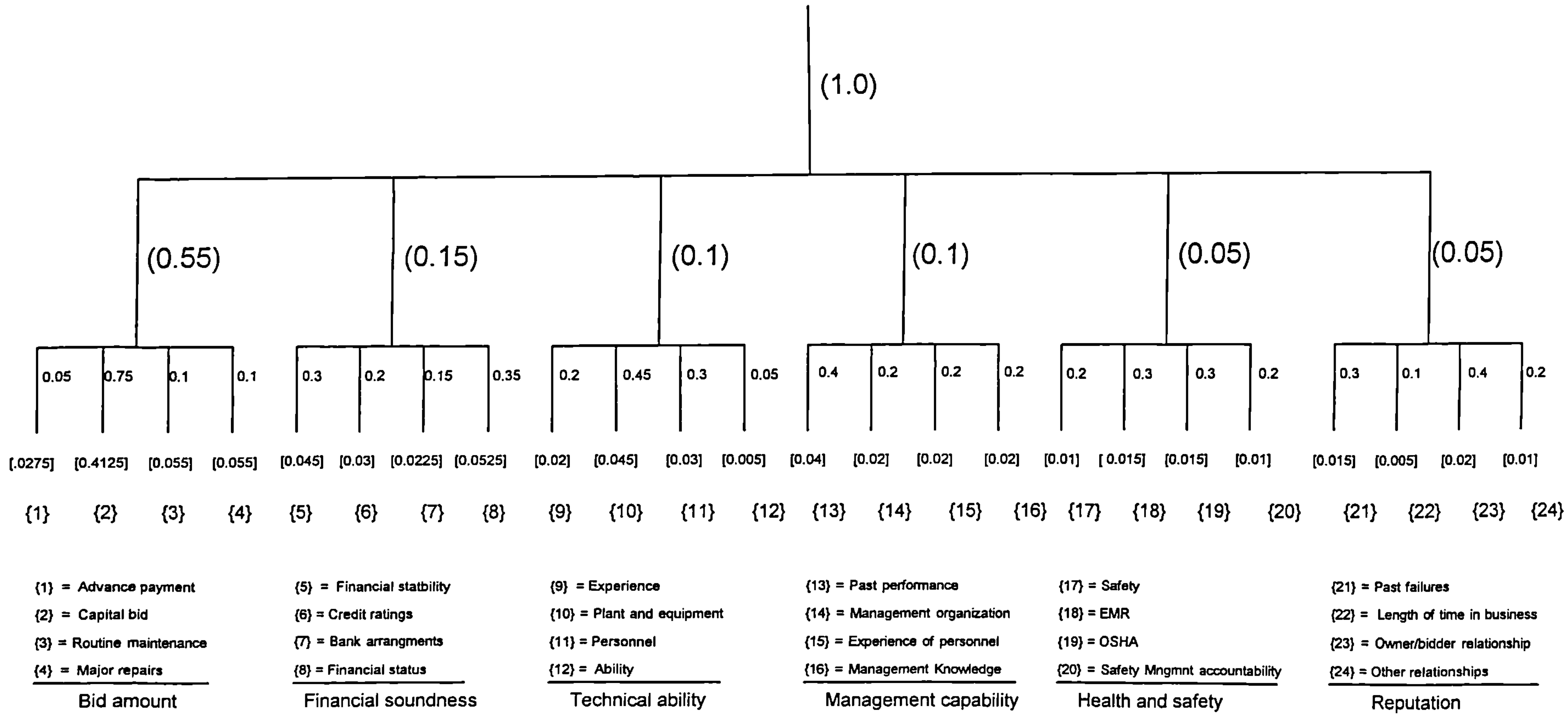

Fig 6.5. Scaling constants in a hierarchical structure

Fig 6.6 shows the decision tree for the contractor selection problem. The tree depicts the sequence of events in the decision tree, reading from left to right. The problem starts with a point of decision which represented by a square, from which emanate five alternatives (in this case five bidder A,B,C,D,E), each one of the five alternatives has its chance node represented by a circle.

Six levels of scores for different type of criteria will be the consequence of each chance node. Each one of the six main criteria again emanate four outcomes or scores. This will make a total of 24 outcome for each bidder that has to be compared against the other four bidders.

Table 6.4 given earlier shows clearly the outcome of each alternative for different type of criteria, in other words it shows the consequences of choosing any alternative from the five in hand for this case. If the decision maker clearly identify the consequences of each alternative and he feels that this alternative is his preference that can match the objectives, he must certainly choose the best possible alternative that justifies his objectives.

In a decision problem that involve many alternatives of which tangible and intangible criteria are the description of each one of the alternatives, a utility theory can simply assist the decision maker to reach a decision in a systematic way, it offers a system of thinking of preferences among the levels of outcomes for each attribute, then for the decision maker to choose which outcome he prefers, the details will come later.

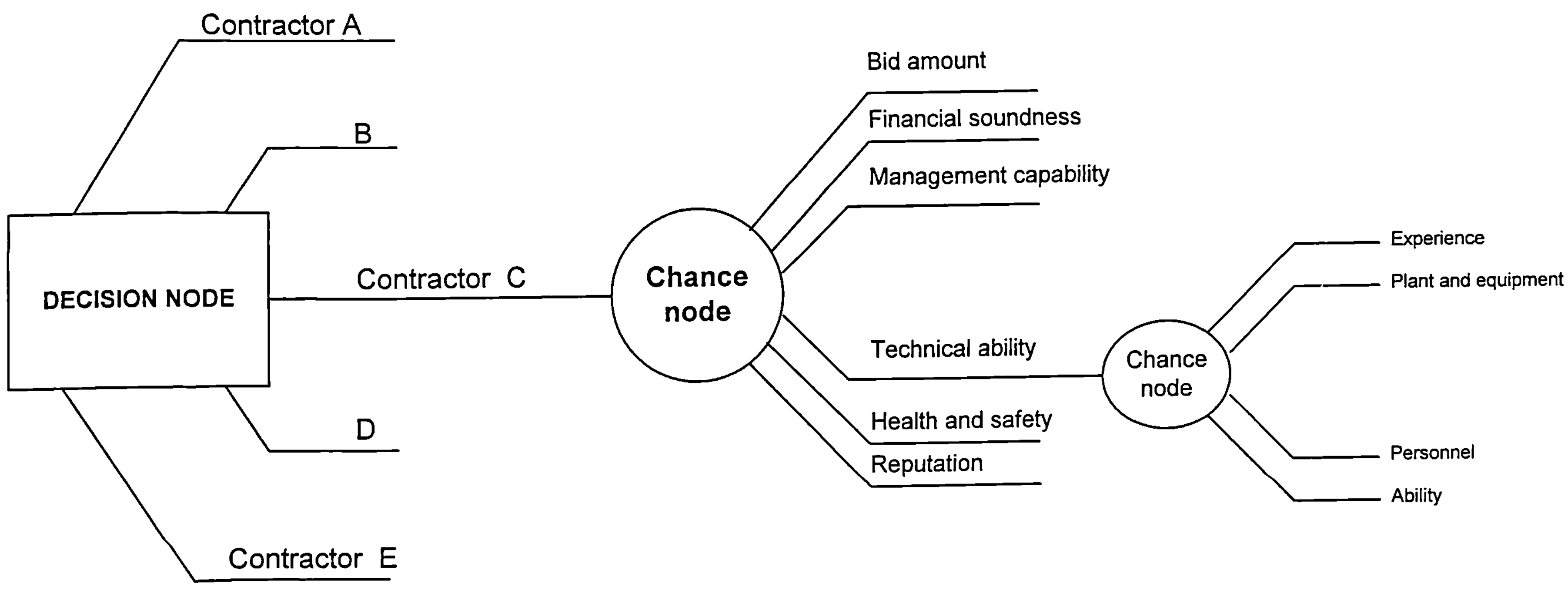

Fig 6.6 Decision Tree for the case study

6.11 IDENTIFICATION OF THE DECISION MAKER

To build a utility function for each attribute **real** interviews with a group of a decision makers is the best way to investigate their preferences and for the purpose of this research, the researcher will act as the only facilitator of a decision making group. This situation is very similar to the real case when dealing with medium size projects where only one person acting as Contract Administrator performs the evaluation and awards the contract, or prepares a recommendation of award for the client. The result that will be presented in the next sections for this example is the outcome of a **real** interview with one decision maker Mr (Oztash).

6.12 DETERMINATION OF UTILITY FUNCTIONS

Utility functions can be developed by a technique known as a standard gambling. For the construction of the utility functions in this example, the decision maker preferences for gambles were investigated following the method suggested by Bell et al (1978), Ang and Tang (1984) and Keeney and Raiffa (1993).

The first step consists in the identification of the best and worst outcomes (scores of bidders) for each one of the attributes defined in this example Table 6.4. To these outcomes, arbitrary values of 1 and 0 are assigned respectively.

The decision maker is free to set these utilities values so long as the best outcome receives the higher value. The usual choice is to assign the worst outcome a utility value of zero (=0), and the best outcome a utility value of one (=1). This establishes the range of utility values to be 0 to 1 between the worst and the best possible outcome.

To determine the utility of intermediate values, the decision maker offered the choice between the following two options.

a) Certain option: In this case the decision maker is offered a **certain** outcome with a probability (p) of 100%

b) Risky option: In this case the decision maker is offered a **probabilistic** outcome in the form of a gamble, in which he is either receive the best outcome with a probability p or the worst outcome with a probability 1-p.

The following is an example using material from a real interview of how the utility values for attribute *{10} plant and equipment*, with a relative weight of 4.5% or 0.045 (see Table 6.8 and Fig 6.5), were obtained and from which a utility curve was then established. The author has acted as a facilitator with Mr Oztash

Attribute {10} Plant and equipment: The scores of the five bidders for this criterion is shown in the Table below.

Contractor	A	B	C	D	E
{10} Plant and equipment score (points)	13	14	10	18	16

The first step was to identify the best and worst outcomes for this attribute and assign arbitrary utility values of 1 for the best outcome (bidder D with 18 points) and 0 for the worst outcome (bidder C with 10 points) as shown in Table 6.9.

Contractor	D	C
Plant and equipment score (points)	18	10
Utility value	1	0

Table 6.9. Utility values for the best and worst outcomes for the attribute {10}

To determine the utility of intermediate values, the decision maker offered by a facilitator to choose between the following pair of lotteries, see Fig 6.7.

Lottery 1: go to route R1 for a certain (i.e P=1=100%) consequence of 13 points for the plant and equipment attribute

Lottery 2: go to route R2 for either a best consequence of 18 points (bidder D) with a probability of (p=?) or a worst consequence of 10 points (bidder C) with a probability of 1-p.

For the decision maker to make a good decision and choose among the two routes he must assess the utility value of the 13 points score and then compare that with expected utility from the risky option. So what utility value should the decision maker assign to the certain outcome or the 13 points score? The decision maker measures his relative preference for a 13 point consequence by finding the probability p for the best outcome (18 point score) see Fig 6.7, **that leaves him indifferent** between the certain route R1 for a 13 point outcome and the gamble route R2 for the two possible outcomes of 18 and 10 points.

Suppose after mental trial and error, he judges his indifference probability to be P=0.5, that he is indifferent between a certain 13 points outcome and a 50-50 risk between 18 and 10 points. The fact that he is indifferent (at P = 0.5) allows us to find the utility value of 13 points i.e U(13).

From the principles of expected values (Spiegel 1980: ch 3) and from the probability theory, the expected utility from the route R2 of the 50-50 gamble is equal.

$$p \times (\text{utility of best outcome score}) + (1\text{-}p) \times (\text{utility of worst outcome})$$

$$0.5\ U(18) + (1 - 0.5)\ U(10) = 0.5\ (1) + 0.5\ (0) = 0.5$$

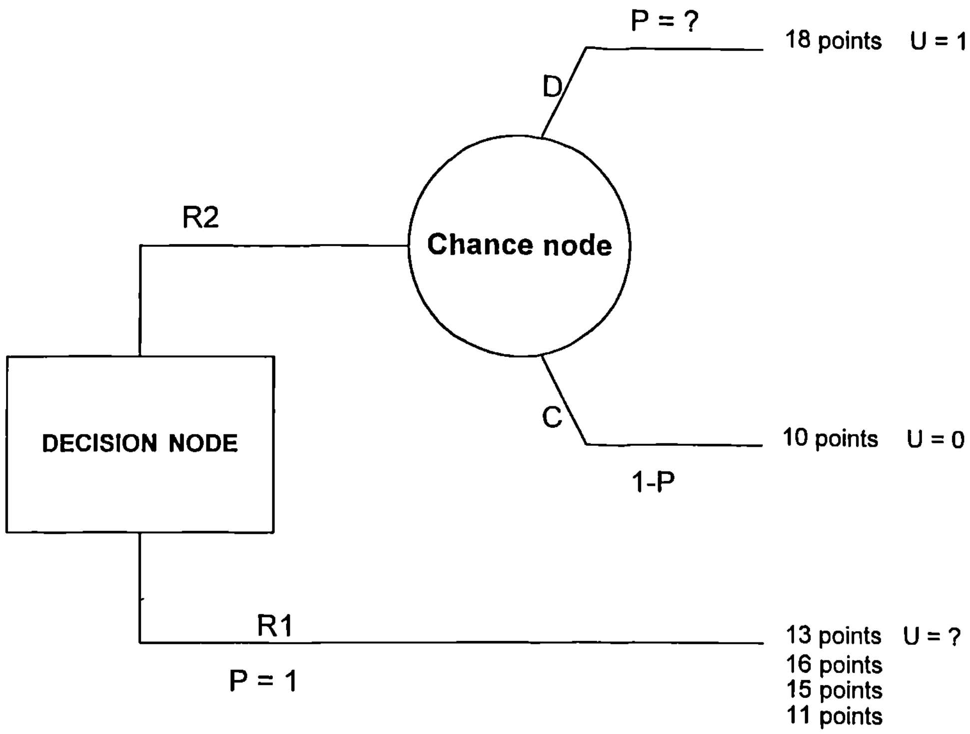

Fig 6.7. Pair of lotteries for attribute {10} plant and equipment

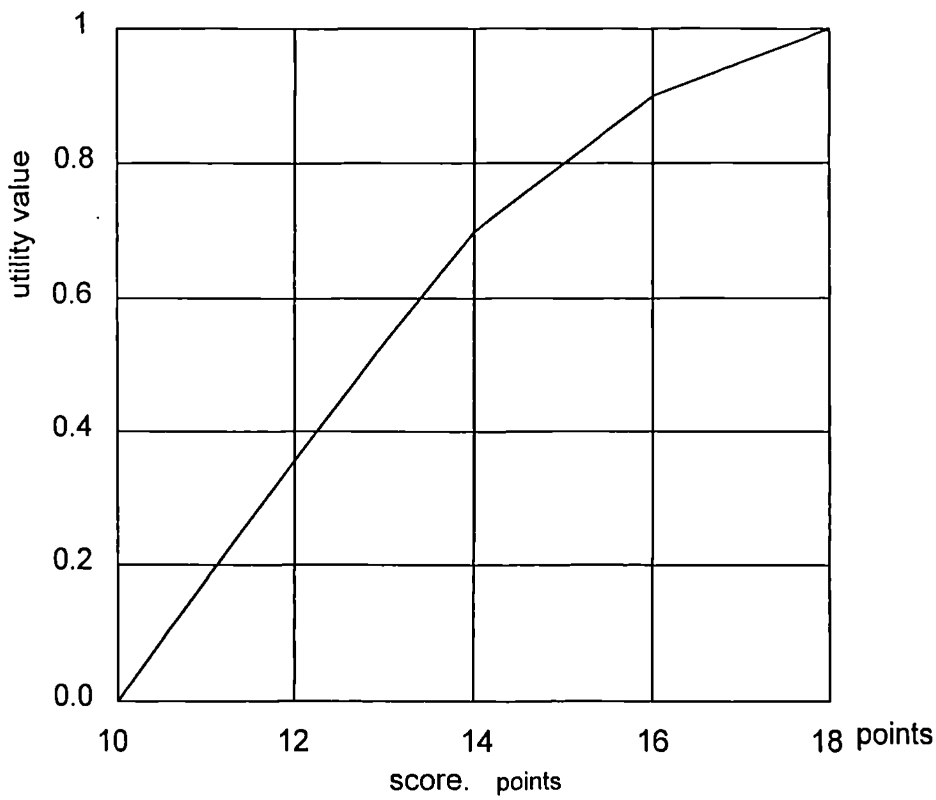

Fig 6.8. Utility curve for attribute {10} plant and equipment

Since the decision maker is indifferent between 13 points for certain and this gamble, the two alternatives must have the same utility value, that is U(13) = 0.5.

This procedure can be used for the scores between 10 and 18, i.e, for this attribute to find out their utility values, and not necessarily the score of the bidders, the more the utility values obtained the better the utility curve will appear. Table 6.10 summarises the utility values for different scores for the attribute *{10} plant and equipment* and Fig 6.8 shows a utility curve, in which the scoring points is plotted against the utility values.

Contractor	A	B	C	D	E
Score (points)	13	14	10	18	16
Utility value	0.5	0.7	0	1	0.9

Table 6.10. Utility values for different scores for the plant and equipment attribute

Once the utility or preference curve for this specific decision maker is constructed, any utility value for any score between 10 and 18 points can be directly extracted form the curve.

Appendix 6 shows the detailed interview with the decision-maker, Mr Oztash involved in this example for building a utility function for attribute *{10} plant and equipment* and attribute *{18} experience modification rate* .

The procedure was applied for each attribute and a utility values assigned for each attribute for the four contractors by Mr Oztash. Table 6.11 summarises the utilities values obtained in this way for the whole set of attributes.

Contractor	A	B	C	D	
{1}. Advance payment	1	0	0	0.8	1
{2}. Capital bid	0.55	1	1	0	0.85
{3}. Routine maintenance	0	0.85	0	0.85	1
{4}. Major repairs	0	0.8	1	0	0
{5}. Financial stability	0.9	0.85	1	0	0
{6}. Credit rating	0.95	1	0.95	0	0.70
{7}. Bank arrangements	1	0.85	1	0	0.85
{8}. Financial status	1	1	0.95	0	0.55
{9}. Experience	0.85	0.95	0.6	1	0
{10}. Plant and equipment	0.5	0.7	0	1	0.9
{11}. Personnel	0.7	0.95	0.95	1	0
{12}. Ability	0.85	0.85	1	0.95	0
{13}. Past performance	0.95	0	1	0	0
{14}. Management organization	0	1	0.85	0	0.7
{15}. Experience of technical personnel	0.80	1	0.70	0	0.90
{16}. Management Knowledge	0.5	0.5	0	1	0.5
{17}. Safety	0	1	0.95	0.5	1
{18}. EMR	0.85	0.4	0.95	0	1
{19}. OSHA	0	0.7	0.5	0.6	1
{20}. Management safety accountability	0	0.90	1	0.5	0.90
{21}. Past failures	0.90	1	0.50	0	0.5
{22}. Length of time in business	0.95	1	0.95	0.75	0
{23}. Client/contractors relationship	0	0.90	1	0	0
{24}. Other relationships	0	0.70	1	0	0.75

Table 6.11 Utility values for the five bidders as assigned by Mr Oztash

6.13 SELECTION OF THE BEST BIDDER USING MULTIATTRIBUTE UTILITY COMPUTATIONS: AN ADDITIVE MODEL

At this stage, all the elements needed for the calculations are known; the list of attributes is defined Table 6.2, the scores of the bidders achievements in these attributes have been assigned Table 6.4, the relative weights of the attributes have been determined Table 6.8, and the utility values of the decision maker for these attributes have been defined and drawn Table 6.11.

The next step is to determine the overall utility of each contractor using the additive model equation 6.1 for one decision-maker (Mr Oztash). To do this, the utility value corresponding to each attribute is multiplied by its corresponding scaling factor and the products are summed up to obtain the overall utility value for each bidder.

Table 6.12. shows the overall utility of the five bidders using the additive model. It can be clearly seen that **bidder B** has the highest utility of **(0.857)**, therefore considered the best bidder for this project by Mr Oztash.

Contractor	A	B	C	D	E
{1}. Advance payment	1 x 0.0275	0 x 0.0275	0 x 0.0275	0.8 x .0275	1 x 0.0275
{2}. Capital bid	0.55 x 0.4125	1 x 0.4125	1 x 0.4125	0 x 0.4125	0.85 x 0.4125
{3}. Routine maintenance	0 x 0.055	0.85 x 0.055	0 x 0.055	0.85 x 0.05	1 x 0.055
{4}. Major repairs	0 x 0.055	0.8 x 0.055	1 x 0.055	0 x 0.055	0 x 0.055
{5}. Financial stability	0.9 x 0.045	0.85 x 0.045	1 x 0.045	0 x 0.045	0 x 0.045
{6}. Credit rating	0.95 x 0.03	1 x 0.03	0.95 x 0.03	0 x 0.03	0.7 x 0.03
{7}. Bank arrangements	1 x 0.0225	0.85 x 0.0225	1 x 0.0225	0 x 0.0225	0.85 x 0.0225
{8}. Fianancial status	1 x 0.0525	1 x 0.0525	0.95 x 0.0525	0 x 0.0525	0.55 x 0.0525
{9}. Experience	0.85 x 0.02	0.95 x 0.02	0.6 x 0.02	1 x 0.02	0 x 0.02
{10}. Plant and equipment	0.5 x 0.045	0.7 x 0.045	0 x 0.045	1 x 0.045	0.9 x 0.045
{11}. Personnel	0.7 x 0.03	0.95 x 0.03	0.95 x 0.03	1 x 0.03	0 x 0.03
{12}. Ability	0.85 x 0.005	0.85 x 0.005	1 x 0.005	0.95x0.005	0 x 0.005
{13}. Past performance	0.95 x 0.04	0 x 0.04	1 x 0.04	0 x 0.04	0 x 0.04
{14}. Management organization	0 x 0.02	1 x 0.02	0.85 x 0.02	0 x 0.02	0.7 x 0.02
{15}. Experience of technical personnel	0.8 x 0.02	1 x 0.02	0.7 x 0.02	0 x 0.02	0.90 x 0.02
{16}. Management Knowledge	0.5 x 0.02	0.5 x 0.02	0 x 0.02	1 x 0.02	0.5 x 0.02
{17}. Safety	0 x 0.01	1 x 0.01	0.95 x 0.01	0.5 x 0.01	1 x 0.01
{18}. EMR	0.85 x 0.015	0.4 x 0.015	0.95 x 0.015	0 x 0.015	1 x 0.015
{19}. OSHA	0 x 0.015	0.7 x 0.015	0.5 x 0.015	0.6 x 0.015	1 x 0.015
{20}. Management safety accountability	0 x 0.01	0.90 x 0.01	1 x 0.01	0.5 x 0.01	0.9 x 0.01
{21}. Past failures	0.9 x 0.015	1 x 0.015	0.5 x 0.015	0 x 0.015	0.5 x 0.015
{22}. Length of time in business	0.95 x 0.005	1 x 0.005	0.95 x 0.005	0.75x0.005	0 x 0.005
{23}. Client/contractors relations.	0 x 0.02	0.9 x 0.02	1 x 0.02	0 x 0.02	0 x 0.02
{24}. Other relationships	0 x 0.01	0.70 x 0.01	1 x 0.01	0 x 0.01	0.75 x 0.01
OVERALL UTILITY	**0.558**	**0.857**	**0.814**	**0.211**	**0.648**

Table 6.12. Overall utility values for the decision maker Oztash

Table 6.13 shows the overall utility values for the five bidders by the four decision-makers interviewed (**real interviews**) in this example. The overall utility values of the other decision makers confirmed **bidder B** with the highest overall utility value and therefore ranked number 1. Thus, although **bidder E** submitted the lowest bid price, this bidder is ranked only 3 by this method, and the best choice is bidder B.

Interviewee Contractor	A	B	C	D	E
Oztash	0.558	0.857	0.814	0.211	0.648
Ahmet	0.522	0.815	0.783	0.191	0.633
Hussin	0.516	0.792	0.792	0.177	0.673
Kamalain	0.511	0.761	0.758	0.175	0.653
Rank order	4	1	2	5	3

Table 6.13: Overall utility and ranking of the five bidder from four decision makers

6.14 CONCLUSION

This chapter proposes that more than one attribute should be considered in contractor selection. Multiattribute utility theory provides one such approach and is especially useful as it allows the treatment of both quantitative and qualitative criteria and in situations where there are many decision parties.

The theoretical basis of the technique is provided. An additive model is proposed for its simplicity. The utility model uses utility curves to represent the relationship between a specific capability of a contractor and the value of that capability in risky situations. The individual importance of each contractor attribute is specified using a weighting which also incorporates the risk of the decision maker.

An example is described to illustrate the data requirements, mechanics, and solution nature of the theory and in which **real interviews** with four professionals were conducted for building the utility functions. A method of building utility functions using a gambling technique is described using **a real interview**. Precise assessment of the relative weights was shown to have a crucial bearing on the solution suggested by the analysis technique.

The question that raises itself, does the current techniques of selecting contractor that mainly depend on the contractor selection criteria (CSC) achieve the project success factors (PSF) in terms of time, cost and quality ? Table 5.13 of the previous chapter showed that the clients are not fully satisfied with the performance of the contractors in terms of these three goals.

Our survey show that for traditional contracts only 31.6% of public clients are satisfied with contractor's performance in terms of time, 68.4% are not satisfied to moderately satisfied with time, in terms of cost 43.3% of public clients are not satisfied to moderately satisfied, on the other hand 56.7% are satisfied, in terms of quality the level of satisfaction balanced 50.1% satisfied and 49.9% are not satisfied to moderately satisfied.

Most client (and consultant) prequalifiers being more concerned with process of retrieving completed proforma details from candidate contractors than undertaking any serious study of the relationships of this data with the project success factors. The relationship between the contractor selection criteria (CSC) and project success factors (PSF) in terms of time, cost and quality which should be used as an ends for the selection of contractors will be tackled in the next chapter.

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7. EVALUATING CONTRACTOR PREQUALIFICATION DATA:SELECTION CRITERIA AND PROJECT SUCCESS FACTORS

CHAPTER 7

Evaluating contractor prequalification data: selection criteria and project success factors

7.1 INTRODUCTION

One of the most difficult decisions taken by the client in the construction industry is selecting the contractor. Every construction project faces adversity and uncertainty. An inappropriate contractor increases the chances of delays, cost overruns, sub-standard work, disputes, or even bankruptcy. One method of ensuring a contractor's ability to execute the assigned project in accordance with all client and project objectives is to assess the contractor's capabilities at a prequalification stage and tender evaluation stage.

Prequalification is a pre-tender process used to investigate and assess the capabilities of contractors to satisfactorily carry out a contract should it be awarded to them. The current practice of prequalification involves a screening procedure based on a set of criteria and has been examined by several researchers (eg., Hunt and others, 1966; Helmer and Taylor, 1977; Russell and Skibniewski, 1987,88; Merna and Smith, 1990; Ng, 1992; Holt *et al*, 1994; Potter and Sanvido 1994).

For prequalification to be useful, it is necessary to know how these different criteria are likely to have impact on the main project success factors in terms of time, cost, and quality. The findings of chapters 2,3 and 5 suggest that such knowledge is lacking, with most client (and consultant) prequalifiers being more concerned with process of retrieving completed proforma details from candidate contractors than undertaking any serious study of the relationships of these data with the project success factors. Neither of these relationships received attention from researchers in the field. This may be as a result of the long term confidence attributed to pre-selection and the fact that final selection is made predominantly on the cost elements of tenders (Holt *et al*, 1994).

Another possible reason may be the lack of postconstruction evaluation (Akatsuka, 1994). Russell *et al* (1992) for instance suggests that clients do not feel that prequalification of contractors is important enough to warrant the expenditure involved. As a result clients may be subjecting themselves to unnecessary risk of admitting contractors with inadequate ability, capacity, and experience to fulfil the required project objectives.

This chapter presents the results of a Delphi study investigating the perceived relationship between contractor selection criteria (CSC) currently in use and predominant project success factors (PSF), in terms of time, cost and quality involving a sample of six experienced construction professionals and two validators. A consensus of the likely impact of each criterion on time, cost and quality is established in terms of pessimistic, average and optimistic values which are then converted into expected means and variances via the PERT (Program Evaluation and Review Technique) approach. The ten most and ten least important CSC are identified and examined for differences and similarities between PSF.

The results showed that past failures, financial status, financial stability, credit ratings, experience, ability, management personnel, management knowledge are the most dominant CSC affecting all three PSF, with safety criteria (safety, experience modification rate, occupational housing association, management safety accountability) and the length of time in business having the least effect overall. Some CSC, such as "past performance, bank arrangements, project management organization, plant and equipment", were found to affect only one or two PSF.

The major benefits of this study is a documented identification of the anticipated effect that various CSC have on client objectives in terms of PSF, and also to provide a basis for the development of quantitative techniques for contractor selection.

7.2 PROJECT SUCESS FACTORS (PSF)

All procurers have got goals or concerns that can be described in similar terms. They are concerned to different degrees about the predominant project success factors in terms of *time, cost and quality*. The reasons for considering only these three factors will be described in chapter eight.

Time: The time to complete the project is scheduled to enable that project to be used by a date determined by the client's future plans. Clients vary in their willingness to employ only those contractors who are able to meet target dates. Some contracts include a bonus clause to encourage the contractor to speed up the construction process and to avoid any delays.

Cost: Historically, cost is the factor considered by clients to be the most important. Most seek value for money, although this is often taken to mean spending as little as possible. It is from this premise that traditional competitive tendering system arose. One result of this is that cost, measured by the bid price submitted by the contractor, is often regarded as the sole criterion for selection. A large majority of projects, however, end up costing more than the original bid price (Hardy, 1978; Merna and Smith ,1990).

Quality: Quality in construction is defined as " the totality of features required by a product or service to satisfy a given need" (BS5750, 1987). It is thought that the implementation of new procurement systems has resulted in a decline in quality in recent years (Hindle and Rwelamila, 1993) and, for this reason alone, quality factor should be regarded as one of the main criteria in contractor selection (Latham, 1994).

7.3 RESEARCH METHODOLOGY

A questionnaire (see Appendix 7A) was developed to enable information to be collected on each subject's perception of the extent to which each CSC identified in chaters 3 and 5 affects the three PSF of time, cost, and quality.

The questionnaire was designed to allow the interviewee complete freedom to enter any value that reflects his opinion on the influence of the CSC and not to restrict him to some values. There are two reasons for this: a) There is no guidance in the literature that has investigated in quantitative scale the effect of CSC on PSF b) The author believes that by letting the interviewee put any value that represents his own opinion makes the investigation more flexible to the interviewee and to give the researcher an insight idea of the ranges of these values. The difficulty of this technique is in interpreting and finding some compromise among all these different values.

In order to make the interviewing more effective and to save the time of the interviewees, the questionnaire, with a description of the purpose and needs of the research, was sent to the interviewees several days in advance of the interviews. In addition, the purpose of the interview was explained briefly to the professional through a telephone conversation. This was then reinforced and discussed further during the interview itself and included as part of the data collection exercise.

A list of potential interviewees was compiled randomly from different organisations and from personal contacts of the author. A sample of eight construction professionals with relevant construction industry experience were ultimately interviewed. The interviews were conducted at the interviewees' own offices comprising three public client organisations and five private client organisations in the north west of England. Each interview ranged from 1 to 2 hours and was tape-recorded. The interview procedure comprised three phases:

First phase. In the first phase six professionals were requested to describe the effect of each criterion on time, cost, and quality in terms of three values - pessimistic (P), average (A), optimistic (O) - for two types of contractors. In question one appendix 7A ("financial stability"), for example, interviewees were requested to provide P, A and O values for financially stable contractors and also P, A and O values for financially unstable contractors in terms of the likely effect on project time, cost and quality, this has to be applied for the whole list of questions.

All values were requested as percentages, where 100% is considered as the desired level to be achieved for time, cost, and quality. The lower the value for time and cost the better while for quality, the higher the better. For example 108% for cost and time means an expectation of 8% overrun on scheduled cost and time whilst 108% for quality means an expectation of 8% improvement in specified quality.

Once the data from the six interviewees were collected, the **mean** of P, A and O values was calculated for each criterion and for the three objectives for both types of contractors.

Second phase. The second phase of the procedure involved the same six interviewees again being visited. This time the interviewees were shown the **mean** values produced by the first phase along with their original estimated values. They were then given the opportunity to change their original values if they wished. This was carried out with each interviewee for all 20 CSC and 18 elements of the questionnaire. The means of the revised values were then recalculated as shown in Appendix 7B.

Third phase. Interviews with another two professionals were next conducted to validate the values thus far obtained and to check whether the revised means could be accepted as reasonable default values for possible use in any future system development. Each validator was provided with the mean values shown in appendix 7B and requested to describe how much each criterion affected time, cost, and quality, and either to agree on the value given or modify if there is a significant change. The result of this phase was very encouraging with one validator agreeing to all values without single change and the other validator making a very slight change in the safety criterion. This was taken to indicate that a reasonable consensus existed on the default status of the values given in Appendix 7B.

7.4 STATISTICAL ANALYSIS

The *expected mean* and *variance* values for the three PSF for each decision criterion were determined and an analysis of their impact made. The 90, 95, and 99% confidence intervals for the expected means and standard deviation were calculated. The relationships between CSC for each PSF using the linear Correlation Coefficients were determined. Tests of hypotheses of the population correlation coefficient for the three PSF were evaluated for different statistical significance. In the subsequent section, each analysis technique is described along with their results. A summary of these statistical analyses results are also highlighted.

7.4.1 Expected means and variance values

The expected means and variances of the time, cost and quality for each criterion and for each type of contractor were calculated from the P, A and O values given in Appendix 7B by the use of the PERT method (eg., Loomba, 1978; Harris, 1978; Horowitz, 1967) as follows:

Expected time E[t] $= (P_t + 4A_t + O_t)/6$ **(7.1)**

Expected cost E[c] $= (P_c + 4A_c + O_c)/6$ **(7.2)**

Expected quality E[q] $= (P_q + 4A_q + O_q)/6$ **(7.3)**

Sigma(S)= (the highest value P or O - The lowest P or O)/6 **(7.4)**

in which P and O are the same as defined above. The variance is given by squaring Sigma(S).

For example, the three estimated values for the 'financial stability' criterion are, from Appendix 7B:

	Financially unstable contractor			Financially stable contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	118	107	102	105	100	95
Cost	118	108	100	105	100	97
Quality	87	93	100	95	100	108

Using eqns (7.1) to (7.4) gives, for unstable contractors

E_t= (118+4x107+102)/6 =108 (S_t)= (118-102)/6=2.67 Var$(V_t)=(S_t)^2$=7.12

E_c= (118+4x108+100)/6 =108 (S_c)= (118-100)/6=3.00 Var$(V_c)=(S_c)^2$=9.00

E_q= (87+4x93+100)/6 = 93 (S_q)= (100-87)/6 =2.17 Var$(V_q)=(S_q)^2$=4.70

For stable contractor

E_t= (105+4x100+95)/6 =100	(S_t)= (105-95)/6=1.67	$Var(V_t)=(S_t)^2$=2.78
E_c= (105+4x100+97)/6 =100	(S_c)= (105-97)/6=1.33	$Var(V_c)=(S_c)^2$=1.77
E_q= (95+4x100+108)/6 =100	(S_q)= (108-95)/6=2.17	$Var(V_q)=(S_q)^2$=4.70

The expected mean values, standard deviations and variances of all the CSC were calculated in this way and the results are shown in Appendix 7C.

7.4.2 Confidence intervals of the expected mean and standard deviation values

The expected mean values and variance parameters for time, cost and quality calculated so far are for a sample of a population. 90%, 95% and 99% confidence interval estimates of the population expected mean values (μ) and population standard deviation (r) for time, cost, and quality were calculated using small sample (n<30) theory (see eg Spiegel, 1980). It should be noted that in the small sample theory the standard deviation of the sample is used instead of the population standard deviation (r) which is usually unknown. It is generally desirable that the width of a confidence interval be as small as possible.

Tables 7.1 and 7.2 show the 90% confidence intervals of μ along with the sample expected mean values (E) and r along with the sample standard deviation (S) for the whole list of CSC respectively.

7.4.3 Highest rated CSC by expected values

Since the risk in most cases comes from selecting a contractor with weak characteristics (i.e financialy unstable, low credited, inadequate plant, ..), therefore, in this and the following sections, in each analysis technique data of such a contractor are used. For analysis and for the sake of clarity, the 10 CSC that have the largest and smallest effects are presented in Tables 7.3 and 7.4 for both charectristically weak and strong contractors.

Contractor Selection Criteria	Project Sucess Factors	Undesirable contractor			Desirable contractor		
		Maximum (μ)	E	Minimum (μ)	Maximum (μ)	E	Minimum (μ)
financial stability	time	110.02	108	105.25	101.51	100	98.49
	cost	110.82	108	105.3	101.53	100	99.02
	quality	90.77	93	94.79	98.55	100	102.56
credit rating	time	110.26	107	104.74	101.45	100	97.44
	cost	112.97	110	107.25	101.17	100	98.06
	quality	92.970	95	96.48	98.34	100	101.5
bank arrangements	time	113.60	111	108.18	100.95	100	97.94
	cost	109.79	108	105.77	101.11	100	98.05
	quality	93.480	95	96.24	99.27	100	101.28
financial status	time	115.48	112	108.80	101.69	100	97.98
	cost	113.08	111	108.31	100.96	100	98.04
	quality	87.97	90	91.48	98.75	100	101.25
experience	time	112.75	110	106.98	101.58	100	97.97
	cost	112.22	110	106.95	101.34	100	98.38
	quality	90.80	93	95.31	98.92	100	101.53
plant and equipment	time	111.41	109	106.64	101.51	100	98.49
	cost	108.72	106	104.45	100.95	100	98.89
	quality	95.20	97	97.96	99.68	100	101.04
technical personnel	time	110.08	109	106.31	101.06	100	97.94
	cost	108.15	107	104.63	101.61	100	98.50
	quality	89.61	91	92.72	98.92	100	101.53
ability	time	113.57	111	107.54	101.51	100	98.49
	cost	111.11	108	105.84	101.25	100	98.75
	quality	88.89	92	94.16	98.48	100	101.24
past performance	time	112.2	109	106.63	101.02	100	97.15
	cost	108.95	107	104.88	101.35	100	98.49
	quality	89.69	92	94.36	99.49	100	102.35
project management organization	time	112.77	110	107.50	102.00	100	97.83
	cost	108.97	107	105.20	101.51	100	98.65
	quality	89.55	92	93.67	98.92	100	101.53
management personnel	time	114.96	112	108.93	101.32	100	97.96
	cost	109.68	108	105.76	101.60	100	98.34
	quality	89.37	92	93.13	99.38	100	102.34
management knowledge	time	113.36	111	108.59	101.34	100	98.33
	cost	107.83	106	103.56	101.50	100	98.39
	quality	90.51	92	94.77	99.35	100	101.81
safety	time	103.62	103	101.66	100.64	100	99.19
	cost	102.53	102	101.08	100.38	100	99.18
	quality	100.23	100.2	100.43	99.86	100	100.31
experience modification rate	time	103.35	102	101.65	100.39	100	99.33
	cost	103.35	102	101.65	100.39	100	99.33
	quality	98.43	99	99.29	99.59	100	100.14
occupational housing rate	time	104.34	103	102.33	100.31	100	98.91
	cost	102.43	102	101.18	100.33	100	99.17
	quality	100.00	100	100.00	100.00	100	100.05
management safety accountability	time	101.69	101.6	101.14	100.00	100	100.0
	cost	101.69	101.6	101.14	100.00	100	100.0
	quality	99.47	99.67	99.97	99.79	100	100.10
past failures	time	114.52	113	110.76	101.57	100	97.60
	cost	116.98	114	111.46	101.51	100	98.49
	quality	86.88	89	90.90	98.77	100	101.78
length of time in business	time	102.10	101	99.84	100.85	100	99.15
	cost	102.36	102	100.86	101.65	100	99.19
	quality	94.36	96	96.87	98.90	100	101.10
client/contractor relation	time	106.51	105	103.49	101.06	100	98.10
	cost	109.47	107	104.70	101.53	100	98.92
	quality	93.79	96	97.05	99.42	100	101.13
other relations	time	111.74	110	107.98	100.95	100	97.94
	cost	110.06	108	106.05	101.53	100	99.02
	quality	91.55	93	94.56	99.01	100	101.27

Table 7.1: 90% confidence intervals of the expected values

Contractor Selection Criteria	Project Sucess Factors	Undesirable contractor			Desirable contractor		
		Maximum (r)	S	Minimum (r)	Maximum (r)	S	Minimum (r)
financial stability	time cost quality	6.04 6.99 5.09	2.67 3.00 2.17	1.94 2.25 1.63	3.82 3.18 5.09	1.67 1.33 2.17	1.23 1.02 1.63
credit rating	Time cost quality	6.99 7.25 4.45	3.00 3.17 2.00	2.25 2.33 1.43	5.09 3.94 4.01	2.17 1.67 1.67	1.63 1.27 1.29
bank arrangements	time cost quality	6.87 5.09 3.50	3.00 2.17 1.50	2.21 1.63 1.12	3.82 3.88 2.54	1.67 1.67 1.00	1.23 1.25 0.82
financial status	time cost quality	8.46 6.04 4.45	3.67 2.67 2.00	2.72 1.94 1.43	4.71 3.69 3.18	2.17 1.50 1.33	1.51 1.19 1.02
experience	time cost quality	7.31 6.68 5.72	3.17 2.83 2.50	2.35 2.15 1.84	4.58 3.75 3.31	2.00 1.67 1.50	1.47 1.21 1.06
plant and equipment	time cost quality	6 04 5.41 3.50	2.50 2.33 1.50	1.94 1.74 1.12	3.82 2.61 1.72	1.67 1.17 0.67	1.23 0.84 0.55
technical personnel	time cost quality	4.77 4.45 3.94	2.17 1.83 1.67	1.53 1.43 1.27	3.94 3.94 3.31	1.83 1.67 1.50	1.27 1.27 1.06
ability	time cost quality	7.63 6.68 6.68	3.33 3.00 2.83	2.45 2.15 2.15	3.82 3.18 3.50	1.67 1.33 1.50	1.23 1.02 1.12
past performance	time cost quality	7.06 5.15 5.91	3.17 2.17 2.67	2.27 1.66 1.90	4.90 3.62 3.62	2.17 1.67 1.67	1.57 1.16 1.16
project management organization	time cost quality	6.68 4.77 5.21	3.00 2.00 2.17	2.15 1.53 1.68	5.28 3.62 3.31	2.33 1.67 1.50	1.70 1.16 1.06
management personnel	time cost quality	7.63 4.96 4.77	3.33 2.17 2.17	2.45 1.59 1.53	4.26 4.13 3.75	2.00 1.67 1.67	1.37 1.33 1.21
management knowledge	time cost quality	6.04 5.41 5.41	2.67 2.33 2.33	1.94 1.74 1.74	3.82 3.94 3.12	1.67 1.67 1.33	1.23 1.27 1.00
safety	time cost quality	2.48 1.84 0.25	1.17 0.83 0.17	0.80 0.59 0.08	1.84 1.53 0.57	0.83 0.67 0.17	0.59 0.49 0.18
experience modification rate	time cost quality	2.16 2.16 1.08	1.00 1.00 0.33	0 69 0.69 0.17	1.34 1.34 0.70	0.50 0.50 0.33	0.43 0.43 0.22
occupational housing rate	time cost quality	2.54 1.59 0.00	1.17 0.67 0.00	0.82 0.51 0.00	1.78 1.46 0.06	0.67 0.67 0.00	0.57 0.47 0.02
management safety accountability	time cost quality	0.70 0.70 0.64	0.33 0.33 0.33	0.22 0.22 0.20	0.00 0.00 0.38	0.00 0.00 0.22	0.00 0.00 0.12
past failures	time cost quality	4.77 6.99 5.09	2.00 3.00 2.17	1.53 2.25 1.63	5.02 3.82 3.82	2.17 1.67 1.67	1.61 1.23 1.23
length of time in business	time cost quality	2.86 1.91 3.18	1.33 0.83 1.33	0.92 0.61 1.02	2.16 3.12 2.80	1.00 1.33 1.33	0.69 1.00 0.90
client/contractor relation	time cost quality	3.82 6.04 4.13	1.67 2.67 1.83	1.23 1.94 1.33	3.75 3.31 2.16	1.67 1.50 1.00	1.21 1.06 0.69
other relations	time cost quality	4.77 5.09 3.82	2.17 2.17 1.67	1.53 1.63 1.23	3.82 3.18 2.86	1.67 1.33 1.17	1.23 1.02 0.92

Table 7.2: 90% confidence intervals of standard deviation values

Contractor Selaction Criteria	Expected value
(a) Time	
Past failures	113
Management Personnel	112
Financial status	112
Bank arrangements	111
Ability	111
Management Knowledge	111
Project management organization	110
Experience	110
Other relations	110
Past performance	109
(b) Cost	
Past failures	114
Financial status	111
Credit rating	110
Experience	110
Financial stability	108
Ability	108
Bank arrangements	108
Management personnel	108
Other relations	108
Client/contractor relationship	107
(c) Quality	
Past failures	89
Financial status	90
Technical personnel	91
Ability	92
Past performance	92
Management Knowledge	92
Management personnel	92
Project management organization	92
Experience	93
Financial stability	93

Table 7.3: Rank order of the 10 criteria with largest expected values

Contractor Selection criteria	Expected value
(a) Time	
Management safety accountability	102
Experience modification rate	102
Length of time in business	102
Safety performance	103
occupational housing rate	103
Client/contractor relationship	105
Credit rating	107
Financial stability	108
Technical personnel	109
Plant and equipment	109
(b)Cost	
Management safety accountability	102
Occupational housing rate	102
length of time in business	102
Safety performance	102
Experience modification rate	102
Plant and equipment	106
Management Knowledge	106
Technical personnel	107
Past performance	107
Project management organization	107
(c) Quality	
Management safety accountability	100
Safety performance	100
Occupational housing rate	100
Experience modification rate	99
Plant and equipment	97
Client/contractor relationship	96
Length of time in business	96
Credit ratings	95
Bank arrangements	95
Other relations	93

Table 7.4: Rank order of the 10 criteria with lowest expected values

Table 7.3 presents the CSC that had the highest expected effect ranked in decreasing order for each of time, cost and quality. The highest common risk contractor selection criterion observed in all three PSF is the "past failures" of the contractor. Thus, it can be concluded that this criterion is very important and should be applied when performing prequalification or in the evaluation stage of tenders. "Financial status" is the second highest risk decision factor for all PSF. Other risk decision criteria that are among the highest 10 CSC in all the PSF are the "ability" of the contractor, "management personnel" and "experience".

In further comparison of the three PSF groups it is interesting to note their commonalities. For example "bank arrangements" is considered to be an important factor for time and cost. Although this criterion is not in the top 10 for quality, it received 95% expected value and it is viewed as a significant factor for quality. "Management knowledge", "project management organization", and "past performance" are indicated as important risk decision criteria for time and quality as they appear in the top 10 list for each of these PSF and receiving about 110% for time and 92% for quality. These same three CSC scored only 107% for cost and appear in the list of the lowest 10 CSC in Table 7.4. The "Other relations" criterion is considered important for time and cost and is the lowest in quality list indicating the criterion to be also considered important for quality. "Financial stability", on the other hand, seems to have a moderate effect on cost and quality.

"Credit ratings" from subcontractors and suppliers and "owner/contractor relationships" are the only CSC to appear in the top 10 questionnaire items for cost. This result reflects the emphasis placed on these two CSC on reducing the cost risk and in achieving the bid price set for the project. "Technical personnel" is the only criterion that appears in quality indicating the importance placed on the technical personnel in achieving the quality standard.

7.4.4. Lowest rated CSC by expected values

Table 7.4 gives the 10 questionnaire CSC that had the lowest expected values ranked in ascending order for each group. The only one criterion agreed upon that comes at the top of the list as having a small effect on time and cost and no effect on quality is "management safety accountability". The other two CSC that have a small effect on time and cost and no effect on quality are the "safety performance" and "occupational housing rate". "Experience modification rate" has a small effect, from 1 to 2%, on the three project objectives. It can be concluded that these four CSC, which all are related to the safety issues, are not important and all are considered to have a small to no effect on time, cost and quality. This conclusion is substantiated by the fact that none of the interviewees had experienced, directly or indirectly, these CSC as causing any problems in terms of time, cost and quality although it is of course a legal requirement that contractors should provide the necessary safety policy. Despite the high cost associated with selecting an unsafe contractor (*cf.*, Samelson, *1982; Russell, 1992, referring to Business Roundtable, 1982b),* safety issues are clearly still not regarded as important criteria that might affect the progress and budget of the work.

"Length of time in business" appears in the list for the three objectives and it has a small effect on time and cost (2%) and with a moderate effect on quality (4%). " Plant and equipment" was found to have a high effect (9%) on time, but a moderate (6%) to small (3%) effect on cost and quality. This indicates the importance of plant and equipment being available at any time needed to avoid delays on project time schedules.

In further comparing the three groups it is interesting to note their commonalities. The "owner/contractor relationship" criterion appears in the list of the lowest expected values for time and quality and also at the bottom of list in the highest expected values for cost, with a moderate effect on cost and time (7%) and little effect on quality (4%). "Credit ratings" has a moderate effect on time (7%) and quality (5%) indicating the importance of investigating the relationship between main contractors and subcontractors/suppliers in terms of payment and honesty, confirming the findings of Birrell (1985) and Cheetham and Lewis (1993). The three PSF are affected moderately by the "technical personnel" criterion as it appears in the lowest 10 list for time and cost (with 9% and 7%) and in the highest 10 list (with 9%) for quality indicating the criterion lies in the middle for the three PSF and with an almost equal effect.

In contrast, in the lowest expected value list, there are some CSC that appear against one of the project objectives but not others. "Financial stability", with a moderate effect of 8%, appears in the time list only. "Management knowledge", "Past performance" and "Project management organization", which all are related to the management capabilities of the contractor, appear in the lowest expected value cost list only, having a moderate effect (6% to 7%) but in the highest list, with a highly moderate effect from 8 to 10%, for time and quality. "Bank arrangements" and "other relations" appear in the quality list only but with little effect.

7.4.5 Highest rated CSC by variance values

The 10 CSC that have the largest and smallest variance values are presented in Tables 7.5 and 7.6. The variance values in the two lists range from 0 to 15. For the sake of consistency in the explanation and comparison between CSC in the two lists, variance values from 0 to 5 are considered to be very small to small, 5.1 to 10, moderate to high moderate and 10.1 to 15, high to very high.

Contractor Selection Criteria	Variance value
(a) Time	
Financial status	13.44
Management personnel	11.11
Ability	11.11
Experience	10 00
Past performance	10.00
Bank arrangements	9.00
Project management organization	9.00
Credit rating	9.00
Management knowledge	7.11
Financial stability	7.11
(b) Cost	
Credit rating	10.0
Past failures	9 00
Financial stability	9 00
Ability	9 00
Experience	8.00
Financial status	7.11
Client/contractor relationship	7.11
Plant and equipment	5.44
Management knowledge	5.44
Bank arrangements	4.69
(c) Quality	
Ability	8 00
Past performance	7 11
Experience	6 25
Past failures	4 69
Project management organization	4 69
Management personnel	4.69
Financial stability	4.69
Management knowledge	4.44
Financial status	4.00
Credit rating	4.00

Table 7.5: Rank order of the 10 criteria with largest variance values

Contractor criteria	Variance value
(a) Time	
Management safety accountability	0.11
Experience modification rate	1.00
Safety	1.36
Occupational housing rate	1.36
Length of time in business	1.78
Client/contractor relationship	2.78
Past failures	4 00
Technical personnel	4.69
Other relations	4.69
Plant and equipment	6.25
(b)Cost	
Management safety accountability	0 11
Occupational housing rate	0.44
Safety performance	0.69
Experience modification rate	0.69
Length of time in business	1.00
Technical personnel	3 36
Project management organization	4.00
Other relations	4.69
Past performance	4 69
Management personnel	4.69
(c) Quality	
Occupational housing rate	0 00
Safety performance	0 03
Management safety accountability	0 11
Experience modification rate	0 11
Length of time in business	1 78
Plant and equipment	2 25
Bank arrangements	2 25
Other relations	2 78
Technical personnel	2 78
Client/contractor relation	3 36

Table 7.6: Rank order of the 10 criteria with lowest variance values

Table 7.5 presents the CSC with the highest variance values ranked in decreasing order for time, cost and quality. In this list, six common CSC appears in the top 10 for time, cost and quality with "Financial status" being the major risk variance factor with a very high (13.44) effect on time but only a moderate and small effect on cost and quality. The second criterion with a relatively high degree is "ability" which ranges from high, high moderate, and high moderate for time, cost and quality respectively. "Experience" takes the third place and it ranges from high moderate, high moderate and moderate for the three PSF. The other three CSC that appear in all three PSF are "credit rating", "management knowledge" and "financial stability" with the results indicating that time and cost are affected by "credit ratings" (9% and 10%) while quality scored 4% only. "Management knowledge" is important for time but has a small effect on cost and quality while "financial stability" is considered to have a moderate effect on time and cost and a relatively small effect on quality. *Thus, it can be concluded that the most dominant CSC* in terms of variance values that affect PSF are "financial status", "credit rating" and "financial stability" which all related to the financial soundness of the contractor, in addition to the technical CSC of "experience" and "ability", followed by that of "management knowledge".

In a further comparison of the three groups, it was found that some CSC are common to two PSF with different degree of importance. Table 7.7 shows these CSC and their degrees of effect in different PSF. This indicates that the management CSC ("management personnel", "past performance", "project management organization") are important for time and quality but not for cost whilst "bank arrangements", which is a measure of the financial soundness of the contractor, is found to be an important factor for time and cost, strengthening the conclusion that financial soundness is very important. "Past failures" is also important for cost and quality but it is interesting to note that none of the safety issues are included in the top 10 list.

PSF	CSC and its effects				
	management personnel	past performance	bank arrangements	project management organizat.	past failures
Time	high	high moderate	high moderate	high moderate	----
Cost	---	------	small	----	high moderate
Quality	small	moderate	-----	small	small

Table 7.7: Effect of CSC on PSF

7.4.6 Lowest rated CSC by variance values

Table 7.6 presents the 10 questionnaire CSC with the lowest variance values, ranked in ascending order for each group. The most common clear CSC at the top of the list for time, cost and quality is the safety CSC, with the four CSC ("safety", "experience modification rate", "occupational housing rate" and "management safety accountability") having a very small (0 to 1.36) effect compared to the others. The "length of time in business" also has a very small (1.78) effect and appears in fifth place for time, cost and quality. "Technical personnel" and "other relations" have a quite a moderate effect (4 to 4.69) on time and cost but with a small effect (2.78) on quality.

The results also showed the "client/contractor relation" and "plant and equipment" to have some effect on time and quality with the technical personnel having a moderate effect on time despite being in the lowest 10. In addition there are some CSC which appear in one of the groups but not in the other, although their effects are small.

Overall, in comparing the CSC for the three PSF, it appears that time is the most sensitive being affected by 3 CSC of a "high" to a "very high" degree, 8 CSC of "moderate" to "high moderate" and 9 CSC of "small" to "vary small". This is followed by cost, which is affected by 9 CSC of "moderate" to "high moderate" and 11 CSC of "small" to "very small" degree. Finally, the quality PSF is affected by only three CSC of "moderate" degree and 17 of "small" to "very small" degree.

7.4.7. Relationships between CSC

Using the expected mean values of the six people interviewed, the correlation coefficients between the twenty CSC listed in the questionnaire were obtained and these are presented in Tables 7.8, 7.9 and 7.10 for time, cost, and quality respectively. The corresponding population correlation coefficient (r) was tested for significance at 0.001, 0.01 and 0.05 levels (*cf.* Spiegel, 1980). The CSC which are statistically significant (ie., where the population correlation coefficient is significantly greater than 0) at 0.001, 0.01, 0.05 are indicated by a, b and c in the Tables.

For ease of interpretation and explanation, the criteria from rows were taken as a base and then this criteria compared with the whole list of CSC from the columns. For example, in Table 7.8, Q3 "bank arrangements" was strongly associated with "experience", Q4 "financial status" was associated with "experience", "ability", and "past performance", Q5 "experience" was associated with "ability" and "past performance", Q6 "plant and equipment" was associated with "management knowledge", Q7 "technical personnel" was associated with "project management organization", Q10 "project management organization" was associated with "management personnel" and "past failures" and Q13 "Safety" with "experience modification rate".

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
Q1	1.00	0.37	0.25	0.01	0.19	-.04	-.11	-.27	0.48	-.31	0.34	-.15	-.69	-.68	-.69	-.25	-.63	-.49	----	-.40
Q2		1.00	0.39	-.30	-.13	-.91	-.06	-.32	-.24	-.70	-.39	-.92	0.20	0.13	0.20	0.56	-.69	-.31	----	-.80
Q3			1.00	0.67	.84[c]	-.22	0.19	0.64	0.65	-.22	-.06	-.19	0.20	0.24	0.34	-.37	-.19	-.83	----	-.67
Q4				1.00	.91[b]	0.45	0.61	.93[a]	.76[b]	0.54	0.53	0.50	0.11	0.24	0.11	-.70	0.49	-.75	----	0.10
Q5					1.00	0.33	0.29	.82[c]	.90[c]	0.20	0.30	0.32	-.05	0.05	0.15	-.79	0.18	-.77	----	-.25
Q6						1.00	0.14	0.32	0.51	0.72	0.63	.88[c]	-.49	-.40	-.34	-.79	0.62	0.08	----	0.69
Q7							1.00	0.51	0.08	.73[c]	0.70	0.18	0.30	0.41	0.09	-.07	0.62	-.51	----	0.39
Q8								1.00	0.58	0.45	0.25	0.50	0.42	0.52	0.30	-.53	0.50	-.63	----	0.09
Q9									1.00	0.16	0.42	0.43	-.44	-.35	-.23	-.91	0.02	-.67	----	-.18
Q10										1.00	.79[c]	0.68	-.02	0.11	-.07	-.40	.92[b]	-.06	----	0.85
Q11											1.00	0.51	-.43	-.30	-.49	-.50	0.50	-.38	----	0.56
Q12												1.00	-.16	-.07	-.40	-.62	0.56	-.03	----	0.72
Q13													1.00	.99[a]	0.63	0.52	0.21	-.08	----	-.05
Q14														1.00	0.62	0.43	0.31	-.16	----	0.02
Q15															1.00	0.18	0.30	0.10	----	-.26
Q16																1.00	-.31	0.37	----	-.13
Q17																	1.00	0.12	----	.77[c]
Q18																		1.00	----	0.38
Q19																			----	----
Q20																				1.00

[a] Significant at 0.001 level [b] Significant at 0.01 level [c] Significant at 0.05 level ------ = undefined

Table 7.8: Correlation coefficient between criteria for time

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
Q1	1.00	0.33	.75[c]	0.69	0.33	-.65	-.25	-.01	0.02	-.09	0.07	-.50	-.58	-.03	-.42	-.57	-.03	-.91	-.11	-.10
Q2		1.00	0.20	0.57	.84[c]	0.01	0.35	0.71	.82[c]	-.14	0.26	0.18	-.45	-.84	-.28	-.40	0.05	-.48	-.26	-.36
Q3			1.00	0.16	0.41	-.90	-.47	-.19	-.07	-.46	-.41	-.83	-.18	0.15	0.03	-.16	-.46	-.52	-.52	-.47
Q4				1.00	0.50	-.19	0.42	0.54	0.38	0.14	0.61	-.01	-.50	-.34	-.38	-.45	0.28	-.81	0.40	0.31
Q5					1.00	-.40	0.46	.75[c]	0.72	-.34	0.20	-.25	-.01	-.53	0.22	0.06	-.32	-.34	-.14	-.23
Q6						1.00	0.23	0.11	0.19	0.46	0.28	.96[a]	-.15	-.41	-.35	-.19	0.54	0.38	0.17	0.14
Q7							1.00	.89[b]	0.65	0.37	.82[c]	0.36	0.37	-.41	0.37	0.39	-.12	0.18	0.71	0.63
Q8								1.00	.90[b]	0.26	.73[c]	0.31	0.12	-.71	0.20	0.13	-.20	-.06	0.37	0.30
Q9									1.00	0.30	0.58	0.40	-.07	-.91	0.01	-.10	-.28	-.07	0.01	0.00
Q10										1.00	.76[c]	0.61	-.01	-.32	-.18	-.16	-.09	0.15	0.53	0.67
Q11											1.00	0.48	0.02	-.45	-.03	-.04	-.01	-.11	.77[c]	.78[c]
Q12												1.00	-.23	-0.6	-.40	-.29	0.44	0.25	0.22	0.21
Q13													1.00	0.40	.96[a]	.98[a]	-.61	.79[c]	0.33	0.37
Q14														1.00	0.35	0.43	-.01	0.18	0.17	0.19
Q15															1.00	.97[a]	-.69	0.64	0.24	0.25
Q16																1.00	-.52	-.7[c]	0.32	0.32
Q17																	1.00	-.34	0.11	-.04
Q18																		1.00	0.09	0.16
Q19																			1.00	.97[a]
Q20																				1.00

[a] Significant at 0.001 level [b] Significant at 0.01 level [c] Significant at 0.05 level

Q1=Financial stability
Q2=Credit rating
Q3=Bank arrangements
Q4=Financial status
Q5=Experience;
Q6=Plant and equipment
Q7=Technical personnel
Q8=Ability
Q9=Past performance
Q10=Project management organization
Q11=Management personnel
Q12=Management knowledge
Q13=Safety
Q14=Experience modification rate
Q15=Occupational housing rate
Q16=Management safety accountability
Q17= Past failures
Q18=length of time in business
Q19=Owner/contractor relationship
Q20= Other relations

Table 7.9: Correlation coefficient between criteria for cost

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20
Q1	1.00	0.70	-.04	0.70	0.16	0.58	0.40	0.14	-.23	-.03	0.52	-.08	-.44	-.22	—	0.70	0.27	0.46	0 41	0.47
Q2		1.00	0.43	0.25	0.21	0.17	-.16	-.21	-.02	-.64	0.12	-.55	-.63	-.40	—	0.25	-.09	0.64	0.28	0.19
Q3			1.00	-.03	.75[c]	-.42	-.11	0.33	.83[c]	-.26	0.33	-.03	-.55	0.20	—	-.03	0.29	.81[c]	0.50	0.27
Q4				1.00	0.21	0.17	0.28	0.57	0.03	0.19	.81[c]	0.16	-.63	-.10	—	1.0[a]	0.23	.36[c]	0.28	0.19
Q5					1.00	0.13	0.42	.77[c]	0.9[b]	0.23	0.61	0.22	-.42	0.16	—	0.21	.76[c]	.88[c]	.92[b]	0.50
Q6						1.00	0.65	0.13	-.26	0.32	0.10	0.01	0.22	-.28	—	0.17	0.45	0.10	0.50	0.39
Q7							1.00	0.52	0.14	.84[c]	0.58	.74[c]	0.32	0.50	—	0.28	0.9[b]	0.21	0.68	.84[c]
Q8								1.00	0.71	0.57	.82[c]	0.47	-.36	0.19	—	0.57	0.72	0.53	0.70	0.33
Q9									1.00	0.15	0.46	0.22	-.39	0.25	—	0.03	0.55	0.71	0.66	0.25
Q10										1.00	0.49	.91[b]	0.49	0.65	—	0.19	.74[c]	-.14	0.36	0.56
Q11											1.00	0.55	-.48	0.36	—	.81[c]	0.68	0.59	0.63	0.59
Q12												1.00	0.42	.90[b]	—	0.16	0.69	-.08	0.27	0.66
Q13													1.00	0.42	—	-.63	0.09	-.07	-.26	0.14
Q14														1.00	—	-.10	0.51	-.05	0.13	0.65
Q15															—	—	—	—	—	—
Q16																1.00	0.23	0.36	0.28	0.19
Q17																	1.00	0.52	.88[c]	.84[c]
Q18																		1.00	.81[c]	0.46
Q19																			1.00	0.69
Q20																				1.00

[a] Significant at 0.001 level [b] Significant at 0.01 level [c] Significant at 0.05 level — = undefined

Table 7.10: Correlation coefficient between criteria for quality

7.5 SUMMARY AND CONCLUSIONS

In order to invite suitable bidders it is necessary to clarify and develop appropriate pre-determined contractor selection criteria (CSC), improve and organise the assessment of information relating to these, and develop methods for evaluating them against various project success factors (PSF) in the prequalification and bid evaluation stages of the procurement process. Data were collected from interviews with a sample of six experienced construction professionals concerning their views on the effect of the twenty contractor CSC on the three PSF of time, cost, and quality. Following a Delphi round and further interviews with two additional experienced construction personnel in which it was confirmed that the mean values received were sufficiently representative to become values for further research and any future systems development.

The results of the research indicate that "past failures, financial status, financial stability, credit ratings, experience, ability, management personnel, management knowledge" are considered to be the most dominant CSC affecting all three PSF with safety CSC (safety, experience modification rate, occupational housing association, management safety accountability) and the length of time in business being considered to have the least effect overall. It was also found that some CSC, such as "past performance, bank arrangements, project management organization, plant and equipment", are considered to affect only one or two PSF.

The results presented provide an insight into how time, cost, and quality are differently affected by contractors' capabilities in terms of different CSC. This can aid clients in reviewing their current prequalification procedures and provide them with suggestions for changes in tender evaluation stage if priority is not always to be given to the bid price. The major benefits of this study is a documented identification of the effect that various CSC have on project objectives, and also to provide a quantitative technique for contractor selection in terms of their own goals either for prequalification or bid evaluation.

The following chapter 8 will discuss how to combine the effect of the whole set of CSC on the PSF in terms of time, cost and quality.

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8. ASSESSMENT AND EVALUATION OF CONTRACTOR DATA AGAINST CLIENT GOALS USING PERT APPROACH

CHAPTER 8

Assessment and evaluation of contractor data against client goals using PERT approach

8.1 INTRODUCTION

In order to reduce the risk of appointing an inappropriate contractor, practical steps need to be taken to assess the likelihood of the selected contractor being able to execute the assigned project in accordance with the project objectives.

The current practice of prequalification involves a screening procedure based on a set of prequalification criteria. The **prequalification criteria** currently in use which were described in chapters 3 and 5 (eg financial capacity of contractors), however, are only indirect measures which are likely to determine contractor performance in meeting **project objectives** (ie time, cost and quality **of the project**)

It is important, therefore, that the effect of prequalification criteria on the predominant project objectives is known for the prequalification process to be logically complete. Unfortunately, this does not seem to be the case in practice, and may account for the neglect of potentially relevant information concerning bidders in the later bid evaluation stage.

One reason for this may be the long standing confidence attributed to pre-selection and final selection procedures which discriminate predominantly on the cost elements of tenders (Holt *et al*, 1994). Another possibility is the lack of postconstruction evaluation of contractors in practice (Akatsuka, 1994) which limits the amount of data available for predicting the likely performance of contractors. A further factor may be that clients do not feel that prequalifying contractors is important enough to warrant the expenditure involved (Russell *et al*, 1992).

Solutions to this problem have been offered by several researchers by way of improved methodologies for evaluation of contractors (eg., Holt *et al*, 1994; Herbsman and Ellis, 1992; Ellis and Herbsman; 1991; Russell and Ahmad, 1990; Hardy, 1978; Vorster, 1977) but all fail to link contractors' capabilities directly to client goals. What is needed is a means of choosing an appropriate contractor with the overall capabilities to achieve client goals. This implies the existence of an evaluation strategy that involves the consideration of both the client goals as **ends** and prequalification criteria as the **means**, and is the key to optimum, appropriate and fair contractor selection for standing or project lists in prequalification.

This chapter describes research aimed at developing such a strategy by means of a mathematical model based on the PERT approach. The PERT methodology was chosen in order to permit the uncertainty in contractor data to be quantified. The results of interviews with a sample of construction professionals are presented, in which the importance of different criteria in the contractor selection process was investigated. A method of evaluating and selecting an appropriate contractor is then proposed by means of a lexicographical ordering of aspiration levels and risk analysis with sensitivity methods and which provides a direct indication of the likelihood that a contractor will meet the main client goals in terms of time, cost and quality. The assumptions, advantages, and disadvantages of the proposed techniques as well as an example are also presented.

8.2 CLIENT GOALS

The development of different procurement systems is a result of increased construction complexity, reduced client staff, changes in client needs and increased desire to avoid risks associated with the construction. In reporting a recent survey of current practice, the author suggested in chapters 2 and 5 that all types of procurement arrangements comprise five common process 'elements', or sub-systems. These are *project package*, *invitation*, *prequalification*, *short list* and *bid evaluation*.

For each of these sub-systems there are a variety of actual and possible alternatives available - different types of project packages, invitational forms, prequalification systems, short listing methods and bid evaluation procedures - which provide different combinations of expertise, risk, flexibility and costs (Nahapiet and Nahapiet, 1985).

Despite the variety and alternatives in the sub-systems all procurers have goals that can be described in similar terms (NEDO, 1985). These comprise, to different degrees, the ultimate project goals of *cost*, *time*, *quality*, and associated operational goals including the level of *uncertainty* surrounding the likely cost and time, the *flexibility* to make changes, the allocation of *risks* and responsibilities and the ability of the contractor to cope with the level of *complexity* involved. All procurement systems have different levels and emphases on these goals (Ireland, 1985; Skitmore and Marsden, 1988; Franks, 1990; Curtis *et al*, 1991; Huru, 1992) with different methods of accommodating them. The traditional tendering system of procurement, for instance, aims to achieve these goals by a combination of normative (contractual provisions governing time, quality, flexibility and risk allocation) and competitive (simultaneous identification of cost and contractor by auction) methods.

Cost: Historically, cost is the goal considered to be the most important by clients as most seek value for money. It is from this premise that traditional competitive tendering system arose. One result of this is that cost, measured by the bid price submitted by the contractor, is often regarded as the sole criterion for selection. A large majority of projects, however, end up costing more than the original bid price (Hardy, 1978).

Time: The time to complete the project is scheduled to enable the building to be used by a date determined by the client's future plans and polices. Clients vary in their willingness to employ only those contractors who are able to meet target times. Some contracts include a bonus clause to encourage the contractor to speed up the construction process and to avoid any delays.

Quality: Quality in construction is defined as " the totality of features required by a product or service to satisfy a given need"(BS5750, 1987) and is usually prescribed in project specification documents. It is thought that the implementation of new procurement systems has resulted in a decline in quality in recent years (Hindle and Rwelamila, 1993) and, for this reason alone, quality is regarded as one of the main criteria in contractor selection (Latham, 1994).

Uncertainty: Is a contractor able to finish the project on a scheduled time? Is he committed to the bid price? Is he capable of constructing the project? These questions of uncertainty may, though perhaps not often in practice, be addressed.

Flexibility: How well will a contractor respond to changes in circumstances during the construction process? Is he able to rearrange his programme and schedule accordingly?

Where there is a high expectation of plan changes or other disruptive events in the course of construction, it may be better to select a contractor who can cope best with such changes.

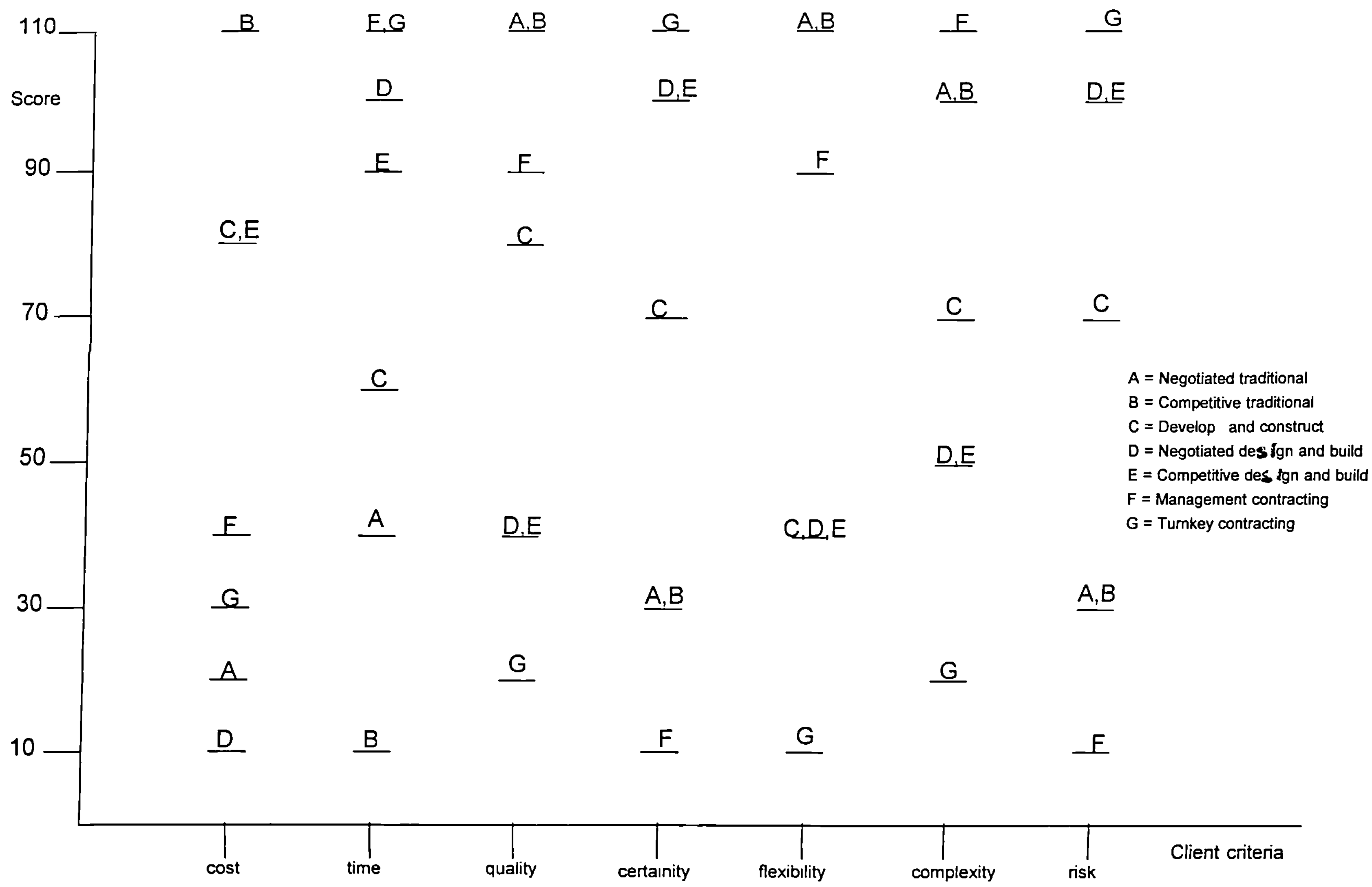
Risk: In the competitive tendering procurement system, if the risk is small, clients are advised to ensure that all bidders understand the risks allocated to them and that they have made appropriate provision in their bids. If the risks are large, clients should consider specifying the proposed allocation of risk in the tender documents and requiring bidders to state their provision for risks in their bids. As Thompson and Perry (1992) pointed out, one of the biggest risks is that the final contract value will exceed the tender amount as there is always the possibility of physical changes to unforseen ground conditions, or design changes,in addition to mistakes made due to the limited time available to prepare bids. All these risk factors and their effect on the whole progress have to be considered and it may be better to select a contractor who best understands the risks involved and will accept responsibility when a loss occurs.

Complexity: Different clients have different needs relating to the complexity of their buildings in terms of level of specialisation, technological advancement or services requirement. The ability to cope with complexity depends on the contractor's degree of familiarity with the technology used in the construction process. Complex forms of construction may be unfamiliar to site staff or require an usually large number of opertational steps to be followed. For this reason, and because of the differences in contractors' experiences in such situations, this attribute is considered by the client for evaluation where there is a highly specialized or advanced technique to be used.

Clients' needs vary according to their differences in emphasis on each of the seven goals described above. For a given client, the emphases vary for each project, depending largely on the type and size of the projects and other issues involving external constraints and conditions (Love and Skitmore, 1995). Fig 8.1 (from Skitmore and Marsden, 1988) shows the relation between the different criteria (goals) and the level of interest or utility of each for different procurement systems. This indicates that competitive traditional contracting (B), develop and construct (C), and competitive design and build (E) to be the systems that are most appropriate when the major emphasis is on the cost of project. Contract arrangements F,G,D,E on the other hand, are more appropriate when the emphasis is on the timing of the project. This indicates that the emphases on the different criteria can be matched with the characteristics of each system to identify the optimum system for the project (Skitmore and Marsden, 1988).

An important aspect of procurement system selection by this means is that there is a much greater variety of client criteria scores (each criteria having a range of scores from 1 to 20, ie., 7^{20} total possible permutations of criteria scores) than there are procurement systems available. Thus one procurement system will be optimal for a range of criteria scores. In other words, the procurement system alone is not sufficient to guarantee that the client goals are met as it almost certainly will not exactly match the client and project needs. Furthermore, procurement selection by Skitmore and Marsden's (1988) approach is necessarily based on an aggregation of perceptions of what is likely to be achieved and does not take into account the performance characteristics of individual contractors.

The problem then is to devise a method of assessing individual contractors' performance characteristics in such a way that they can be compared directly with the client's goals.



• Source Skitmore and Marsden 1988

Fig 8.1 Scoring of client criteria in different procurement systems

For the purposes of this study, only the client ultimate goals (ie time, cost and quality) were considered as, collectively, these alone are both necessary and sufficient to provide the solution required. The status of the operational goals (eg level of uncertainty, flexibility to make changes, risk allocation, ability of contractor to cope with the project complexity), is less certain because they are neither universally necessary (they are not always present) nor sufficient (the list given here is not comprehensive). Thus, although it is an empirical fact that the pursuit of operational goals often contributes substantially to the realistic achievement of the ultimate goals, they are subsumed within the theoretical framework provided by the ultimate goals.

8.3 CONTRACTOR SELECTION CRITERIA

Several researchers (Holt *et al*, 1994; Russell *et al*, 1992; Ng, 1992) have identified different criteria in use for contractor selection. In chapter 3 and 5, the author found that all clients use what are implicitly the same **type** of criteria, but vary in the way they quantify the criteria, with most having to resort to a very subjective assessment based on information provided by the contractors. As a result, the author proposed in chapter 3 (Tablt 3.10) an explicit set of criteria which subsumes all the criteria identified previously and arranged to facilitate a more objective assessment of contractors both in prequalification and bid evaluation. This is summarised in Table 8.1 and comprises five **main criteria** relating to the contractors' *Financial* soundness **(F)**, *Technical* abilities **(T)**, *Management* capabilities **(M)**, *Safety* performance **(S)**, and *Reputation* **(R)**. The main criteria are subdivided into further **subcriteria**, which are intended to be the main source of assessing the main criteria.

Financial Soundness (F)	1. Financial stability 2. Credit rating 3. Banking arrangements and bonding 4. Financial status
Technical Ability (T)	1. Experience 2. Plant and Equipment 3. Personnel 4. Ability
Management Capability (M)	1. Past performance and quality 2. Project management organization 3. Experience of technical personnel 4. Management Knowledge
Health and Safety (S)	1. Safety 2. Experience Modification Rating (EMR) 3. Occupational Safety and Housing Adminstration OSHA Incidence rate 4. Management safety accountability
Reputation (R)	1. Past failures 2. Length of time in business. 3. Past client/contractor relationship 4. Other Relationships

Table 8.1: The main and source of criteria for contractor prequalification.

Clearly, the degree of emphasis on each criterion will depend on the circumstances and specifics of the project as well as the preferences of the decision makers and their different experiences. This will, of course, be reflected in the weights attached to the criteria and is expected to vary from project to project or, in the case of prequalification for standing lists, across a range of types and sizes of projects.

8.4 CURRENT EVALUATION STRATEGIES

Before proposing a methodology for evaluation a brief review of what was explained in chapters 3 and 4 concerning evaluation strategies will be very helpful. Previous research in the United Kingdom (Merna and Smith, 1990) suggests that most public sector clients use and evaluate different contractors criteria in prequalification and mainly based on the judgement of the individual personnel involved. In bid evaluation, no judgement is necessary as the bid price is the sole factor for selecting the best bidder. Fieldwork studies in prequalification practices in the USA by Russell and Skibniewski (1988) identified several evaluation strategies in use comprising dimensional weighting, two-step prequalification, dimension wide strategy, prequalification formula in addition to subjective judgement. In general, however, the bid price is still the sole criterion used at bid evaluation stage (see Q15 chapter 5).

Additional criteria have been proposed. Ellis and Herbsman (1991), for example, suggest using time as a means of evaluating bids of highway construction contractors. By this method, bidders enter a bid price together with a time to finish the contract, the total combined project bid being converted into cost terms by the formula $CT = C + (R \times T)$ where

CT = Total bid	C = Contractor's bid price
R = Time value of the road user cost	T = Contractor's time bid

In a later paper (Herbsman and Ellis, 1992) they also proposed the consideration of the past performance of contractors as a means of assessing likely quality to be achieved, and past accidents records as a means of assessing safety performance levels, with both of these criteria values being converted into cost terms to simplify comparison between bidders. A further approach by Vorster (1977) and Hardy (1978) considers the bid price as a series of payments to be made by the client over the course of the construction period. A discounted cash flow technique is used in this case to estimate a single cost in the form of a net present value.

From this brief review of previous work in the field it is clear that no current or proposed evaluation strategies fully link client goals with contractors' criteria. Even the most advanced of these utilise only a few of the criteria for which information is available (often collected at considerable expense) and then by a somewhat arbitrary method of conversion into a single cost value. Furthermore, in reducing the bidders' attributes to a single cost value, some information is necessarily lost in the process. Finally, there is also the possibility that there is an **indirect** impact of different contractors' criteria on different client goals. In the next sections, a method is proposed for overcoming these weaknesses.

8.5 ASSESSING CONTRACTORS CRITERIA AGAINST CLIENT GOALS USING PERT APPROACH

8.5.1 Effect of contractors criteria on project objectives using PERT approach

It has been established that current evaluation procedures do not contain direct links between client goals and contractor selection criteria. The procedures therefore assume that, if contractors comply with the selection criteria, they will automatically be capable of meeting the client's goals.

Similarly, the current evaluation procedures also assume that any trade-offs that are made between criteria measures (eg., where some doubt over a contractor's financial position is compensated by a superior technical capability) will be equally valid in terms of the time, cost, quality etc goals affected. In other words, it is assumed that trade-offs between the **means** of production are in one-to-one correspondance with trade-offs between the **ends** of the production process.

To examine the nature of these links between means and ends, an empirical study was made in chapter 7 to investigate the relationship between each of the contractor selection criteria in Table 3.10 and the three predominant client goals of time, cost and quality covered in this study. This was conducted in a series of individual questionnaire interviews with a sample of experienced prequalifiers of clients and construction companies. The object was to obtain quantitative measures of the effect of different levels of each selection criterion on each of the three client goals.

Appendix 8A shows part of questionnaire used in the empirical study in the last chapter. The procedure used was to ask the interviewees for their opinion on the likely outcome of a project if a contractor was rated as (1) low and (2) high on a selection criteria. For example, in investigating the "financial stability" of the contractor the interviewees were asked to consider the case where a contractor who was thought to be financially unstable was selected for a construction project. They were then asked to quantify, in their experience, the likely effect on contract time if such a contractor was employed. As not all such contractors will have the same effect, the interviewees were also asked to give their opinion on the most pessimistic, average and most optimistic time. This procedure was then repeated for the cost and quality goals. The interviewees were then asked to assume a stable contractor to be selected and the process of eliciting the three values for each of time, cost and quality repeated again.

The statistical data collected by this way allow the investigator or analyst to quantify the relationship between each of these different contractor criteria and client goals. The data can also be used to calculate the expected mean and its variance using the Program Evaluation and Review Technique (PERT) approach (a more complete discussion regarding this technique can be found in Loomba, 1978; Harris, 1978; Horowitz, 1967) by employing the common assumption of a Beta distribution to adequately model the data[1]. In other words finding the weighted average of the pessimistic (P), most likely (A) and optimistic (O) obtained by the investigator.

Expected time E[t] $= (P_t + 4A_t + O_t)/6$ **(8.1)**

Expected cost E[c] $= (P_c + 4A_c + O_c)/6$ **(8.2)**

Expected quality E[q] $= (P_q + 4A_q + O_q)/6$ **(8.3)**

The estimated variance is:

$\mathrm{Var}[t] = (P_t - O_t)^2/36$ **(8.4)**

$\mathrm{Var}[c] = (P_c - O_c)^2/36$ **(8.5)**

$\mathrm{Var}[q] = (O_q - P_q)^2/36$ **(8.6)**

To illustrate this approach, an example is offered. Let us take the "financial stability" and "credit rating" criteria. After investigation let us assume that contractor A is financially stable but it is low credit rated. The P, A and O values for the effect of each of these two criteria on time, cost, and quality are shown below.

	-------- Financially stable---------		
	pessimistic	average	optimistic
	P	A	O
Time	110	100	95
Cost	105	100	95
Quality	95	100	110

[1]The Beta distribution is a very common model that is applied *a priori* to subjective data of this kind on account of its general validity, flexibility and ease of use.

------ Low credit -------

	pessimistic	average	optimistic
	P	A	O
Time	120	105	100
Cost	125	110	110
Quality	85	95	100

100 is the desired level for each of the client goals. Thus the estimated average completion time of a "financially stable" contractor in this example, with a score of 100, is predicted to exactly meet the client's time goal. But the contractor is "low credited" and, with an average completion time of 105, is predicted to overrun by 5%. This means the expected mean time for this contractor will be 100+5=105%, a total predicted overrun of 5%.

The expected mean and variance values for time, cost, and quality are calculated from eqns (8.1) to (8.6). For financial stability

$E[t] = (110+4x100+95)/6 = 100.8 \quad Var[t] = ((110-95)/6)^2 = 6.25$

$E[c] = (105+4x100+95)/6 = 100.0 \quad Var[c] = ((105-95)/6)^2 = 2.56$

$E[q] = (95+4x100+110)/6 = 100.8 \quad Var[q] = ((110-95)/6)^2 = 6.25$

and for credit rating

$E[t] = (120+4x105+100)/6 = 106.6 \quad Var[t] = ((120-100)/6)^2 = 10.89$

$E[c] = (125+4x110+110)/6 = 112.5 \quad Var[c] = ((125-110)/6)^2 = 6.25$

$E[q] = (85+4x95+100)/6 = 94.1 \quad Var[q] = ((100-85)/6)^2 = 6.25$

8.5.2 Aggregate expected mean, variance, and standard deviation values of project objectives(Time, Cost and Quality)

Having calculated the expected means and variances of time, cost and quality due to the effect of each criterion, it is necessary to estimate their combined effect. To do this it is first necesary to consider the underlying assumptions of the PERT model which have been considered valid for contractor selection criteria (Russell and Ahmad, 1990) and considered valid for client goals as well. These are that

1 The client goals (time, cost, and quality) for each criterion for each contractor are random variables.

2 The random variables representing the client goals can be converted to a common continuous probability distribution when they added together.

3 The weighted sum of the expected means is the aggregate expected mean of different client goals (AE[t], AE[c], AE[q]) described by a normal distribution whose standard deviation is the square root of the sum of the variances of all the criteria for each contractor.

In the last chapter (7), the author investigated the "relation coefficient" between the different contractor criteria. The population correlation coefficient was found to be significantly greater than zero for only a small number of these criteria. This result substantiates the third assumption of the PERT approach. The central limit theorem was therefore applied to calculate the desired aggregate values.

The weights of the contractor selection criteria are shown in Table 8.2. These weights were obtained through interviews conducted with a sample of four construction professionals experienced in prequalification and bid evaluation. Part of the questionnaire used for this purpose is shown in appendix 8B. Firstly, the interviewees were requested to describe the importance of criteria by giving a weight to the main five criteria, with a total weight of 100. Then, for each of the five main criteria, the interviewees were requested to give weight to the associated subcriteria, with a total weight of 100 for the subcriteria also.

Criteria	Subcriteria	Weight
Financial Soundness (F)	1. Financial stability	0.05175
	2. Credit rating	0.04100
	3. Banking arrangements and bonding	0.04575
	4. Financial status	0.06650
Technical Ability(T)	1. Experience	0.07250
	2. Plant and Equipment	0.03625
	3. Personnel	0.07875
	4. Ability	0.07500
Management Capability (M)	1. Past performance and quality	0.044375
	2. Project management organization	0.040625
	3. Experience of technical personnel	0.046250
	4. Management Knowledge	0.043750
Health and Safety(S)	1. Safety	0.018875
	2. Experience Modification Rating (EMR)	0.016875
	3. Occupational Safety and Housing Adminstration OSHA rate	0.014500
	4. Management safety accountability	0.019750
Reputation (R)	1. Past failures	0.068125
	2. Length of time in business.	0.085000
	3. Past client/contractor relationship	0.086250
	4. Other Relationships	0.048125

Table 8.2: The weights of the twenty criteria

The importance of each one of the subcriteria in the whole process for the twenty criteria was then obtained by multiplying the weight of each main criterion by the weight of its subcriteria, the total weight of the whole set of subcriteria again amounting to 100. The weights obtained here represent the opinion of the four professionals interviewed in this study, and not necessarily be taken as default values.

For example, refering to appendix 8B, the weight of the main criterion "financial soundness" is 0.21 (21%) and the weight of its four associated subcriteria "financial stability" is 0.20 (20%), "credit rating" is 0.20 (20%), "bank arrangements" is 0.20 (20%) and "financial status" is 0.4 (40%). Then the importace of these subcriteria in the whole set of criteria is:

financial stability	= 0.21 x 0.2 = 0.042	credit rating	= 0.21 x 0.2 = 0.042
bank arrangements	= 0.21 x 0.2 = 0.042	financial status	= 0.21 x 0.4 = 0.084

From the assumptions of the PERT approach and findings of the previous chapter, the formulae that are used for calculating the aggregate expected mean, variance and standard deviation are:

$$AE[t] = \text{Sum of } (W \times E[t]) \text{ of all criteria} \quad (8.7)$$
$$Var\,[At] = \text{Sum of } (W \times Sigma[t])^2 \text{ of all criteria} \quad (8.8)$$
$$Sigma\,[At] = Sqrt(Var[t]) \quad (8.9)$$

$$AE[c] = \text{Sum of } (W \times E[c]) \text{ of all criteria} \quad (8.10)$$
$$Var\,[Ac] = \text{Sum of } (W \times Sigma[c])^2 \text{ of all criteria} \quad (8.11)$$
$$Sigma\,[Ac] = Sqrt(Var[c]) \quad (8.12)$$

$$AE[q] = \text{Sum of } (W \times E[q]) \text{ of all criteria} \quad (8.13)$$
$$Var\,[Aq] = \text{Sum of } (W \times Sigma[q])^2 \text{ of all criteria} \quad (8.14)$$
$$Sigma\,[Aq] = Sqrt(Var[q]) \quad (8.15)$$

where AE[t], AE[c] and AE[q] represent the aggregate expected mean of time, cost and quality due to the effect of all criteria, Var[At], Var[Ac] and Var[Aq] represent the variance of the aggregate expected mean of (time, cost, and quality), Sigma[A]t, sigma[Ac] and sigma[Aq] represent the aggregate standard deviation of time, cost and quality and W represents the weight of the criteria.

Assume, from the previous example, that the weights calculated for "financial stability" and "credit rating" are 0.8 and 0.2 respectively (0.8 + 0.2 = 1). Then the aggregate expected mean, variance, and standard deviation values of different client goals for contractor A will be:

AE[t] = (0.8x100.8) + (0.2x106.6) = 101.96
Var[At] = $(0.8x2.5)^2 + (0.2x3.3)^2$ = 4.44
Sigma[At] = Sqrt(Var[At]) = 2.1

AE[c] = (0.8x100.0 + 0.2x112.5) = 102.50
Var[Ac] = $(0.8x1.6)^2 + (0.2x2.5)^2$ = 1.89
Sigma[Ac] = Sqrt(Var[Ac]) = 1.37

AE[q] = (0.8x100.8) + (0.2x94.1) = 99.46
Var[Aq] = $(0.8x2.5)^2 + (0.2x2.5)^2$ = 4.25
Sigma[Aq] = Sqrt(Var[Aq]) = 2.1

Therefore Contractor A is predicted to score the following aggregate expected mean, variance, and standard deviation values for time, cost and quality:

AE[t]=102 Var[At]=4.44 Sigma[At]=2.1
AE[c]=102.5 Var[Ac]=1.89 Sigma[Ac]=1.37
AE[q]=99.46 Var[Aq]=4.25 Sigma[Aq]=2.1

Thus, Contractor A is expected to overrun on time by an average of 2% with a variance of 4.44, overrun on cost by an average of 2.5% with variance of 1.89, and produce a quality below the required standard by less than 1% on average but with a variance of 4.25.

8.6 METHODOLOGY FOR EVALUATION

The following proposed methodology considers the contractor criteria and client criteria (goals). Fig 8.2 shows how the criteria may be assessed against each other. This is illustrated by the following example.

Using the contractors' selection criteria in Table 8.1 and their relevant information, the client managed to investigate and assess the capabilities of all the necessary criteria of the four contractors (A,B,C and D) and how these criteria affect time, cost, and quality using the PERT approach described above. Aggregate expected means, variances and standard deviations for time, cost and quality were also calculated and these are shown in Table 8.3 for all contractors for different client goals. This shows that the maximum expected delay is by contractor D (112-100=12%, SD=2.5), the maximum expected cost overrun is by contractor B (110-100=10%, SD=2.2) and the maximum expected quality below standard is by contactor C (100-92=8%, SD=2.7).

Client goal	Aggregate expected means, variance and standard deviation values of the four contractors				
	parameter	A	B	C	D
Time	AEt	108	102	106	112
	V of(AEt)	4.84	7.84	3.61	6.25
	S of (AEt)	2.2	2.8	1.9	2.5
Cost	AEc	106	110	102	104
	V of (AEc)	3.57	4.84	4.41	3.24
	S of (AEc)	1.89	2.2	2.1	1.8
Quality	AEq	99	98	92	100
	V of (AEq)	4.84	6.25	7.29	4.84
	S of (AEq)	2.2	2.5	2.7	2.2

Table 8.3: Expected mean, variance and standard deviation values for contractors A,B,C,and D in different client goals

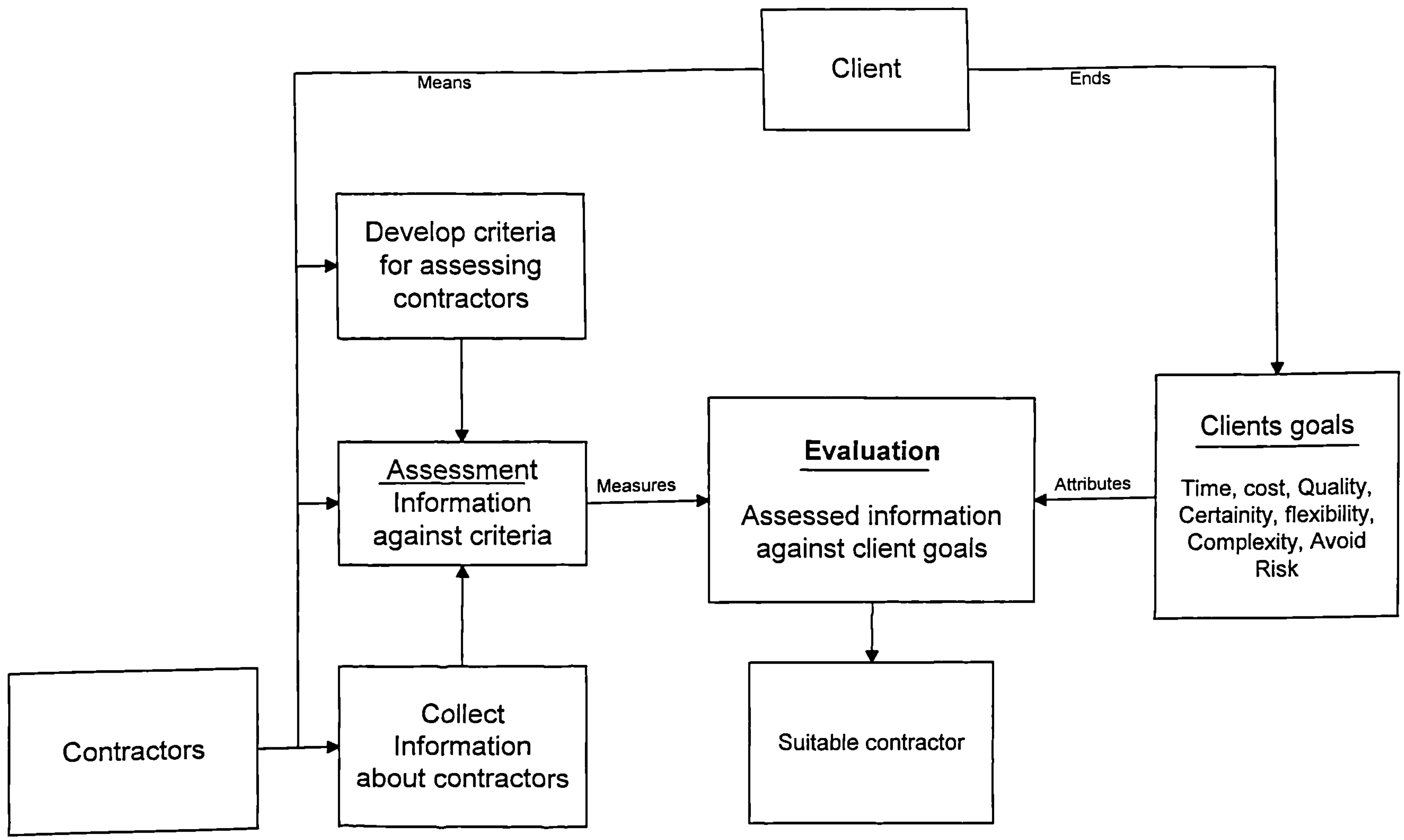


Fig 8.2 Methodolgy for contractor evaluation

Fig 8.3 shows the normal distribution curves of the four contractors in the three attributes time, cost, and quality. For plotting the curves, only aggregate values over or less than 100% are considered. The normal distribution curves can be used to find the probability that any value is less than or equal to a selected value (SMv). This probability is equal to the area under the curve to the left of (SMv). The z values are calculated as follows:

$$z = \frac{\text{selected value (SMv) - calculated aggregate expected mean of T or C or Q}}{\text{aggregate standard deviation of T or C or Q}}$$

from which the area under the normal curve can be obtained by reference to standard statistical tables. For example, the probability that contractor A will delay by 10% or less is derived from z = (10-8)/2.2 = 0.909 from which the area under the curve is 0.8186. Thus the probability that the project carried out by this contractor will be delayed by at least 10% is 81.86%, similarly the probability for less than or equal to 5% delay is 0.0869. Also, the probability that there will be at least a 8% delay is 0.5, ie., a 50-50 chance of an 8% delay. Of course, such predictions can also by made for each contractor and for each of the time, cost and quality factors.

Probabilities can also be obtained for a range of such events. For example, the probability that contractor A will delay between 5 and 8 percent is equal to the probability of an up to 8% delay minus the probability of an up to 5% delay, ie., 0.8186 - 0.0869 = 0.7317.

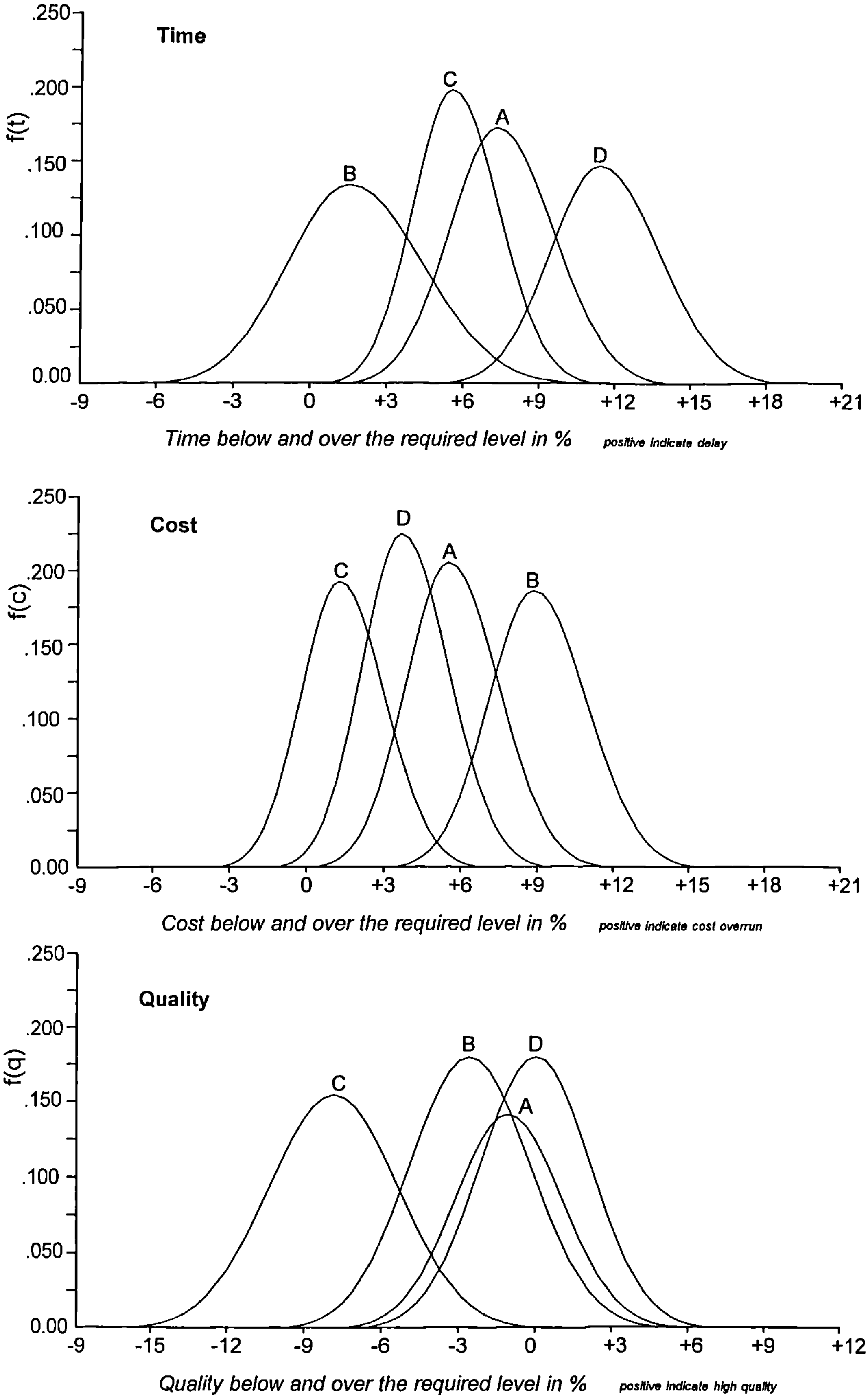


Fig 8.3 Normal distribution curves for contractors A, B, C, and D

8.6.1 Lexicographical ordering with aspiration level

Although the probability curves provide some insight into the expected performance of contractors and also give the range of uncertainty, it is quite difficult to draw any conclusion from these curves for selecting the rank order of the contractors. Analyses can be performed using the aggregate means and variance. For example, a lexicographical ordering with aspiration level decision technique (Keeney and Raiffa, 1993:77) can be used to evaluate and identify the rank order of these four contractors. In this technique, the three client goals are ordered according to their importance.

In our example let us assume that the order of importance is time then cost then quality i.e time is more important than cost and quality and cost is more important than quality for this case. For each attribute (time, cost, quality) an aspiration level is set and the following rules applied:

Contractor A > (preferred to) contractor B whenever the aggregate value of contractor A in the attribute time is greater than the aggregate value of contractor B for the same attribute and the aggregate value of contractor B is less than the aspiration level set by the analyzer for the same attribute. In this case, the attribute time overrides all others as long as its aspiration level is not met. If the aspiration level of time is met by contractor B, then the cost attribute overrides all others as long as the aspiration level of cost is not met and so forth. If all aspiration levels are met, then we may be willing to give up some of the time attribute for a suitably large increase in cost and so on.

In the example of the four contractors A,B,C,D given in Table 8.3, let us assume the aspiration level is set to be the average of the aggregate expected mean and variance values of the four contractors, ie., the aspiration level for expected mean for time is

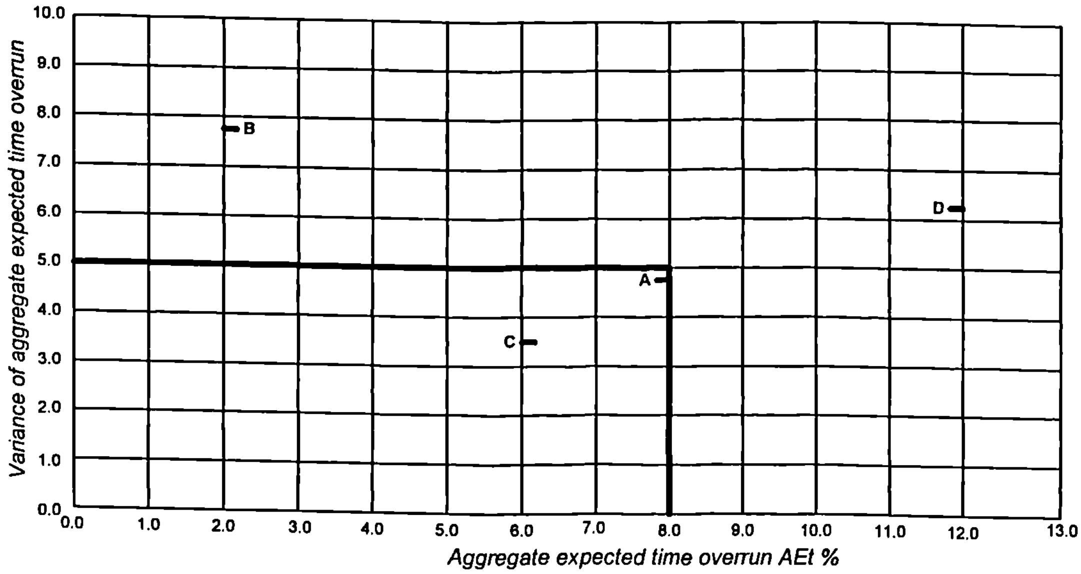
(8+2+6+12)/4 = 7% and the aspiration level for variance for time is (4.84+7.84+3.61+6.25)/4 = 5.635%, in other words the client sets a maximum acceptable delay of 7% of the scheduled time with a variance of 5.635. It is clear that contractor C is the only one that meets the aspiration level of the expected mean and variance for the time attribute. If a different trade-off is made where the expected mean is increased to 8% and variance decreased to 5, in this case contractor A will met the new aspiration level along with contractor C. The aggregate values of both contractors B and D are quite far from the parameters of the reset aspiration level and they either excluded or just ranked in order after contractors A and C.

Now only contractors A and C are to be tested for the cost attribute. In a similar way, the aspiration level for cost is set first by taking the average of the aggregates of the two contractors A and C only in this case. The aspiration level could be set according to the conditions and constraints at hand, the expected mean set not to exceed (6+2)/2 = 4% and variance is (3.57+4.41)/2 = 3.99%, both contractors will not meet the aspiration level, contractor A has an aggregate value higher than the aspiration level in terms of the mean while contractor C is higher in terms of variance. In this case the aspiration level may be reduced by choosing either to reduce the expected mean or the variance bearing in mind that if the mean was reduced the variance should increase and vice versa. If we reduce the mean of the aspiration level to 3% instead of 4% and the variance increases to 4.5, contractor C in this case will meet the requirements and contractor A will be disqualified or ranked as a second. Since only contractor C is left there is no need for investigating the quality.

If both contractors meet the cost aspiration level then the quality attribute has to be checked similarly, bearing in mind that for time and cost the lower the aggregate expected mean value the better while for quality the higher the better and vice versa, but for the variance value the lower the better for the three attributes. If all aspiration levels set by the client for the three attributes are met by the two contractors, we may be willing to give up some of aspiration level of the first attribute for an increase in the second attribute and so on.

Fig 8.4 shows how the aspiration level technique could be used to observe the differences among the contractors and compare their results. This decision technique is mainly based on the order of the importance of the attributes and also on the aspiration levels set for selecting and passing the hurdles.

The problem with this method is that it is assumed that there is some value of variance above which a contractor will not be acceptable **irrespective of the expected (mean) value.** It is not difficult to think of situations where this may be a poor assumption. Consider the case of two contractors, contractor A and contractor B. Contractor A has an expected value of -2% and variance of 9 whilst contractor B has an expected value of 6% with a variance of 1. Following the above example and using an aspiration level of 7% expected value and 5.635 variance, contractor B would be prefered to contractor A on the grounds that contractor A's variance of 9 exceeded the 5.635 limit. However, if we consider the contractors' likely range of values (typically the expected value plus or minus 2 standard deviations) we find the contractor A's range is -8% to +4% with contractor B's range being 4% to 8%. In other words, contractor A will always outperform contractor B! What is needed therefore is some method of ranking the contractors by considering the expected values and variances **simultaneously**.



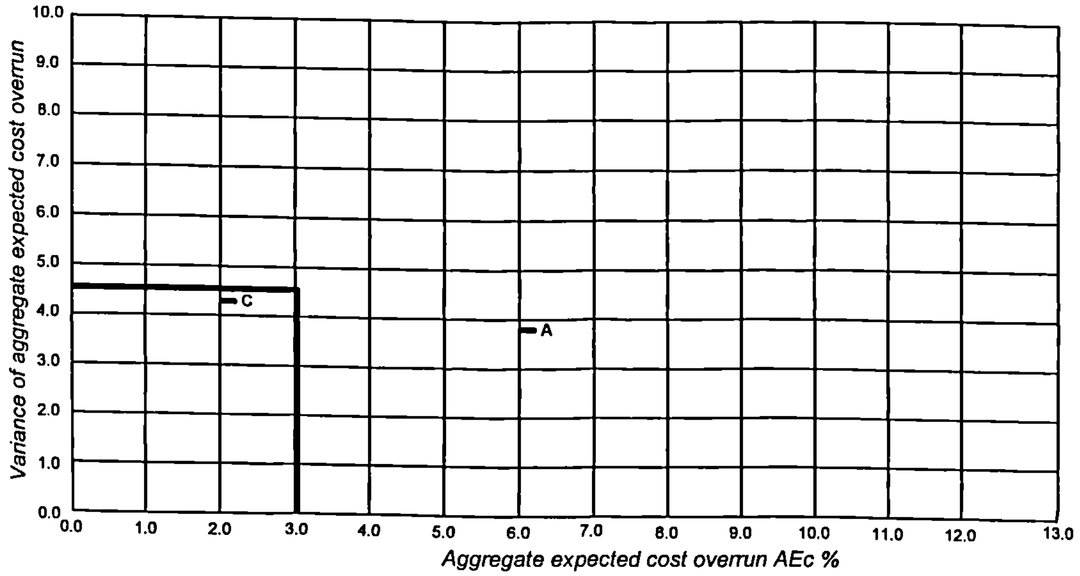


Fig 8.4 Aggregate expected time and cost overrun versus variances for contractors A, B, C and D

8.6.2 Risk analysis technique

One approach to this is to consider the risks involved. What is the probability of a cost overrun, time overrun or quality shortfall for each of the potential bidders? This is equivalent to the area under the normal probability curve at SMv=0. If project cost, time and quality targets are all of equal importance, the smaller the sum of these risks for each contractor the better the contractor. If the cost, time and quality targets are prioritised, then it is the weighted sum of these risks that is important.

This method would avoid the problem described above. Contractor A, with less risk of overrunning, would then be ranked above contractor B with a virtual certainty of overrunning. But consider another example where contractor C has an expected value of 8% with a variance of 25. This contractor has a smaller probability of overrunning than contractor B above and would therefore be ranked second, ahead of contractor B, but will on average overrun by 2% more than contractor B. If the client is intolerant of an overrun beyond, say, 10%, then contractor B must be preferred to contractor C as contractor B has less risk of overrunning beyond 10%. To take this into account in ranking contractors, it is therefore necessary to consider not just the probability of overrunning but the **degree** of likely overrun. The point at which a client becomes intolerant, or **cut-off** point, of an overrun becomes a crucial issue and it is the probability of overruning beyond that point that is now the determining factor in ranking the contractors.

This is illustrated by referring once again to the four contractors in Table 8.3. Assuming, for the sake of simplicity, that cost, time and quality are equally weighted, the rank ordered contractors for a cost, time and quality cut-off of 0% is contractor 4, 2, 1 and 3. This represents the best ordering of contractors based on the criteria of minimum combined risk of overrun on time and cost and substandard quality. When the cost and time cut-offs are 0% and the quality cut-off is 1%, 2% and 3%, the contractor rankings are still 4, 2, 1 and 3. When the quality cut-off is raised to 4%, the positions of the two leading contractors reverse and the rankings become contractors 2, 4, 1 and 3. This ranking holds up to a quality cut-off of 10%, beyond which contractor 3 becomes ranked second with contractors 4 and 1 being thirdly and fourthly ranked respectively.

Holding quality and cost cut-offs at 0%, the contractor rankings change at 2% and 3% time cut-offs to contractors 4, 3, 2 and 1. At the 4 to 6% time cut-offs the rankings change to contractors 4, 3, 1 and 2 and at 7 to 10% time cut-offs to contractors 4, 1, 3 and 2. The full results of this analysis are shown in Fig 8.5 for all percentage increments of time and quality cut-offs between 0 and 20% at 0% cost cut-off. Figs 8.6 and 8.7 give the results for 5% and 10% cost cut-offs respectively. The analysis is easily extended to different time, cost and quality weightings.

Perhaps the most striking aspect of this analysis is the sensitivity of the rankings obtained by this method to slight changes in cut-off values. Ideally, we would hope to find the same optimum ranking for all cut-off values, but this is clearly not the case in this example even though the expected values and variances are quite different between contractors and client goals. Closer inspection however indicates that there are a few consistencies of note. For the 0 and 5% cost cut-offs, for example (Figs 8.5 and 8.6), contractor 1 is never ranked higher than second, irrespective of the time and quality cut offs. As the usual aim in practice is to find the top five or six contractors rather than optimum rankings as shown here and it is possible that, with a much larger set of potential contractors, this top set will be generally quite stable even though the order within the set may change with different cut-offs.

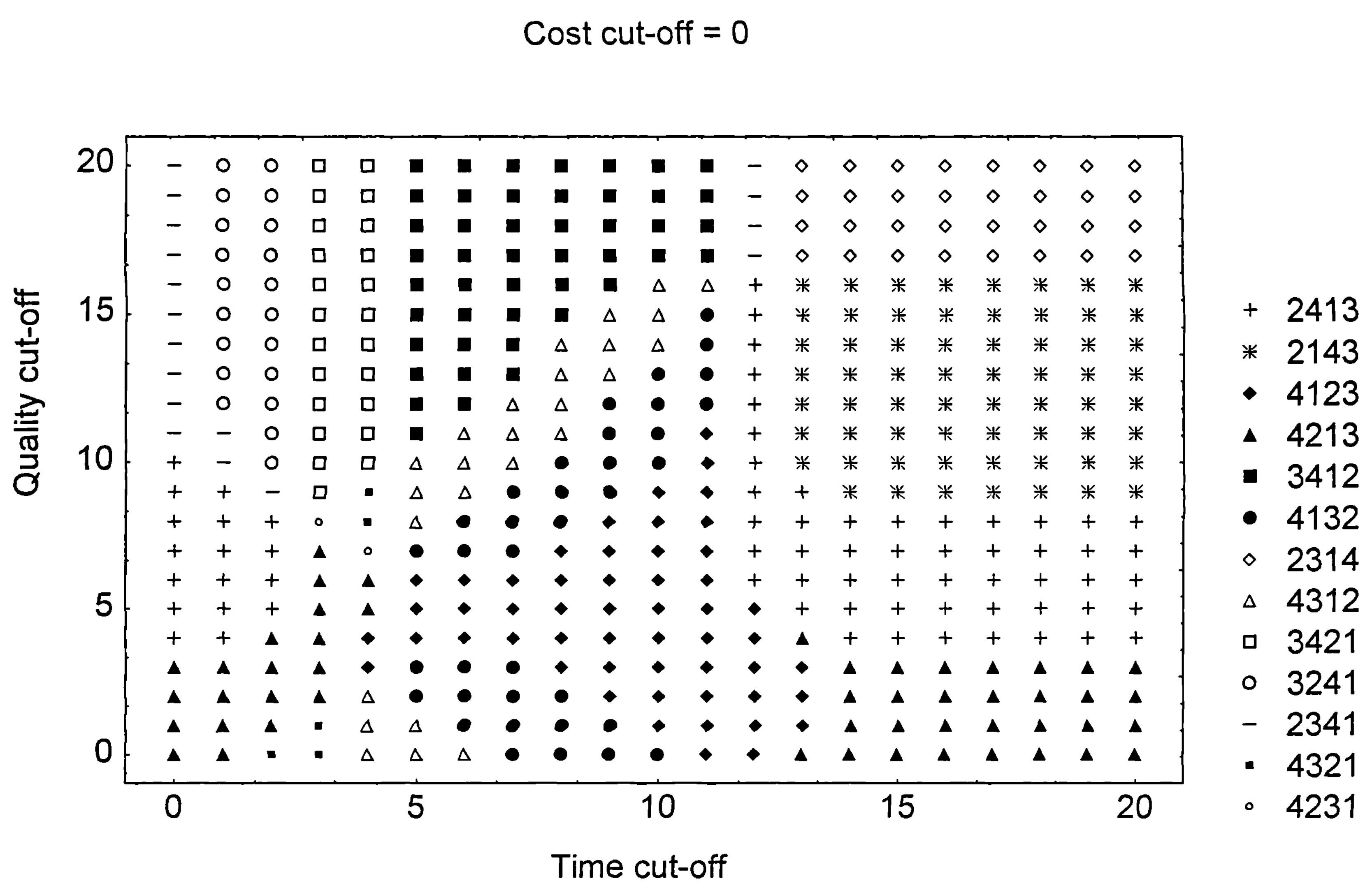


Fig. 8.5 Rank order of contractors A,B,C and D at Cost cut-off=0

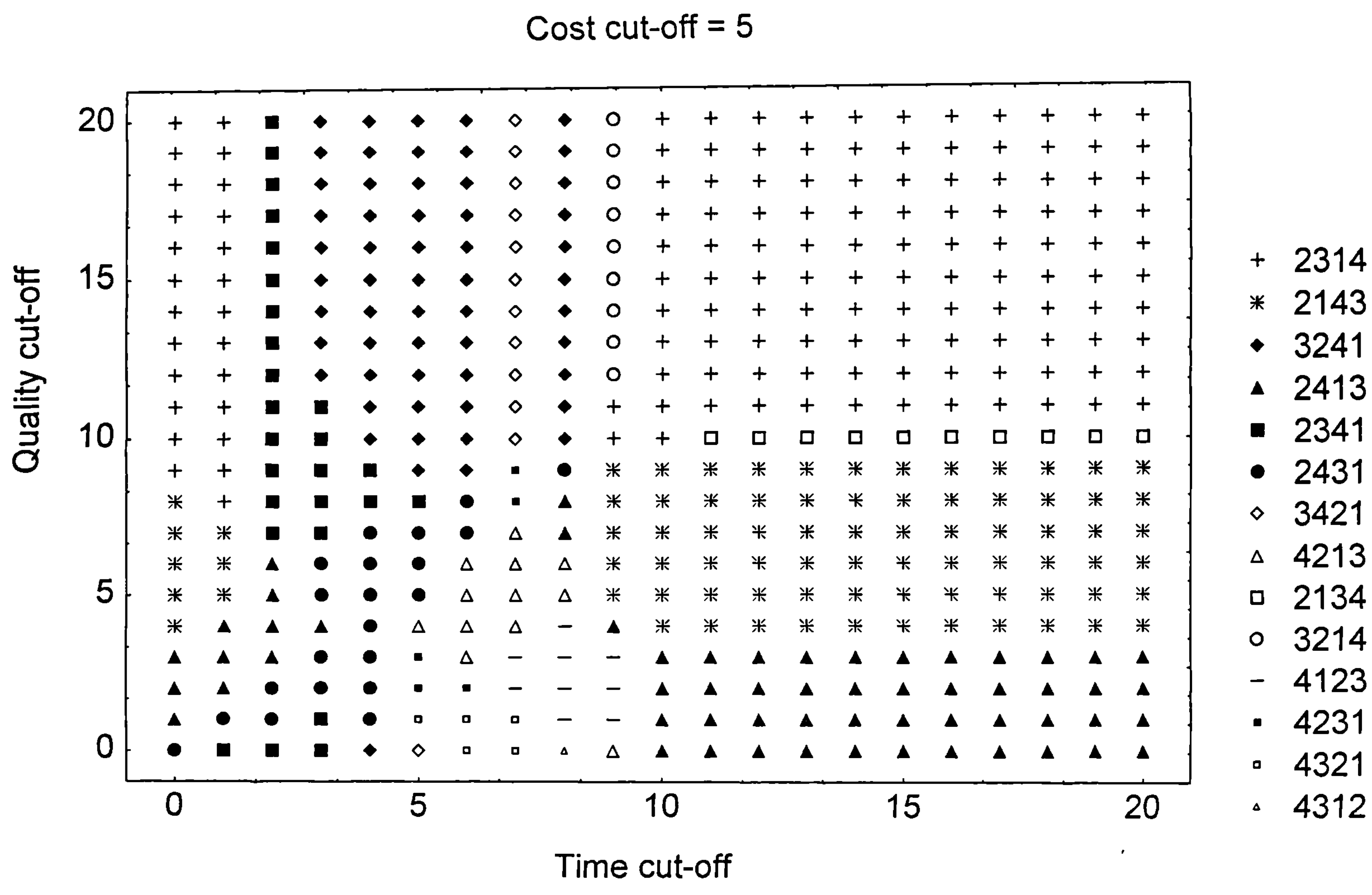


Fig. 8.6 Rank order of contractors A,B,C and D at Cost cut-off=5

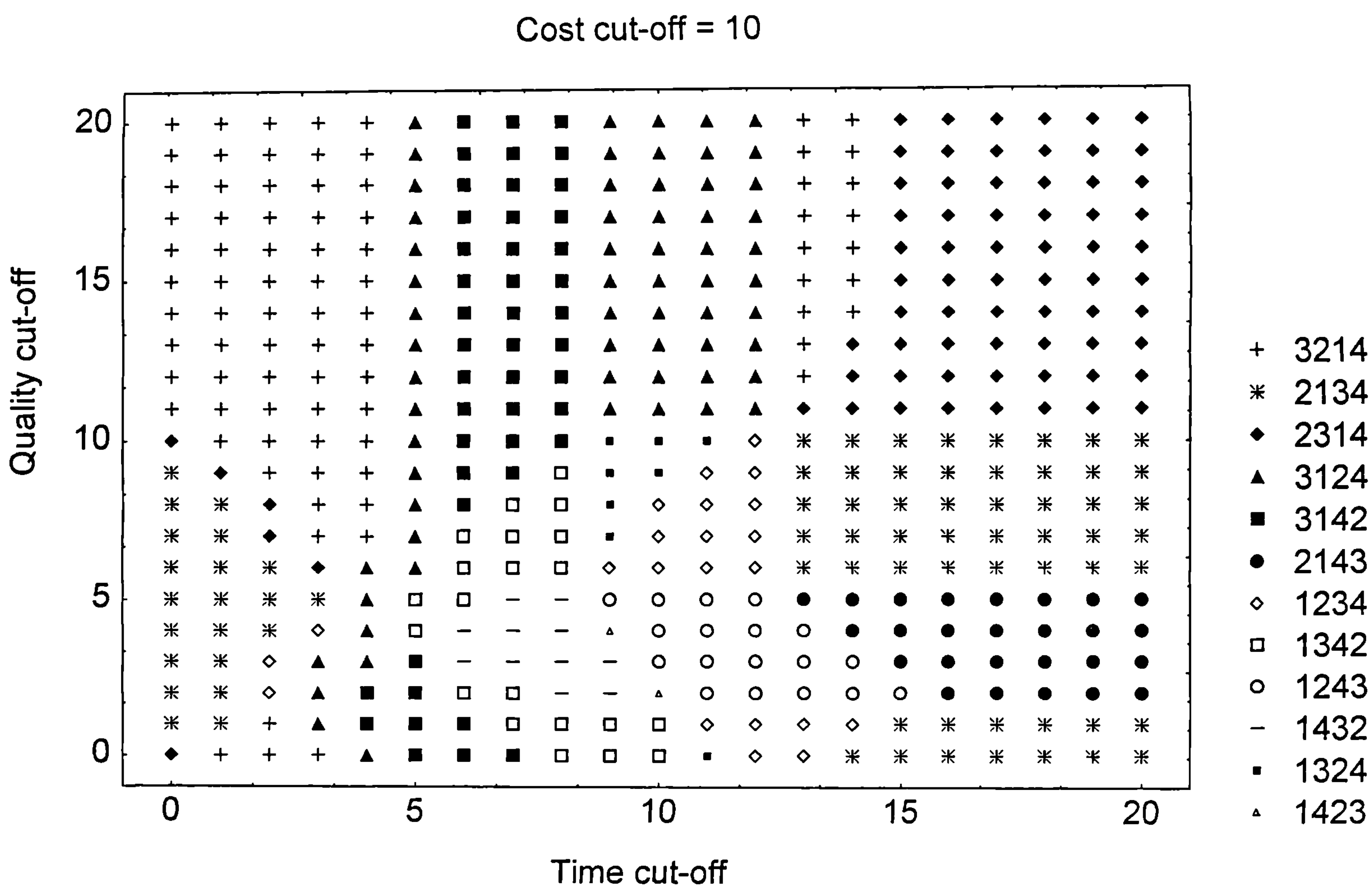


Fig. 8.7 Rank order of contractors A,B,C and D at Cost cut-off=10

8.7 ADVANTAGES, DISADVANTAGES AND LIMITATIONS

Assessment of expected performance of contractors in relation to client goals implies an assumed independence among the contractor selection criteria. The advantage of this approach is that it permits an assessment to be made of the imprecision and/or uncertainty in the contractor data, the contractor data are **directly** evaluated against client goals, and the clients subjective evaluation of the contractors data is formally incorporated into the analysis process. This research is limited to the predominant client goals in terms of time, cost and quality. Other limitations are that the tradeoff in the parameters of the aspiration level for the same attribute and between the aspiration levels between different types of attributes is largely subjective.

It is also important to report here that the three values of the (pessimistic, average and optimistic) ratings for the whole set of criteria for different types of contractors were investigated in chapter 7 and default values were suggested to minimize the effort of assessing the contractors and therefore could be used for this purpose.

8.8 CONCLUSION

This research is based on the premise that selection should concentrate on determining contractor potential for achieving project goals. The major benefit of the work of this chapter is that it provides a means using the PERT methodology to incorporate uncertainty and/or imprecision associated with the assessment of contractors data, all these in terms of the ultimate project goals of time, cost, and quality. The chapter presented a quantitative an evaluation strategy that involves the consideration of both the client goals as ends and contractor data as the means. The strategy of using the aspiration level, risk analysis for the final selection or rank ordering of the contractors is based on the preferences of the client.

Despite of the fact that the study has concentrated on the ultimate project goals of time, cost, and quality, there is suggestion for the inclusion of additional operational to suit alternative procurement forms or types of projects in future. This would be a simple job if the system were computerised.

This work will be extended to the evaluation of contractors by means of multiattribute utility theory. This will be discussed in the following chapter 9.

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9. CONTRACTOR EVALUATION USING MULTIATTRIBUTE UTILITY THEORY

CHAPTER 9

Contractor evaluation using multiattribute utility theory

9.1 INTRODUCTION

From the previous chapter 8 the contractor capabilities was assessed in terms of the three attributes time, cost and quality in a form of normal distribution curves. From some of the examples shown in the last chapter it was found that different contractors might score different levels in the three attributes.

The problem that needs to be solved is how to rank order the contractors by considering the expected mean and variance values of the three attributes simultaneously. This chapter will be devoted to solve this problem using the multiattribute utility theory. In order to apply the utility theory in rank-order the contractors for prequalification , a detailed hypothetical example is offered.

9.2 HYPOTHETICAL EXAMPLE

Using the contractors selection criteria (CSC) and their relevant information, the client managed to investigate and assess the capabilities of all the necessary criteria of four contractors (A,B,C,D) and how these criteria affect the project success factors or attributes (PSF) in terms of time(T), cost(C), and quality(Q) as explained in chapter 7. The aggregate expected mean (AE), variance (V) and standard deviation (S) values for time, cost and quality were also calculated as explained in chapter 8. Table 9.1 shows the aggregate expected mean, variance and standard deviation values for all contractors in different (PSF).

Rank the contractors A, B, C and D in order using multiattribute utility theory ?

Project success factors (PSF)	Aggregate expected means, variance and standard deviation values of the four contractors A, B, C, and D in different (PSF)				
	parameter	A	B	C	D
Time(T)	AEt	108%	103%	107%	102%
	V of(AEt)	4.84	4	4.41	3.062
	S of (AEt)	2.2	2	2.1	1.75
Cost(C)	AEc	106%	108%	102%	104%
	V of (AEc)	3.57	2.89	2.56	3.24
	S of (AEc)	1.89	1.7	1.6	1.8
Quality(Q)	AEq	99%	100%	97%	93%
	V of (AEq)	2.25	1.44	2.89	4
	S of (AEq)	1.5	1.2	1.7	2

Table 9.1 Aggregate expected mean, variance and standard deviation values for contractors A, B, C and D in different project success factors

In Table 9.1 the aggregate expected mean (AE=100%) for time or cost or quality is considered the aggregate expected mean that has to be achieved by the four contractors, therefore any scores over 100% for time is considered as a delay. For example the aggregate expected mean for time (AEt) for contractor A = 108% means a delay of +8%= (108%-100%), while any AEt below 100% indicate finishing before the target time for example a score of 93% indicate a time saving by -7%=(93%-100%). For cost any score over 100% is treated as an expected cost overrun from the contract sum of the project, for example the aggregate expected mean for cost (AEc) for contractor D = 104%, this indicate an expected cost overrun by 4%=(104%-100%), the time and cost attributes are negatively oriented i.e the lower the better, but for quality the higher the better so any score below 100% in this case is considered as an expected low quality. For example the expected mean for quality (AEq) for contractor C=97%, this indicate an expected low quality by -3%=(97%-100%) and vice versa.

Since the risk will arise from contractors scoring above 100% for time and cost and those scoring below 100% for quality, therefore these scores will be the focus of decision. It is necessary to note that a positive sign for time and cost are undesired scores while for quality it represents a good score and vice versa.

Figure 9.1 (a, b, and c) shows the arrangements of how these scores are assessed initially and how the extra values above or below 100% are treated. For example, the time attribute in Fig 9.1 (a) the score 110% correspond to +10% delay, the score 95% correspond to -5% i.e finishing before the target by 5%, the score 100% correspond to 0% which means no delay, Figures 9.1 (b and c) shows the same arrangements for the cost and quality attributes.

Since the values below and above 100% (in other words values above or below 0% see Figures 9.1 a, b, c) shows the expected capabilitie of each contractor above or below the desired level, therefore they are considered as the main decision elements for choosing among the contractors. These values are separated from the 100% in Table 9.1 and given in Table 9.2 along with the variance and standard deviation values.

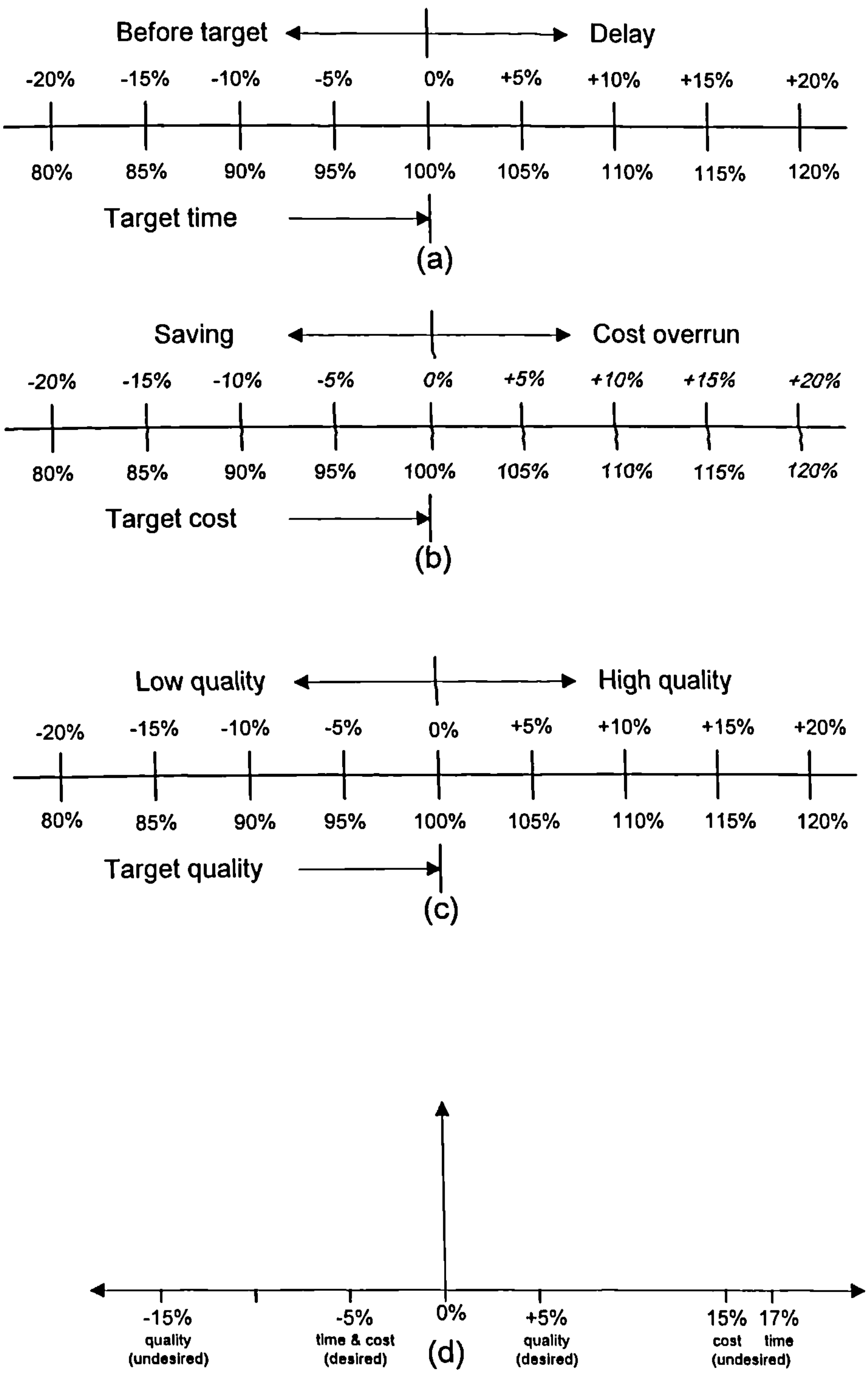

Fig 9.1 Arrangments of ranges and limits of time, cost and quality

Project success factors (PSF)	Expected means, variance and standard deviation values of the four contractors A, B, C, and D in different (PSF)				
	paramete	A	B	C	D
Time(T)	Et	+8%	+3%	+7%	+2%
	V of(Et)	4.84	4	4.41	3.062
	S of (Et)	2.2	2	2.1	1.75
Cost(C)	Ec	+6%	+8%	2%	+4%
	V of (Ec)	3.57	2.89	2.56	3.24
	S of (Ec)	1.89	1.7	1.6	1.8
Quality(Q)	Eq	-1.0%	0.0%	-3%	-7%
	V of (Eq)	2.25	1.44	2.89	4
	S of (Eq)	1.5	1.2	1.7	2

Table 9.2 Expected mean, variance and standard deviation values for contractors A, B, C and D in different project success factors

9.2.1 Distribution curves of the three attributes.

The distribution curves of time, cost and quality are the result of adding individual distribution curves of different contractor selection criteria as described in chapter 8. Russell and Ahmad (1990) assuming that the assumptions that were made for the development of the PERT approach have been considered valid for the contractor prequalification, based on these assumptions the sum of individual distributions of contractor selection criteria is described by a normal distribution.

According to Harris (1978:330) there must a sufficient number of various types of distributions added to ensure the normal tendency in approach. Moder and Phillips (1964) indicated that the minimum number is four, Miller (1963) gives the number as ten. Whatever the minimum number, it is clear that in prequalification process there will be enough number of contractor selection criteria and hence enough number of distributions.

To this, the author has found from the statistical analysis carried out in chapter 7 that the population correlation coefficient are not significant for the contractor selection criteria, therefore the contractor selection criteria are considered independent and the principle of the central limit theorem which states the distribution of the sum tends to the shape the normal curve regardless of the shape of the individual distributions was applicable in this case. These concludes that the distribution curves of the three attributes time, cost and quality will follow the normal distribution curve.

To find the shape of the normal distribution curves of the three attributes for the four contractors, the expected means and standard deviations given in Table 9.2 were used to illustrate these curves simply by using the standard function of the normal distribution curve which could be found in (Neter and others 1982; Clarke and Cooke 1978; Spiegel 1980; Loomba 1978). Figure 9.2 shows the normal distribution curves of the four contractors for time, cost and quality. These curves refered as normal probability density curves for time, cost, and quality and their function are f(t), f(c), and f(q) respectively.

The normal distribution curves could be used to find a probability that any of the contractors expected value is less than or equal a selected value(Sv). This probability is equal to the area under the curve to the left of (Sv). The following formula which could be found in most statistical books is used to find the area under the curve.

z = (selected (Sv) - Expected (mean) of T or C or Q)/ (standard deviation(S) of T or C or Q)

Where z is called the deviation from the Expected mean. Having calculated the value of z, the area under the normal curve which represents the required probability could be taken from the Tables of areas of the normal curve from any statistical book (Loomba 78, Neter and others 1982) .

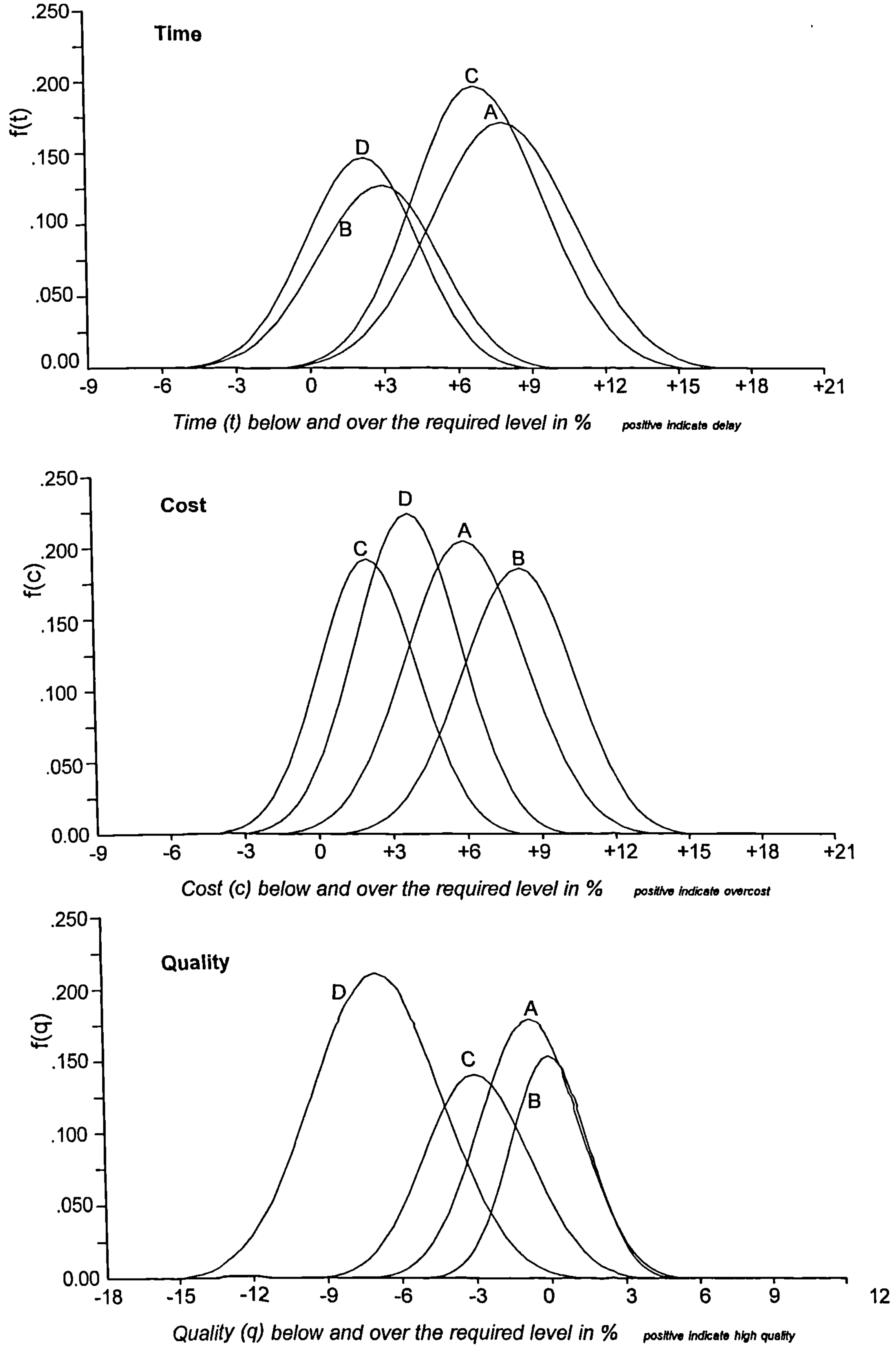

Fig 9.2 Normal distribution curves for contractors A, B, C, and D

It is also important to note that z represents a deviation from the Expected mean so any area calculated from the normal curve Tables correspond to that value of z represents the area from the expected mean so the area should be added to 0.5 if the selected value (Sv) is greater than the expected mean (E) and subtracted from 0.5 if the selected value is less than the expected mean, the value 0.5 represents the area of the normal curve exactly at the expected mean (i.e if (Sv)=expected mean (E)).

For example, the probability that contractor A will delay by 10% or less could be found as follows.

Calculate z using the formula z=((Sv-E)/S) which in this case

Sv=10% E=8% and S=2.2 from Table 9.2, so

$$z = (10-8)/2.2 = 0.909$$

From normal curve Tables (Loomba 1978) the area under the curve correspond to z=0.909 is 0.3186. Since the selected value (Sv) which in the case is 10% greater than the expected mean (E)=(8%), therefore the probability that the contractor will be delayed by 10% is 0.5+ 0.3186=0.8186 or 81.86%.

Following the same procedures the probability that the contractor A will delay by 5% or less is equal.

z = (5-8)/2.2= -1.36, From the normal curve Tables at z=1.36 which is the same as for z = -1.36 the area under the curve is equal 0.4131, since the selected value which in the case is equal 5% is less than the expected mean (8%), the probability that the contractor will delay by 5% is 0.5- 0.4131=0.0869 or 8.69%.

9.2.2 Limits of the distribution curves.

The limits of the normal curves could be found using the same formula used for finding the probabilities in the last section (9.2.1), the maximum value of z for the normal distribution curve could reach up to 3.99 (Loomba 78), this value of z will result in a probability of 99.997% if the selected value (Sv) is greater than the expected mean (E) and will result in probability of .001% if (Sv) is less than the expected mean (E). Using these information together with the expected mean and standard deviation values of each contractor found in Table 9.2, it is possible to find the maximum and minimum expected values for each contractor, in other words finding the limits of the curves for time, cost and quality, this could be found using the following formula.

Expected Maximum E = Expected Mean E + maximum z (S)

Expected Minimum E = Expected Mean E - maximum z (S)

for example the maximum and minimum expected values for contractors A and B for the time attribute is.

Contractor A: Maximum expected value $= 8 + 3.99\,(2.2) = +16.778$

Minimum expected value $= 8 - 3.99\,(2.2) = -0.778$

Contractor B: Maximum expected value $= 3 + 3.99\,(2) = +10.98\%$

Minimum expected value $= 3 - 3.99\,(2) = -4.98\%$

This means contractor A is expected to delay by 16.778% as a worst expected value or to finish before time by 0.778% as a best expected value with expected mean of 8% delay. Contractor B is expected to delay by 10.98% as its worst or to finish before time by 4.98% as its best expected value with a mean of 3%. delay.

The limits of time, cost and quality curves for the four contractors are calculated similarly and given in Table 9.3. Observe that for time and cost all positive values are undesired values, but a positive value for quality is a desired value, while the negative values indicate a good scores or desired values for time and cost and a bad or undesired value for quality.

Project success factors (PSF)	Expected means, standard deviation, and limits values of the four contractors in T, C, and Q				
	parameter	A	B	C	D
Time (T)	Et	+8	+3	+7	+2
	Maxi(Et)	+16.778	+10.98	+15.378	+8.98
	Mini.(Et)	-0.778	-4.98	-1.379	-4.98
	S of (Et)	2.2	2	2.1	1.75
Cost (C)	Ec	+6	+8	+2	+4
	Maxi.(Ec)	+13.54	+14.78	+8.38	+11.2
	Mini.(Ec)	-1.5411	+1.217	-4.38	-3.18
	S of (Ec)	1.89	1.7	1.6	1.8
Quality (Q)	Eq	-1	0	-3	-7
	Maxi.(Eq)	+4.985	+4.778	+3.783	+0.98
	Mini.(Eq)	-6..985	-4.778	-9.78	-14.9
	S of (Eq)	1.5	1.2	1.7	2

Table 9.3 Mean, maximum, minimum and standard deviation values for contractors A,B,C,and D in time, cost and quality

It is quite clear that Table 9.3 include consequences ranges from an expected delay of +16.778% (contractor A) to finishing before the scheduled time by 4.98% (contractors B&D) { +16.778% to -4.98%} for the time attribute, for cost it ranges from 14.78% cost overrun (contractor B) to 4.38% cost saving (contractor C) {+14.78% to -4.38%}, and for quality it ranges from -14.98% below the standard (contractor D) to 4.985% of good quality (contractor A) { -14.98% to +4.38%}.

For the purpose of building the utility functions and find the limits of integration which will come later, these values or ranges will be rounded and will be taken as follows for simplicity for the decision maker.

Time from **{-5% to +17%}**, cost from **{-5% to +15%}** and quality from **{-15% to +5%}** as shown in Figure 9.1 (d).

So the aim is to select the best contractor or to rank the contractors A, B, C, and D in terms of the three attributes time (T), cost(C), and quality(Q), each contractor has scored different expected means with different variances in these three attributes and the four contractors have different scores from each other. The utility theory will take all these parameters into account to rank the contractors.

It is clear that our problem is a three attribute dimension problem. In addition to the basic principles of the utility theory given in chapter 4 and the detailed hypothetical example described in chapter 6, here is some detailed backgrounds of the utility theory with three attributes. From their the problem could easily be solved.

9.3 UTILITY FUNCTION WITH THREE ATTRIBUTES

Here we state four results concerning utility functions with three attributes (Schlaifer 1969;. Hertz and Thomas 1984; Diekmann 1981; Ibbs and Crandall 1982; Bein 1984; Martinelli 1986; Ahmad and Minkarah 1987; Moselhi and Martinelli 1990; Keeney and Raiffa 1993).

Result 1. If preferences over lotteries on T, C, and Q depend only on their marginal probability distributions for these attributes and not on their joint probability distribution, then

$$\mathbf{u(t,c,q) = k_t u(t)+k_c u(c)+k_q u(q)} \tag{9.1}$$

This result is the additive utility function of three attributes. The utility functions u, u(t), u(c), and u(q) can all be scaled from 0 to 1 and k_t, k_c, k_q are scaling constants for time, cost and quality respectively.

Result 2. If T is utility independent (UI) of {C,Q}, and if {T,C} and {T,Q} are preferential independent (PI) of Q and C, respectively, then

$$\mathbf{u(t,c,q) = k_t u(t) + k_c u(c) + k_q u(q) + kk_t k_c u(t)u(c)+kk_t k_q u(t)u(q)+kk_c k_q u(c)u(q)}$$
$$\mathbf{+k^2 k_t k_c k_q u(t)u(c)u(q)} \tag{9.2}$$

This is also applied If C is utility independent of {T,Q}, and if {C,Q} and {C,T} are preferential independent of T and Q, respectively. Also If Q is utility independent of {T,C}, and if {Q,T} and {Q,C} are preferential independent of C and T, respectively.

Each of u, u(t), u(c), u(q) and k_t, k_c, k_q in equation (9.2) have the same meaning as in equation (9.1). In addition, k is an additional scaling constant. Clearly if k=0, then equation (9.2) reduces to the additive form (1). If k not equal zero, then by multiplying each side of equation (9.2) by k, adding 1, and factoring we obtain the multiplicative utility function.

$$\mathbf{k\,u(t,c,q)+1 = (kk_t u(t)+1)(kk_c u(c)+1)(kk_q u(q)+1)} \tag{9.3}$$

There are two important things to note about Result 2: it uses both utility independence and preferential independence assumptions. Both of these characteristics are very important in specifying multiattribute utility function with many attributes. According to Keeney and Raiffa (1993) this result could also be used if the attributes T, C, and Q are mutually utility independent which means if every subset of {T,C,Q} is utility independent (UI) of its complement, means T UI {C,Q}, {C,Q} UI T, C UI {T,Q}, {T,Q} UI C, Q UI {T,C}, {T,C} UI Q.

Result 3. If each of T, C, and Q are utility independent of their respective complements, then

$$\begin{aligned} u(t,c,q) = {} & k_t u(t) + k_c u(c) + k_q u(q) + k_{tc} k_t k_c u(t) u(c) + k_{tq} k_t k_q u(t) u(q) + k_{cq} k_c k_q u(c) u(q) \\ & + k_{tcq} k_t k_c k_q u(t) u(c) u(q) \end{aligned} \qquad (9.4)$$

Again the utility functions u, u(t), u(c), and u(q) and the scaling constants k_t, k_c, and k_q are defined as before. In addition, we need to assess the additional scaling constants k_{tc}, k_{tq}, k_{cq}, and k_{tcq}. Expression (9.4) is referred to as the multilinear utility function in three attributes. It should be clear that both the multiplicative and additive utility functions are special cases of multilinear.

Result 4. If C and Q are utility independent of their respective complements {T,Q} and {T,C}, then

$$u(t,c,q) = k_t u(t) + f_2(t) u(c) + f_3(t) u(q) + f_{23}(t) u(c) u(q) \qquad (9.5)$$

where $f_2(t) = u(t, c^*, q^0) - u(t, c^0, q^0)$, $f_3(t) = u(t, c^0, q^*) - u(t, c^0, q^0)$,

$f_{23}(t) = u(t, c^*, q^*) - u(t, c^*, q^0) - u(t, c^0, q^*) - u(t, c^0, q^0)$.

The star sign(*) indicate the maximum score level or the best expected value while the zero sign(^{0}) indicate the minimum score level or the worst expected consequence.

Of course following the same notation it is also possible to find u(t,c,q) if T and C or T and Q are utility independent of their respective complements.

In equation (9.5), again each of the utility functions is scaled from 0 to 1, with (t^*, c^*, q^*) being the best consequence in our example (-5%,-5%,+5%) and (t^0, c^0, q^0) the worst consequence in our example (+17%,+15%,-15%).

The results 1 and 2 are valid regardless of whether the attributes T, C and Q are scalars or vectors. In the former case, the component utility functions u(t), u(c) and u(q) are single attribute utility function. whereas in the latter case u(t) and/or u(c) and/or u(q) is itself a multiattribute utility function. If any of the three attributes is a vector attribute it is possible, subject to satisfying the requisite assumptions, to reuse results 1 or 2 in the structuring the corresponding utility function.

9.4 ASSESSING MULTIATTRIBUTE UTILITY FUNCTIONS

With the additive, multiplicative, and multilinear utility functions, preferential independence and utility independence have been used (Keeney 1971) to reduce the assessment of 3-attribute utility function u(t,c,q) to the assessment of 3 one-attribute utility functions u(t), u(c), u(q) and some scaling constants k, k_t, k_c, k_q , k_{tc}, k_{tq}, k_{cq}, and k_{tcq}. And so we have

$$\mathbf{u(t,c,q)=f[u(t),\ u(c),\ u(q),\ k,\ k_t, \ldots\ldots,\ k_{tcq}]}$$

where f is a scalar function. Each of the u(t), u(c), and u(q) can be assessed independently, since the scaling constants are meant to ensure consistent scaling among these u_i's. Thus, except for the fact that there are three utility functions that have to be assessed independently, the problems in assessing the 3-attribute utility function are in verifying the independence conditions and assessing the scaling constants. So in order to find the joint utility function u(t,c,q), the first step is to investigating the independence conditions (preferential independence PI and utility independence UI) so the appropriate result(i.e additive, multiplicative, multilinear or general) could be applied, the second step is to find the independent utility functions u(t), u(c), and u(q), finally the scaling constants has to be assessed to join these independent utility functions to form a three attribute utility function.

9.5 VERIFYING PREFERENTIAL INDEPENDENCE AND UTILITY INDEPENDENCE CONDITIONS FOR TIME, COST AND QUALITY

9.5.1 Verifying Preferential Independence.

The concept of preferential independence concerns the decision maker's preferences for consequences (score levels) where no uncertainty is involved. Let us assume the three attributes Time (T), Cost (C), and Quality (Q) comprising a set called X, X={t,c,q}.

Partition X into Y and Y' where Y' in this case is the quality Y'= {q} and Y is the time and cost Y={t,c}. To check whether Y is preferentially independent of Y' in other words time and cost are preferentially independent of quality. First choose y'=(q) at a relatively undesirable level and a list of pairs of y=(t,c) at any level and ask the decision maker his preferences between each of the corresponding two pairs. Then pick another level for y' with a relatively desirable level with the list of the pairs of y remains the same and ask the decision maker if the preferences among the list of pairs are the same for the new level of y'. This must be true if Y is preferentially independent of Y'. To verify preferential independence for time, cost and quality in our example <u>**real**</u> interviews with seven professionals were conducted, it might be useful to proceed along the lines of the one of these interviews between the analyst and the assessor shown in appendix 9A, the author has worked as an analyst in this example.

9.5.2 Verifying Utility independence.

The concept of utility independence concerns the decision maker's preferences for consequences (score levels) where uncertainty is involved. We could go through a similar procedure to check whether Y is utility independent of Y'. According to Schlaifer (1969); Ang and Tang *(1984) Keeney (1971) if Y is UI, then Y is PI. The converse is not* necessarily true. On Table 25 in appendix 9B. we kept Y'=q fixed at -15% level but now, instead of paired comparisons between simple consequences involving (t,c), there would be paired comparison between one 50-50 lottery and either another 50-50 lottery or a single certainty consequence. Of course, all the consequences in the paired comparisons are described in the Y(t,c) attribute space. Throughout, q attribute is held fixed at certain level for the first Table 25 and is held fixed at another level for the second Table 26 in appendix 9B, and so on. The analyst can now go through the same routine as before, and if the assessor sees no reason why the paired comparisons should depend on the value of q, then we can concluded that Y=(t,c) are utility independent of Y'= q. It is also possible to let Y'=two attributes instead of one and let Y=one attribute instead of two, in appendix 9B Tables 37 through 40 an investigation of whether time is utility independent of cost and quality in this case Y'=(c,q) and Y=(t). Tables 41 to 44 in appendix 9B to verify cost is utility independent of time and quality and so on.

In practice, if such a condition were verified for approximately four different values of y' covering the range of Y', we would usually be justified in assuming that Y is utility independent of Y' (Keeney and Raiffa 1993). Let us take one of the attributes Y'=q and check whether it's complement Y=(t,c) is utility independent of Y'.

Partition X into Y and Y' where Y' represent the quality and Y is the time and cost. To check whether Y is utility independent of Y' or time and cost are utility independent of quality we might proceed along the lines of one of the seven interviews conducted between the analyst and the assessor (see appendix 9B).

After interviews with the seven people to investigate the independence condition it was found the three attributes are mutually utility independence (Tables 25-48 appendix 9B), and it was found time and cost are preferential independent of quality {T,C} PI Q (Tables 1-8 appendix 9A)) and time and quality are preferential independent of cost {T,Q} PI C (Tables 9-16 appendix 9A), and cost and quality are PI of time (Tables 17-24 appendix 9A). These findings allows to consider the joint utility function of the three attributes time, cost, and quality u(t,c,q) as a multiplicative utility function result 2.

$$\begin{aligned} u(t,c,q) = {} & k_t u(t) + k_c u(c) + k_q u(q) + k k_t k_c u(t)u(c) + k k_t k_q u(t)u(q) + k k_c k_q U(c)u(q) \\ & + k^2 k_t k_c k_q u(t)u(c)u(q) \end{aligned} \qquad (9.2)$$

in which k_t, k_c, k_q is weighting or scaling terms for attributes time, cost and quality respectively, and k is an independent scaling factor.

Clearly if k=0, then equation (9.2) reduces to the additive form (1). If k not equal zero, then by multiplying each side of (9.2) by k, adding 1, and factoring we obtain the multiplicative utility function.

$$\mathbf{k\ u(t,c,q)+1 = (kk_t u(t)+1)\ (kk_c u(c)+1)\ (kk_q u(q)+1)} \qquad \mathbf{(9.3)}$$

It is clear that the three attribute utility function is equivalent to 3-one dimensional utility and scaling constants for consistency. In order to find the joint utility function u(t,c,q) it is necessary first to assess the utility functions of time, cost and quality independently, then finding the scaling constants to join these functions together, this will be described in the following sections.

9.6 ASSESSING 3-ONE ATTRIBUTE UTILITY FUNCTIONS.

To investigate the preferences of different people for the three attributes **real** interviews with the same seven people were conducted, the following is the detail of one of these interviewees.

9.6.1 Time utility function u(t).

Let us build the independent utility function for the decision makers **Sani Ibrahim** for time attribute in detail, then cost and quality will follow the same procedure.

In the hypothetical case described in chapter 6 the full details of building utility function was described using direct assessment method in that the decision maker was asked to put the probability that makes him indifferent between a lottery and a certain consequence were the best consequence is given a utility value equal 1 while the worst is given 0.

Slightly different procedure is followed in this example by offering the decision maker a lottery I of 50-50 chance Figure 9.3a either to get the worst consequence with a delay 17% i.e (t)=+17% or the best consequence which is finishing before time by 5% so t=-5% and was asked to put according to his preferences the consequence with a probability equal 100% of lottery II that makes him indifferent between the two lotteries I and II.

In this case to establish the utility scale for time, the utilities of +17% and -5% are assigned to be 0 and 1.0 respectively. The first pair of lotteries is presented to the decision maker as follows as shown in Figure 9.3a

with lottery I, the decision maker stands a 50-50 chance of finishing before time by 5% i.e t=-5% or delaying by 17%, so t= +17%; whereas he will get a consequence t_1% for sure with lottery II. To assist the decision maker to put the appropriate preference consequence in lottery II that makes him indifferent between the two lotteries, he was offered different consequences i.e different values for t_1 and asked to choose which lottery he preferred I or II or he could choose the two lotteries if he feels indifferent between the two lotteries for each value of t_1, starting by a consequences which should be very clear to the decision maker to take an easy decision and choose one of the lotteries, The following Table shows this process. At t_1=x% where the two lotteries be indifferent indicate that the utility value of the two lotteries must be equal at that consequence or at t_1.

t_1%	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5
I										*	*	*	*	*	*	*
II	*	*	*	*	*	*	*	*	*	*						

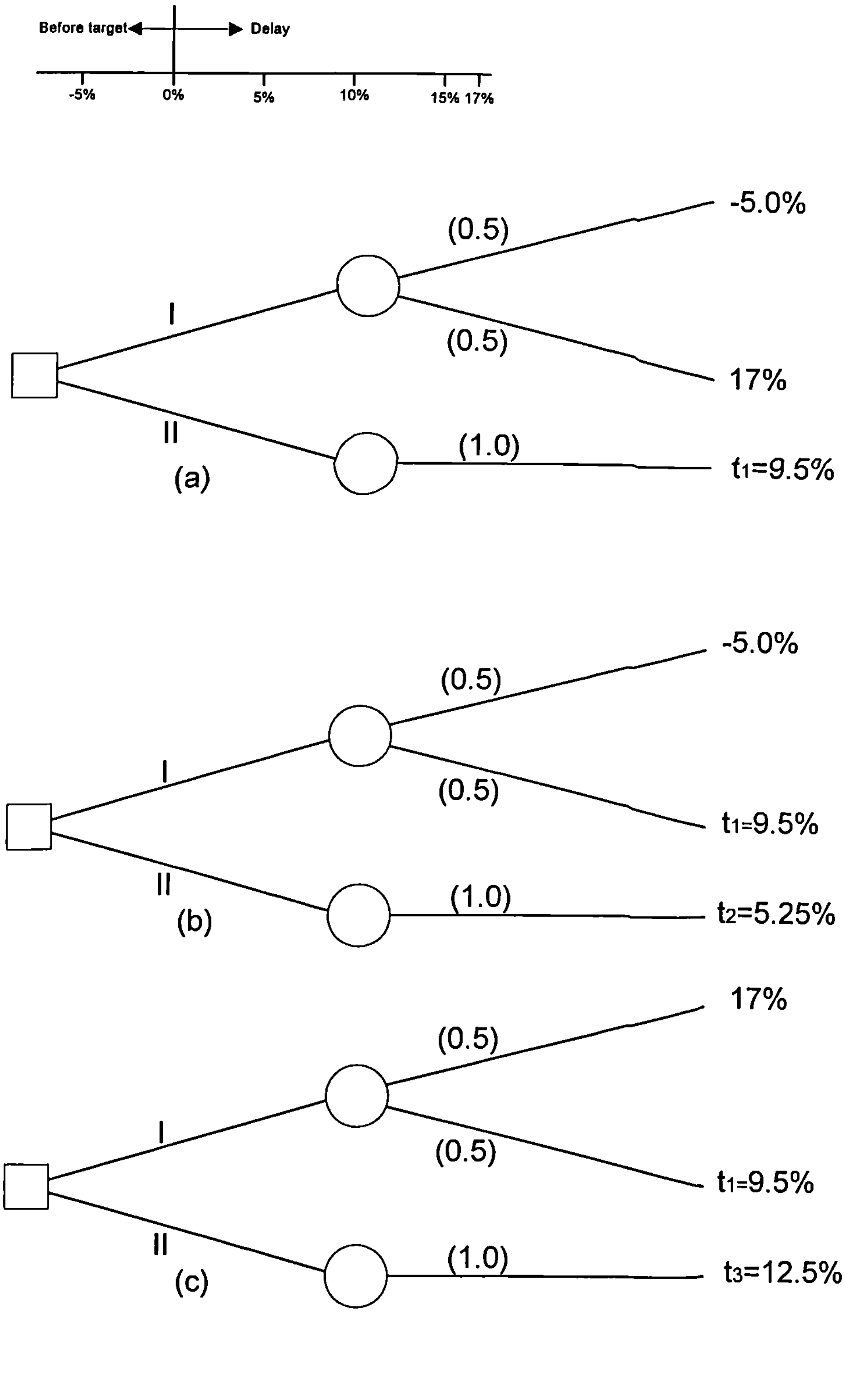

Fig 9.3. Lotteries for building time utility function

The decision maker prefers t_1= 9.5% as the time that makes him indifferent between the two lotteries; then by equating the utility values of the two lotteries it is possible to get the utility value of 9.5%, this is similar to procedure described in Chapter 6.

$$u(9.5) = 0.5\ u(-5) + 0.5\ u\ (+17)$$
$$= 0.5\ (1) + 0.5\ (0) = 0.5$$

The second pair of lotteries presented to the decision maker as shown in Figure 9.3b, with lottery I, the decision maker stands a 50-50 chance of finishing before the target time by 5% so t=-5% or delaying by 9.5% which is found earlier as t_1 so t=9.5%; whereas he will delay t_2% for sure with lottery II. At what value of t_2=x% will the two lotteries be indifferent?

t_2%	2	2.5	3	3.5	4	4.5	4.75	5	5.25	5.5	5.75	6	7	8	9	9.5
I									*	*	*	*	*	*	*	*
II	*	*	*	*	*	*	*	*	*							

The decision maker prefers t_2= 5.25% as the time that makes him indifferent between the two lotteries; then,

$$u(5.25) = 0.5\ u(-5) + 0.5\ u(9.5)$$
$$= 0.5(1) + 0.5\ (0.5) = 0.75$$

Similarly, with a third pair of lotteries Figure 9.3c, with lottery I, the decision maker stands a 50-50 chance of delaying by 17% or delaying by 9.5% found earlier as t_1; whereas he will delay t_3% for sure with lottery II. At what value of t_3=x% will the two lotteries be indifferent?

t_3%	11	11.5	11.75	12	12.25	12.5	12.75	13	14	15
I						*	*	*	*	*
II	*	*	*	*	*	*				

The decision maker prefers t_3= 12.5% as the time that makes him indifferent between the two lotteries; then,

$$u(12.5) = 0.5u(17) + 0.5\ u(9.5)$$

$$= 0.5(0) + 0.5\ (0.5) = 0.25$$

At this stage, five points or utility values on the utility function for the range of time values from -5 % to 17% have been determined as shown in the Table 9.4.

Utility values			mid point		
	1	0.75	0.5	0.25	0
Preferred consequence	-5	5.25	9.5	12.5	17

Table 9.4. Five consequences preferred by the decision maker for different utility values

Table 9.5 shows the consequences preferred for different utility values (i.e for 1, 0.75, 0.5, 0.25, 0) for the seven people interviewed for the time attribute.

Attribute	Decision maker	The consequence preferred by different decision makers for different utility values				
				mid point		
		1	0.75	0.5	0.25	0
Time	Sani	-5	5.25	9.5	12.5	17
	Hussain	-5	3.5	6.5	11	17
	Mislati	-5	6.1	10.1	12.1	17
	Jamal	-5	5.25	11.25	13.25	17
	Latif	-5	3.5	6.5	9.75	17
	Oztash	-5	4.25	7.75	11.25	17
	Ali	-5	5	8.5	11	17

Table 9.5 Consequences preferred by different decision makers for different utility values for the time attribute

Fig 9.4. graphically shows the utility function fitted through the five utility values for our decision maker Sani. Mathematically, the construction of a utility function involves the transformation of the values of the expected time values into respective consistent scales in utility space, representing the decision maker's actual preference for values of the original variables.

Most utility functions are convex such as the one shown in figure 9.4. The preference behaviour of a decision maker exhibited by a convex utility function is commonly referred to as risk-aversiveness. Most people are risk-averse to a certain degree (Keeny and Raiffa 1993); some may be more risk-averse than others. The mathematical forms of utility functions commonly used to model such risk-averse behaviour would include the following (Ang and Tang 1984).

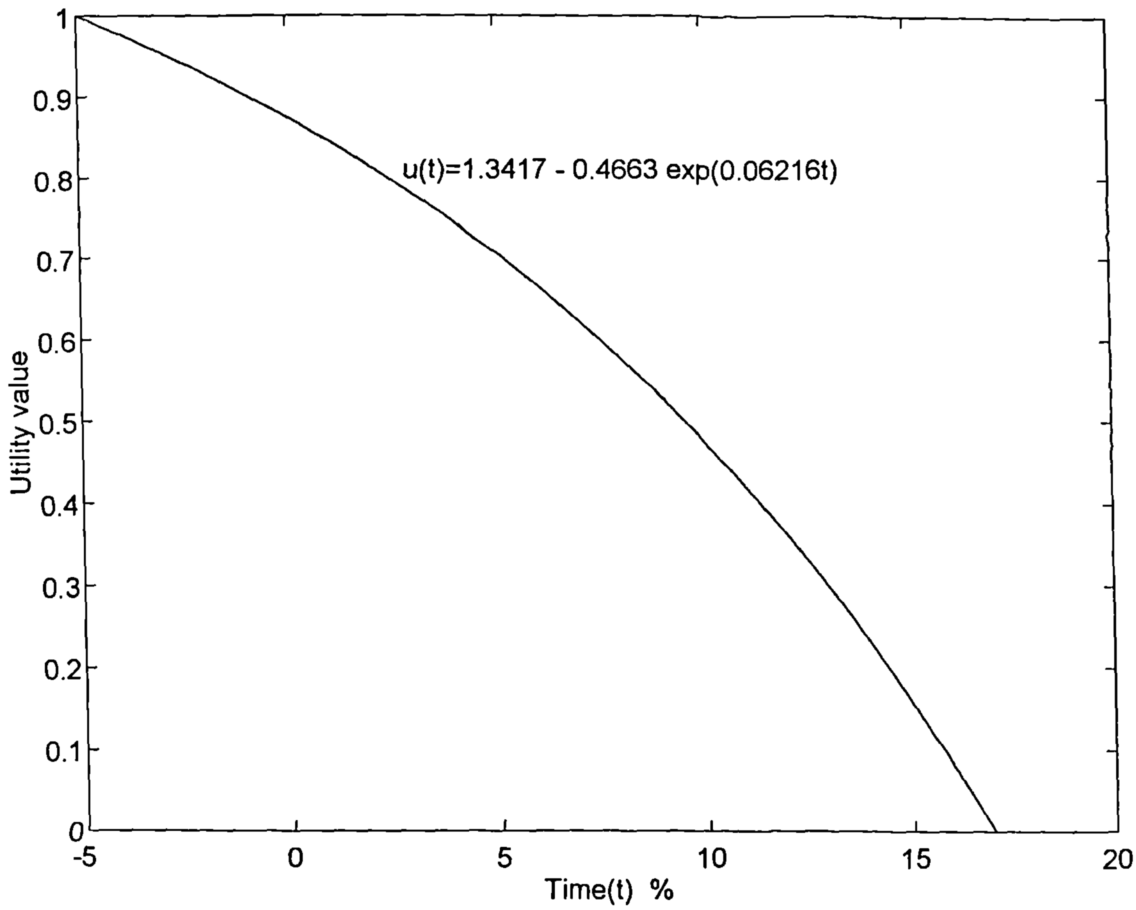

Fig. 9.4 Time utility curve

1. Exponential utility function such as

$$\mathbf{u(x) = a \pm b\ e^{-rx}} \tag{9.6}$$

where r is the measure of risk aversion, and a, b are constants and x is the attribute

2. Logarithmic type

$$\mathbf{u(x) = a\ ln\ (x+\beta) + b} \tag{9.7}$$

where β is a parameter, generally corresponding to the amount of capital reserve of the decision maker.

3. Quadratic type.

$$\mathbf{u(x) = a\ (\ x\text{-}1\ /\ 2\ \alpha\ x^2)} \tag{9.8}$$

where α is the parameter related to the degree of risk-aversion.

According to Ang and Tang (1980) the correct choice of the form of the utility function is not very crucial, especially if the expected (in statistics the word expected is the mean or the average) utility values are not sensitive to the form of the function.

It has been shown in many statistical books (Spiegel 80, Neter and others 1982, Clarke and Cooke 1978) that the expected value (mean) for a function in which the possible outcome from an action can be described by the value of a random variable X is

$$E[g(x)] = \int_{-\infty}^{\infty} g(x)f(x)dx \tag{9.9}$$

In our case, the expected utility of a given action may be expressed as follows

$$E(U) \quad = \quad \int_{-\infty}^{\infty} u(x)f(x)\,dx \qquad \textbf{(9.10)}$$

where *E(u)* is the expected utility, *f(x)* is the probability density function of X and *u(x)* is the utility function. In order to find the result of integration the utility function *u(x)* is expanded using Taylor series, if the second-order term in the result of integration is included, the second order approximation to evaluate the expected utility yields the result 9.11. For more details about this approximation see (Ang and Tang 1975 chapter 4)

$$\mathbf{E(U) \cong u(\mu x) + 1/2\ Var(X) u''(\mu x)} \qquad \textbf{(9.11)}$$

where (μx) and Var(X) are the mean and variance of the random variable X, and u''(μx) is the second derivative of the utility function evaluated at μx. It has been shown by Ang and Tang (1980) that the expected utility is relatively insensitive to the form of the utility function at a given level of risk-aversion, and that the expected utility does not change significantly over a wide range of risk-aversion coefficients. Hence, the exact form of the utility function may not be a crucial factor in the computation of an expected utility. Moreover, the risk-averseness coefficient in the utility function need not be very precise; that is, any error in the specification of the risk-averseness coefficient may not result in a significant difference in the calculated expected utility. In short, the problem of ascertaining an accurate utility function would not be crucial in the application of statistical decision analysis.

As indicated in equation 9.11., an approximate expected utility value may be computed on the basis of the mean and variance of the pertinent random variable. This would suggest that the entire probability density function may not be necessary. In practice, the first two statistical moments could be all the information that may be available for a random variable; hence, Equation 9.11 provides a convenient approximate formula for computing the expected utility of a given alternative.

Let us continue our example and check which type of utility function could represent the curve in Figure 9.4. It was found after trying the three types that the exponential function in equation 9.6 is the best that could fits the five consequences of the decision maker found in Table 9.4, therefore the time utility function of the decision maker could be represented mathematically as follows.

$$\mathbf{u(t)= a\text{-}be^{rt}} \qquad \mathbf{(9.12)}$$

It was found earlier that the sure (i.e probability 100%) 9.5% delay is indifferent to the lottery yielding either -5% or +17% with equal probabilities (50%-50%), so using the lottery

$<(-5,17)> \sim (9.5)$ ($\sim$ read indifferent). Since the lottery and the consequence at t=9.5% are indifferent, therefore the expected utility of the lottery and the consequence must be equal, using this result the parameter r could specified as follows.

$$u<(-5,17)> = u\,(9.5)$$

Substitute using the utility function in equation (9.12) at t=-5%, t=17% on the left side and t=9.5% on the right side

$$0.5\ u(-5) + 0.5\ u(17) = u\ (9.5)$$
$$0.5\ (a- be^{-5r}) + 0.5\ (a-b\ e^{17r}) = a - b\ e^{9.5r}$$
$$0.5\ a - 0.5\ b\ e^{-5r} + 0.5\ a - 0.5\ b\ e^{17r} = a - b\ e^{9.5r}$$
$$-0.5\ b\ (e^{-5r} + e^{17r}) = -\ b\ e^{9.5r}$$

Take b and the minus sign from both sides

$$0.5\ (e^{-5r} + e^{17r}) = e^{9.5r}$$

solving the question the value of r was found equal = 0.06216 as follows

Using Newton's method (Kreyszig 1979:p 765) which is an iteration method for solving equations f(r)=0, where f is differentiable equation. In this case

$$f(r) = 0.5\ (e^{-5r} + e^{17r}) - e^{9.5r} = 0$$

The idea is that we approximate the graph of f by suitable tangents. Using a value r_0 obtained from the graph of f we let r_1 be the point of intersection of the r-axis and the tangent to the curve of f at r_0. Then

$$r_{n+1}=r_n-f(r_n)/f'(r_n) \quad (n=0,1,...)$$

where f'(r) is the derivative of f(r). In our example

$$f'(r) = 0.5\ (-5\ e^{-5r} + 17\ e^{17r}) - 9.5\ e^{9.5r}$$

for n=0 set r_0=0.1

$f(r_0) = 0.4545$ $f'(r_0)=20.4479$ $r_{0+1}=0.1 -(0.4545/20.4479)=0.07777$

for n=1 r_1=0.07777

$f(r_1) = 0.1211$ $f'(r_1)=10.3037$ $r_{1+1}=0.0777-(0.1211/10.3037)=0.06601$

for n=2 r_2=0.06601

$f(r_2) = 0.02308$ $f'(r_2)=6.5273$ $r_{2+1}=0.06601-(0.02308/6.5273)=0.0624$

This has to be carried out until the value of r_{n+1} does not change. The value of r was calculated using a spreadsheet SC5 1989 up to n=9 as shown in Table 9.6

n	0	1	2	3	4	5	6	7	8	9
r_n	0.1	.0777	.0660	.06248	.06216	.06216	.06216	.06216	.06216	.06216
r_{n+1}	.0777	.0660	.0624	.06216	.06216	.06216	.06216	.06216	.06216	.06216

Table 9.6. Value of r up to n=9

For this specific utility function the **[value (9.5%)]** which used for solving the equation represents the mid value between -5% and 17%, in other words it is the consequence that is indifference to a lottery yielding -5% or 17% with equal probabilities. The mid value might be different from one decision maker to another for the same attribute Table 9.5 and it might different from one attribute to another for the same decision maker. The value of r were calculated for different mid value points *for this specific utility function. Table 9.7.* shows the final value of r for these different values, where n was taken up to 20.

Mid value	6.5	6.75	7	7.25	7.5	7.75	8	8.25
r	0.00828	0.01244	0.016621	0.02084	0.025106	0.029425	0.03381	0.03827
Mid value	8.5	8.75	9	9.25	9.5	9.75	10	10.25
r	0.04282	0.047466	0.052231	0.057124	0.062167	0.06738	0.072774	0.07839
Mid value	10.5	10.75	11	11.25	11.5	11.75	12	12.25
r	0.08424	0.090366	0.0968	0.103597	0.110796	0.11846	0.12667	0.13551

Table 9.7. Value of r for different mid points

Having calculated the value of r for the time utility function, the values of a and b for the utility function (9.12) could be found as follows

Since the utility value at (t=-5%) is arbitrarily chosen = 1 and at (t=17%)=0, then

u(t) at t=-5% = 1 substitute this value in equation (9.12) at t=-5%

$$a - b\,e^{-5r} = 1 \qquad \text{or} \qquad a = 1 + b\,e^{-5r}$$

Parameter b in the utility function ($u(t)= a - b\,e^{rt}$) was then determined using the same equation (9.12) at t=9.5% were the utility value assigned by the decision maker at t=9.5%=0.5, and the value of a is substituted by $1+b\,e^{-5r}$

$$0.5 = a - b\,e^{9.5x0.06216}$$

$$0.5 = 1 + b\,e^{-5x0.06216} - b\,e^{9.5x0.06216}$$

solving the equation

the value of b=.4663 and value of a will be equal $1+0.4663\,e^{-5x0.06216}$=1.3417

So the independent utility function over time could be written as

$$\mathbf{u(t) = 1.3417 - 0.4663\,e^{0.06216t}} \qquad \mathbf{(9.13)}$$

It is clear that the value of a and b is calculated using the value of the variables r and the mid value point. The values of a and b for this specific utility function were calculated for different mid value points where the value of r is taken from Table 9.7 corresponding to each mid point, these values of a and b were shown in Table 9.8.

Mid point	6.5	6.75	7	7.25	7.5	7.75	8	8.25
b	5.2191	3.3819	2.4615	1.9079	1.5377	1.2724	1.0727	0.9167
a	6.0076	4.1781	3.2652	2.7191	2.3563	2.0983	1.9059	1.7571
Mid point	8.5	8.75	9	9.25	9.5	9.75	10	10.25
b	0.7915	0.6886	0.6025	.52928	0.4663	.41157	0.3635	0.321
a	1.6389	1.5431	1.464	1.3978	1.3417	1.2938	1.2526	1.2169
Mid point	10.5	10.75	11	11.25	11.5	11.75	12	12.25
b	0.2832	0.2493	0.2189	0.1914	0.1666	0.1441	0.1237	0.1052
a	1.1858	1.1587	1.1349	1.114	1.0957	1.0796	1.0656	1.0534

Table 9.8. Values of constants a and b for different mid points for the range -5 to 17

9.6.2 Cost utility functions u(c).

Using similar procedure, the utility function for cost was represented also by an exponential function similar to time i.e $a - b\ e^{cr}$ bear in mind the limits for cost attribute ranges between -5% and 15%. The consequences of cost attribute preferred for different utility values by the people interviewed were shown in Table 9.9, the values of r, a, and b of the cost utility function are calculated for different mid points as shown in Table 9.10.

		The consequence preferred by different decision maker for different utility values				
				mid point		
Attribute	Decision maker	1	0.75	0.5	0.25	0
Cost	Sani	-5	5	8	11	15
	Hussain	-5	3.5	7.5	11	15
	Mislati	-5	5.25	10.1	12.75	15
	Jamal	-5	3.75	7.75	10.25	15
	Latif	-5	4.75	7.75	10.75	15
	Oztash	-5	2.75	6	8.25	15
	Ali	-5	4.5	7.5	10.5	15

Table 9.9 Consequences preferred by different decision makers for different utility values for the cost attribute

mid point	6	6.25	6.5	6.75	7	7.25
r	0.020134	0.025264	0.030459	0.035735	0.041108	0.046594
b	2.230360	1.725806	1.388057	1.145683	0.962971	0.820079
a	3.016755	2.521008	2.191969	1.958221	1.784057	1.649647
mid point	7.5	7.75	8	8.25	8.5	8.75
r	0.052213	0.057985	0.063932	0.070082	0.076463	0.083107
b	0.705107	0.610483	0.531162	0.463654	0.405472	0.354795
a	1.543095	1.456837	1.385833	1.326597	1.276646	1.234160
mid point	9	9.25	9.5	9.75	10	10.25
r	0.090054	0.097346	0.105038	0.113190	0.121875	0.131183
b	0.310263	0.270841	0.235732	0.204315	0.1761	0.1507
a	1.197777	1.166467	1.139422	1.116014	1.09574	1.07821

Table 9.10 Values of r and constants a and b for different mid points for the range -5 to 15

The mid value point for the decision maker Sani for the cost attribute is equal 8%, therefore from Table 9.10, the value of r=0.06393, value of b= 0.5321, and value of a=1.3858 so the utility functions for cost is.

$$u(c) = 1.3858 - 0.5312\ e^{0.06393c} \qquad (9.14)$$

Figures 9.5 (a,b,c) shows the lotteries for building the utility functions of cost while Figure 9.6 shows the utility curve for the cost attribute.

9.6.3 Quality utility functions u(q).

Using the same principle as for time and cost by offering a decision maker different lotteries, the only difference in this case is that the function is monotonically increasing which means the higher the better and the limits are ranging from -15% to +5%. The consequences preferred for different utility values by the people interviewed were shown in Table 9.11.

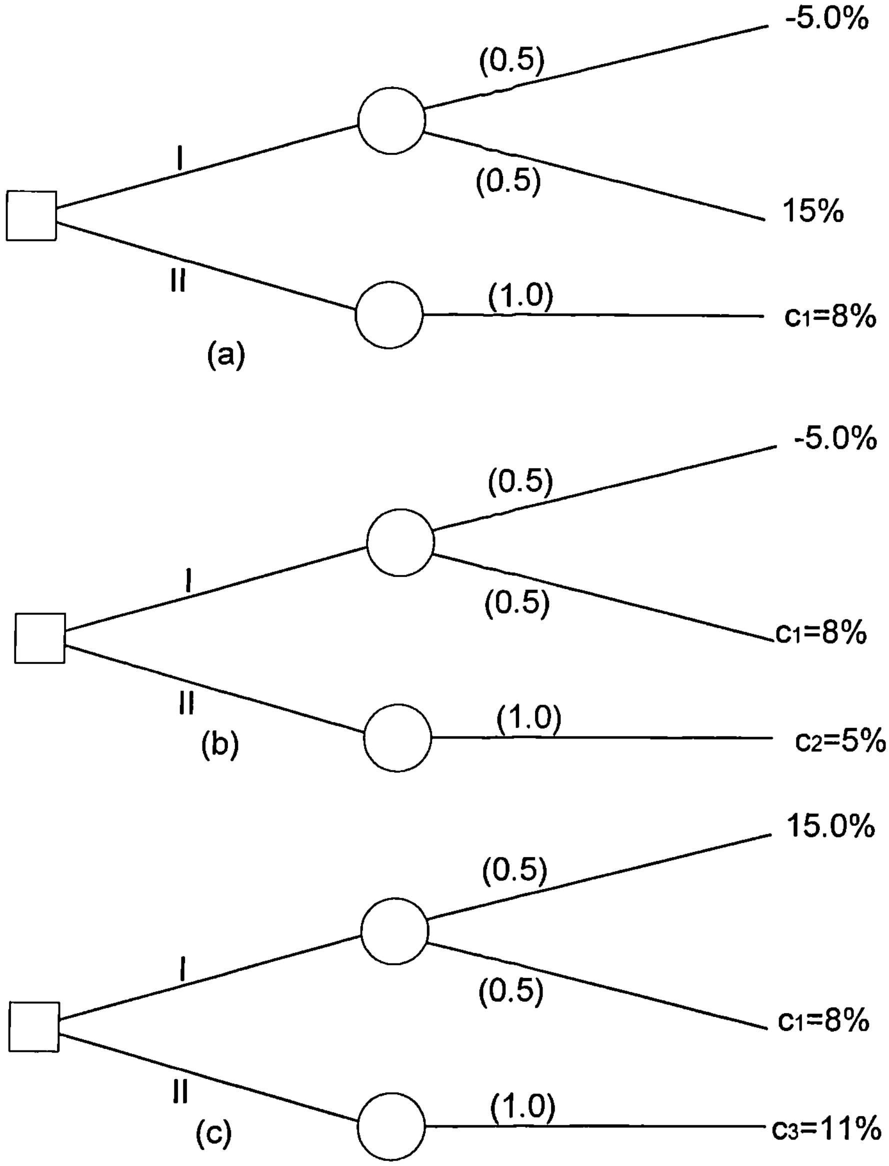

Fig 9.5 Lotteries for building cost utility function

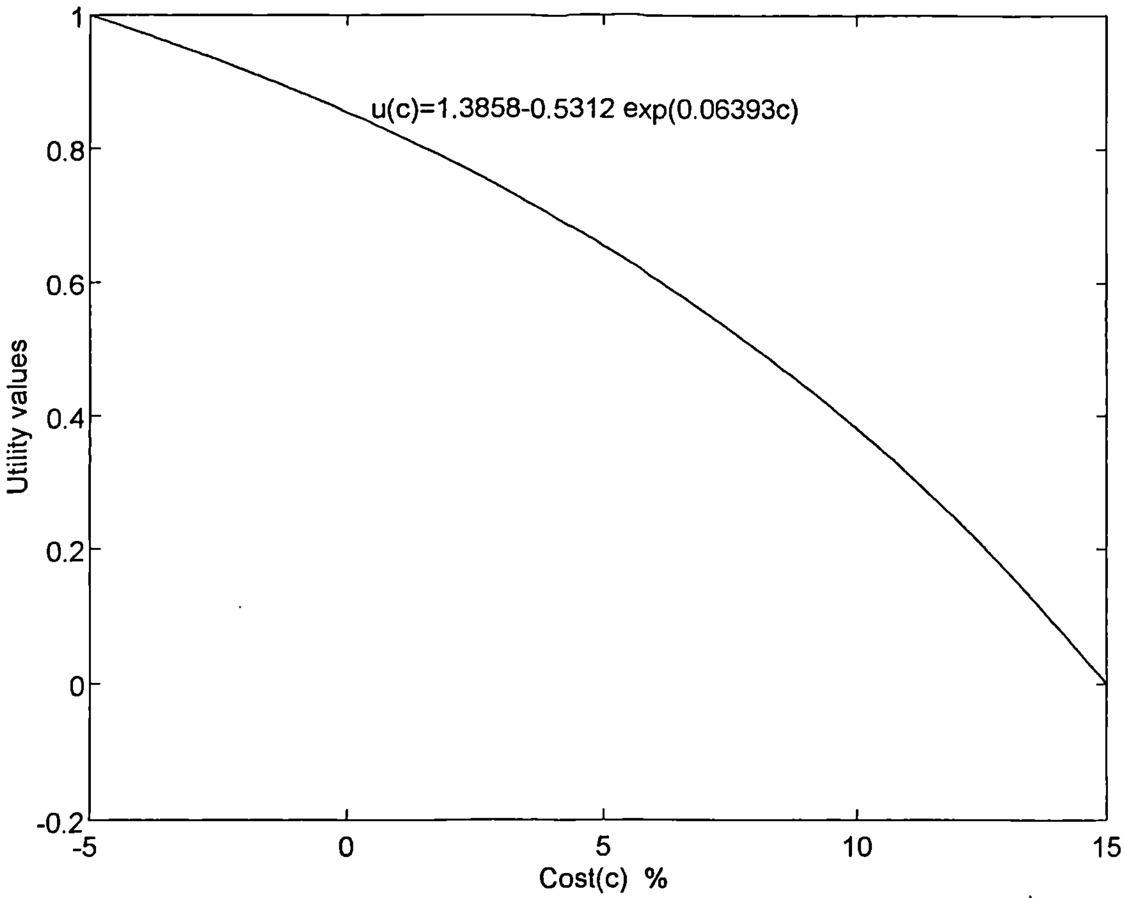

Fig. 9.6 Cost utility curve

Attribute	Decision maker	The consequence preferred by different decision maker for different utility values				
				mid point		
		1	0.75	0.5	0.25	0
Quality	Sani	5	-5	-7.5	-10	-15
	Hussain	5	-3.5	-8	-11.5	-15
	Mislati	5	-5.25	-10.1	-10.6	-15
	Jamal	5	-9.25	-11.25	-13.25	-15
	Latif	5	-4.75	-7.5	-10.75	-15
	Oztash	5	-2.75	-6.75	-9.25	-15
	Ali	5	-4.5	-8	-11	-15

Table 9.11 Consequences preferred by different decision makers for different utility values for the quality attribute

In this case a logarithmic function is found the best that could fits the points preferred by the decision maker, the utility function $u(q) = a \ln (q+\beta)+b$ equation (9.7) is therefore taken to represent the quality utility function. The utility values for -15% and +5% are assigned 0 and 1 respectively. From the same decision maker it was found that -7.5% is indifferent to a lottery yields either -15% or +5% with equal probability (see Table 9.11), this means u(q=-7.5%)=0.5. Substitute with these values in the assumed form we get

$$1 = a \ln (5+\beta)+b$$

$$0.5 = a \ln (-7.5+\beta)+b$$

$$0 = a \ln (-15+\beta)+b$$

solving these three equations we get β=26.25, a=0.9788, and b=-2.369, therefore

$$\mathbf{u(q) = 0.9788 \ln(q+26.25)-2.369} \qquad \mathbf{(9.15)}$$

Figures 9.7(a,b,c) shows the lotteries for building the utility functions of quality while figure 9.8 shows the utility curve for quality attribute.

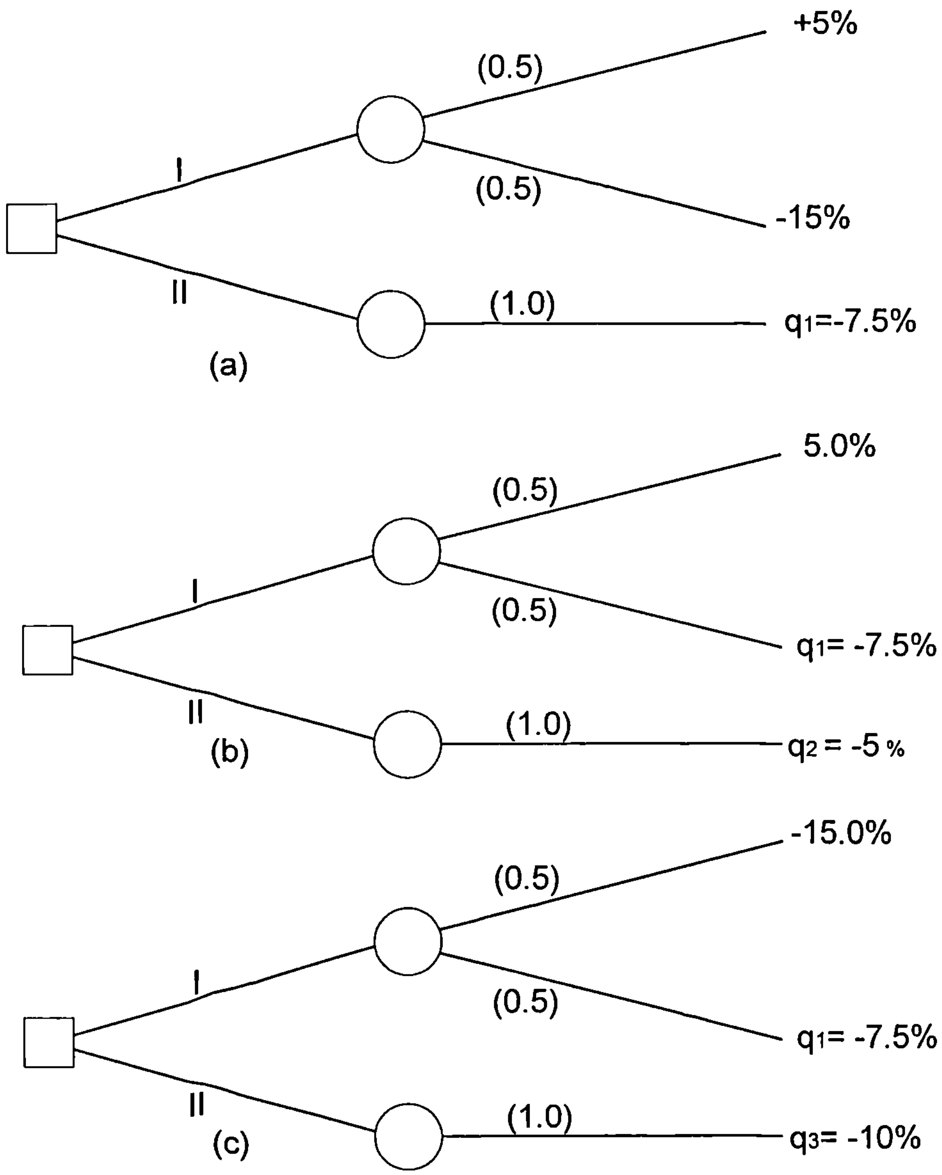

Fig 9.7 Lotteries for building quality utility function

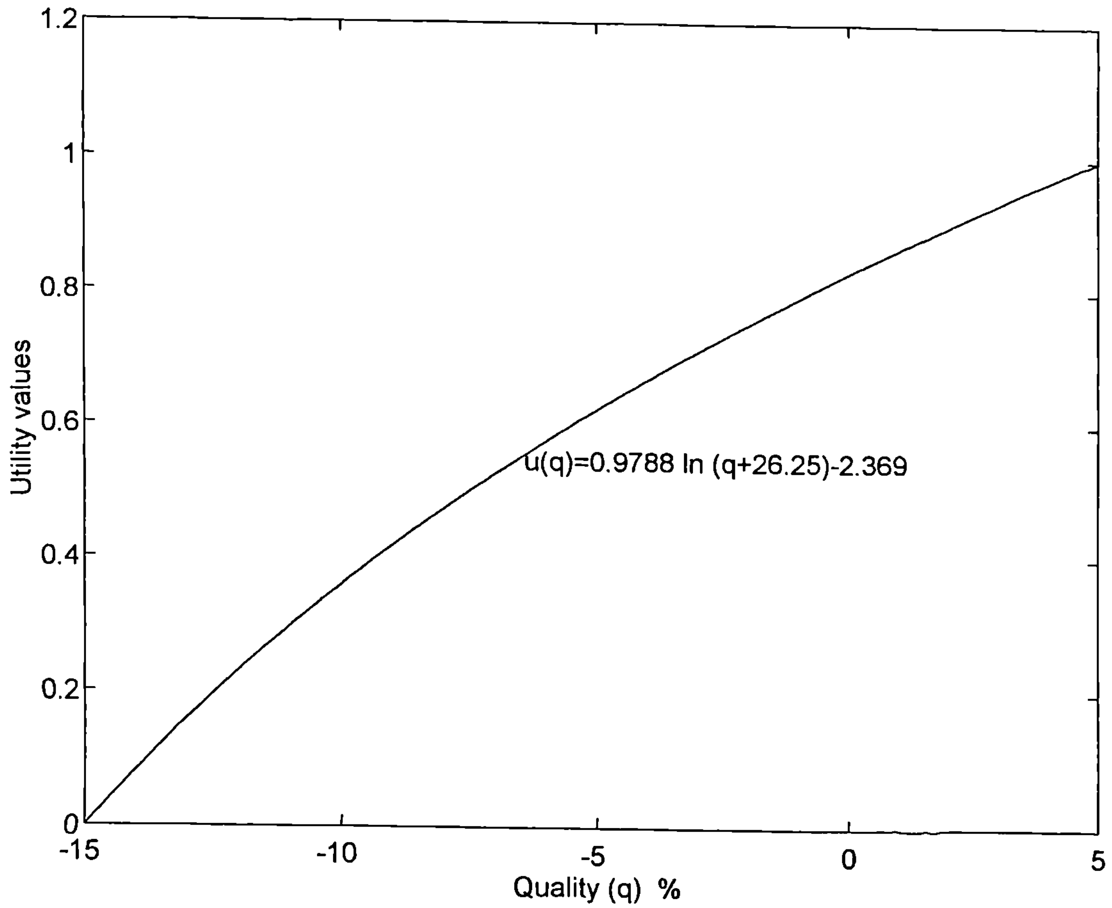

Fig. 9.8 Quality utility curve

Table 9.12 shows the values of β, a, and b for this specific function for different mid value points.

Note: After assessing the mid value points for time, cost and quality for any decision maker Tables 9.7, 9.8, 9.10 and 9.12 could be used directly to get the values of r, a, b, and β, for these specific utility functions and for these specific boundaries, but still checking for other points is advisable.

Mid point	-5.75	-6	-6.25	-6.5	-6.75	-7	-7.25	-7.5
β	72.05	55.5	45.65	39.1	34.45	31	28.35	26.25
a	3.3275	2.4916	1.9908	1.6549	1.4141	1.2331	1.0922	0.9788
b	-13.46	-9.222	-6.813	-5.266	-4.197	-3.419	-2.831	-2.369
Mid point	-7.75	-8	-8.25	-8.5	-8.75	-9	-9.25	-9.5
β	24.55	23.15	22	21.05	20.2	19.5	18.9	18.35
a	0.8853	0.8067	0.7407	0.685	0.6336	0.5901	.5516	.51503
b	-1.997	-1.693	-1.441	-1.232	-1.045	-.8875	-.7507	-.6226
Mid point	-9.75	-10	-10.25	-10.5	-10.75	-11	-11.25	-11.5
β	17.9	17.5	17.15	16.85	16.55	16.35	16.15	15.95
a	.4839	.4551	.4287	.40502	.3799	.3622	.3432	.3233
b	-.5152	-.4170	-.3282	-.2492	-.1665	-.1087	-.0479	.01658

Table 9.12 Values of β, and constants a and b for different mid points for logarithmic function for the range 5 to -15

Having defined the independent utility functions u(t), u(c), and u(q) equations(9.13,9.14,9.15) the only missing parameters needed to find the joint utility function u(t,c,q) equation 9.2 is the scaling constants k_t, k_c, k_q, and k. The scaling constants could be found using the following procedure.

9.7 EVALUATING SCALING CONSTANTS

The formulation of the joint utility function in equation (9.2) is based on the following conditions:

1. Utility is normalized by $u(t^{17}, c^{15}, q^{-15})=0.00$ and $u(t^{-5}, c^{-5}, q^{5})=1$

   in other words the best consequence of (t,c,q) was assigned a utility value 1, while the worst was assigned 0.0
2. u(t) is a conditional utility function *on t, normalized by* $u(t^{-5})=1.00$*.and* $u(t^{17})=0.00$*,* here the best (t%) was assigned a utility value 1 and the worst (t%)was assigned 0.0
3. u(c) is a conditional utility function on c, normalized by $u(c^{-5}) = 1.00$.and $u(c^{15}) = 0.00$
4. u(q) is a conditional utility function on q, normalized by $u(q^{5}) = 1.00$.and $u(q^{-15}) = 0.00$
5. $k_t = u(t^{-5}, c^{15}, q^{-15})$, $k_c = u(t^{17}, c^{-5}, q^{-15})$, $k_q = u(t^{17}, c^{15}, q^{5})$

In addition, the general scaling factor, k, is a solution to

$$\mathbf{(1+k)=(1+kk_t)(1+kk_c)(1+kk_q)} \qquad \mathbf{(9.16)}$$

Equation (9.16) was obtained by substituting in equation (9.3)

$$\mathbf{k\ u(t,c,q) + 1 = (kk_tu(t)+1)(kk_cu(c)+1)(kk_qu(q)+1)} \qquad \mathbf{(9.3)}$$

by t=-5%, c=-5% and q=5%

$$k\ u(t^{-5},c^{-5},q^{5})+1 = (kk_tu(t^{-5})+1)\ (kk_cu(c^{-5})+1)\ (kk_qu(q^{5})+1)$$

By substituting in the joint utility function u(t,c,q) and the conditional or independent utility functions u(t), u(c) and u(q) in equation 9.3, from the conditions 1, 2, 3, and 4 we get equation (9.16).

Keeney and Raiffa (1993) has shown that if Σ of k_t, k_c, k_q is greater than 1, then $-1 < k < 0$; if Σ of k_t, k_c, k_q is less than 1, then $k > 0$.

In order to find the scaling constant k_t which is equal= $u(t^{-5}, c^{15}, q^{-15})$, condition 5. **[note:** k_t is equal the utility value at maximum or best consequence of (t%) and at the minimum or worst consequence of c and q**]**, the decision maker was asked about the probability (p) that makes him indifferent between the consequence (t=-5%, c=15%, q=-15%) and the lottery yields either to the maximum values of t, c, q or to the minimum values of t, c, q with equal probabilities Figure 9.9 a, in this case the lottery could be written as <(-5,-5,5),(17,15,-15)>. The procedure followed for finding k_t is the same procedure as in the hypothetical example described in chapter 6.

The value of k_t is equal the utility value of the joint consequence at (t=-5%, c=15%, q=%-15) which must equal the expected utility of the lottery <(-5,-5,5),(17,15,-15)> since they are indifferent at certain probability preferred by the decision maker

$$(-5, 15, -15) \sim <(-5,-5,5), p, (17,15,-15)>$$

The decision maker found that p=0.45 makes him indifferent between the tow lotteries. Then,

$$u(-5, 15, -15) = p\, u(-5,-5,5) + (1 - p)\, u(17,15,-15)$$

From condition 1

$$u(17, 15,-15) = 0.0 \qquad\qquad u(-5, -5, 5) = 1.0$$

So $\quad u(-5, 15, -15) = 0.45\,(1) + (1-0.45)(0) = 0.45 \qquad$ therefore k_t=0.45

In a similar way, k_c, k_q can be evaluated. Figure 9.9 (b and c) shows the lotteries and the equivalent consequences for assessing k_c and k_q.

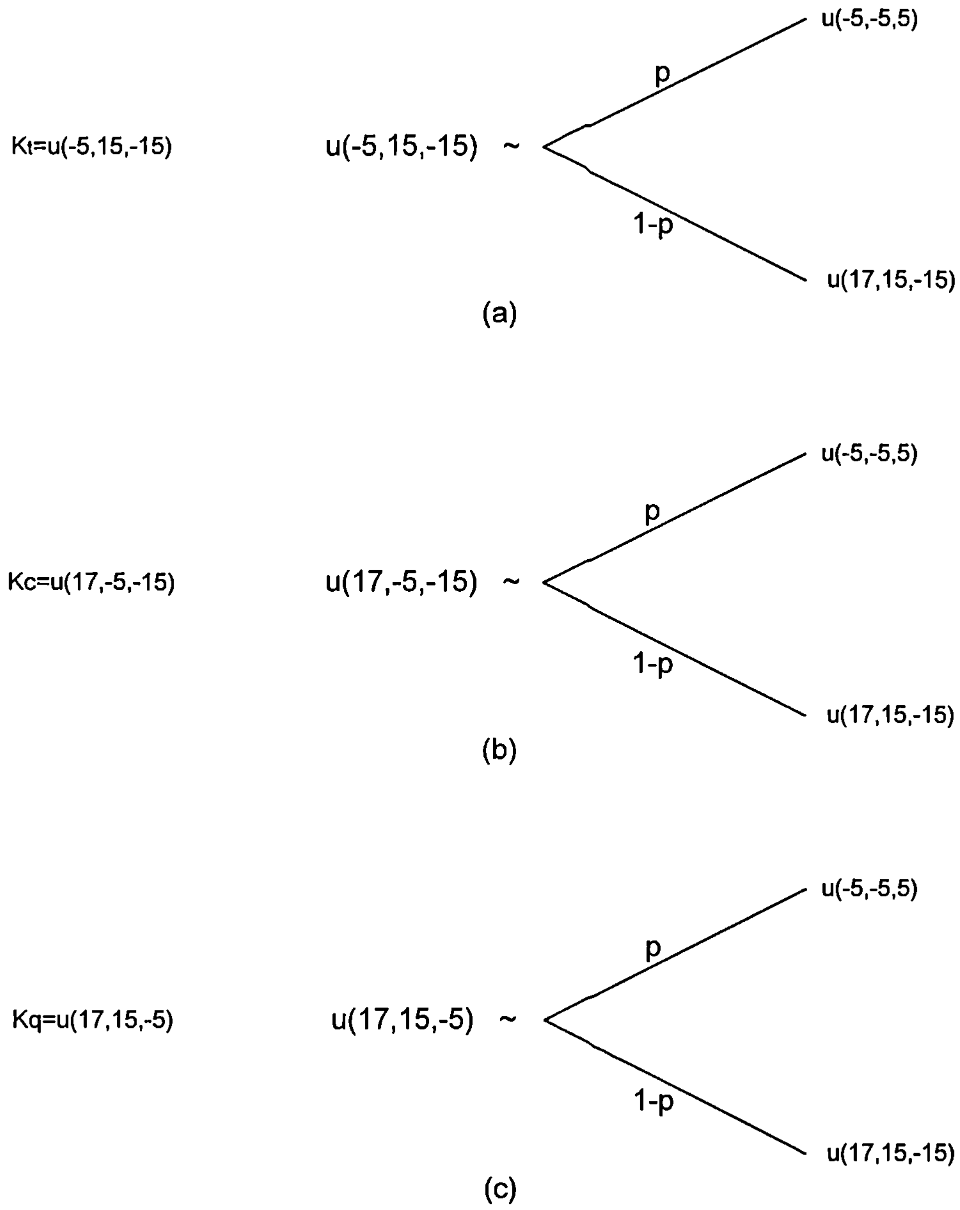

Fig. 9.9 Lotteries for finding the scaling constants k_t, k_c, and k_q.

In order to find the scaling constant k_c which is equal= $u(t^{17}, c^{-5}, q^{-15})$

[note: k_c is equal the utility value at maximum or best consequence of (c%) and at the minimum or worst consequence of t and q] the decision maker was asked about the probability that makes him indifferent between the consequence at (t=17%, c=-5%, q=-15%) and the lottery yields either to the maximum values of t, c, q or the minimum values of t, c, q in this case the lottery is <(-5,-5,5),(17,15,-15)>.

The value of k_c is equal the utility of the joint consequence which must equal the expected utility of the lottery since they are indifferent at that particular probability assigned by the decision maker Figure 9.9b.

$$(17, -5, -15) \sim <(-5,-5,5), p, (17,15,-15)>$$

The decision maker found that p =0.45 makes him indifferent between the two lotteries. Then,

$$u(17, -5, -15) = p\, u(-5,-5,5) + (1 - p)\, u(17,15,-15)$$

From condition 1

$$u(17, 15,-15) = 0.0 \qquad\qquad u(-5, -5, 5) = 1.0$$

So $\quad u(17, -5, -15) = 0.45\,(1) + (1-0.45)(0) = 0.45 \qquad$ therefore k_c=0.45

To find the scaling constant k_q which is equal= $u(t^{17}, c^{15}, q^{5})$ **[note:** k_q is equal the utility value at maximum or best consequence of (q%) and at the minimum or worst consequence of t and c] the decision maker was asked about the probability that makes him indifferent between the consequence at (t=17%, c=15%, q=5%) and the lottery yields either to the maximum values of t, c, q or to the minimum values of t, c, q in this case the lottery is <(-5,-5,5),(17,15,-15)> which similar to that used for finding k_t and k_c

The value of k_q is equal the utility of the joint consequence which must equal the expected utility of the lottery since they are indifferent at a particular probability assigned by the decision maker Figure 9.9c.

$$(17, 15, 5) \sim <(-5,-5,5), p, (17,15,-15)>$$

The decision maker found that p =0.45 also makes him indifferent between the two lotteries. Then,

$$u(17, 15, 5) = p\ u(-5,-5,5) + (1 - p)\ u(17,15,-15)$$

From condition 1

$$u(17, 15,-15) = 0.0 \qquad u(-5, -5, 5) = 1.0$$

So $\quad u(17, 15, 5) = 0.45\ (1) + (1-0.45)(0) = 0.45 \quad$ therefore k_q=0.45

Since Σ k_t, k_c, k_q is greater than 1 i.e 0.45+0.45+0.45=1.35 therefore the general scaling constant k is between -1 and 0 i.e $-1< k <0$, by substituting the values of k_t, k_c, k_q in equation (9.16) we get the value of k= -0.637 and this could be evaluated as follows:

$$\mathbf{1+k=(1+kk_t)(1+kk_c)(1+kk_q)} \qquad \mathbf{(9.16)}$$

$$1+k=(1+0.45k)(1+0.45k)(1+0.45k)$$
$$=(1+0.45k+0.45k+0.2025k^2)(1+0.45k)$$
$$=1+0.45k+0.45k+0.2025k^2+0.45k+0.2025k^2+0.2025k^2+0.091125k^3$$
$$1+k=1+1.35k+0.6075k^2+0.091125k^3 \quad \text{or} \quad 0= +0.35k + 0.6075\ k^2+ 0.091125\ k^3$$

divide by k

$$0.091125\ k^2+ 0.6075\ k + 0.35 = 0$$

k could be found using the general formula $\quad k=(-B \pm \sqrt{B^2 - 4\ A\ C})/2A$ where

A =0.091125, B =0.6075, C =+0.35 solving the equation using the formula

we get k= -0.637

Table 9.13 shows the scaling constants as assigned by the seven professionals interviewed.

Decision maker	k_t	k_c	k_q	k
Sani	0.45	0.45	0.45	-0.63699
Hussain	0.3	0.575	0.225	-0.2789
Mislati	0.275	0.325	0.525	-0.32108
Jamal	0.05	0.05	0.525	5.968
Latif	0.325	0.325	0.425	-0.20115
Oztash	0.375	0.425	0.475	-0.5527
Ali	0.35	0.4	0.475	-0.7877

Table 9.13 Scaling constants k_t, k_c, and k_q assigned by different decision makers and the corresponding constant k

At this stage all the elements needed for the joint utility function equation (9.2) for our decision maker was determined. So by substituting by the independent utility functions equations (9.13,9.14,9.15) and scaling constants k_t, k_c, k_q, and k in equation (9.2)

$$\mathbf{u(t,c,q) = k_t u(t)+ k_c u(c) + k_q u(q) +kk_t k_c u(t)u(c)+kk_t k_q u(t)u(q)+kk_c k_q u(c)u(q)}$$
$$\mathbf{+k^2 k_t k_c k_q u(t)u(c)u(q)} \qquad \mathbf{(9.2)}$$

We get the following equation which is the joint utility function and it represents the preferences of the decision maker in terms of the three attributes time(T), cost(C), and quality(Q).

$$\mathbf{u(t,c,q) = 0.45\ (1.3417 - 0.4663\ e^{0.06216t})}$$
$$\mathbf{+0.45(\ 1.3858\text{-}0.5312\ e^{0.06393c})}$$
$$\mathbf{+0.45(0.9788\ ln\ (q+26.25)\text{-}2.369)}$$

$$\mathbf{-0.637x0.45x0.45\ (1.3417\text{-}0.4663\ e^{0.06216t})(\ 1.3858\text{-}0.5312\ e^{0.06393c})\text{-}0.637x0.45x0.45\ (1.3417\text{-}0.4663\ e^{0.06216t})(0.9788\ ln\ (q+26.25)\text{-}2.369)\text{-}0.637x0.45x0.45(\ 1.3858\text{-}0.5312\ e^{0.06393c})\ (0.9788\ ln\ (q+26.25)\text{-}2.369)}$$

$$\mathbf{-0.637x\text{-}0.637x0.45x0.45x0.45(1.3417\text{-}0.4663\ e^{0.06216t})(\ 1.3858\text{-}0.5312\ e^{0.06393c})\ (0.9788\ ln(q+26.25)\text{-}2.369)} \qquad \mathbf{(9.17)}$$

9.8 EXPECTED UTILITY FOR THE FOUR CONTRACTORS

The expected utility E(U) from any of the four contractor A, B, C, and D could be found using the same principle in equation (9.10). The expected utility of a given action in terms of three attributes may be expressed as follows.

$$E(U) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} u(t,c,q)f(t)f(c)f(q)dtdcdq \qquad \textbf{(9.18)}$$

The expected utility of contractor A could be found using equation (9.18) where the limits of integration is the maximum and minimum limits Found earlier in Table 9.3.

$$E(U) = \int_{-6.9}^{4.9} \int_{-1.5}^{13.5} \int_{-.77}^{16.77} u(t,c,q)f(t)f(c)f(q)dtdcdq \qquad \textbf{(9.19)}$$

As indicated in equation (9.11)., an approximate expected utility value may be computed on the basis of the mean and variance of the pertinent random variables(T, C, Q). In practice, the first two statistical moments could be all the information that may be available for a random variable; hence, Equation (9.11) provides a convenient approximate formula for computing the expected utility of a given alternative.

From Table 9.2. For contractor A the expected mean value of time, cost and quality are 8%, 6%, -1% respectively and the variances are 4.84, 3.57, 2.25 respectively. Using these information and the joint utility function in equation (9.17), it is possible to find the expected utility of contractor A, by substituting these information in equation (9.19), we get equation 9.20.

$$E(U)_A = \int_{-6.9}^{4.98}\int_{-1.5}^{13.5}\int_{-.77}^{16.77} \{0.45\,(1.3417 - 0.4663\, e^{0.06216t})$$

$$+0.45(\,1.3858-0.5312\, e^{0.06393c})$$

$$+0.45(0.9788\ln(q+26.25)-2.369)$$

$$-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216t})(\ 1.3858-0.5312\ e^{0.06393c})-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216t})(0.9788\ \ln(q+26.25)-2.369)-0.637x0.45x0.45(\ 1.3858-0.5312\ e^{0.06393c})\ (0.9788\ \ln(q+26.25)-2.369)$$

$$-0.637x-0.637x0.45x0.45x0.45(1.3417-0.4663\ e^{0.06216t})(\ 1.3858-0.5312\ e^{0.06393c})(0.9788\ \ln(q+26.25)-2.369)\}\ f(t)\ f(c)\ f(q)\ dt\ dc\ dq \quad \textbf{(9.20)}$$

Integrating equation (9.20) term by term using the second approximation as in equation (9.11).

$$\mathbf{E(U)\cong u(\mu x)+1/2\ Var(X)u''(\mu x)} \quad \textbf{(9.11)}$$

μx represents the mean which is in our example the mean values of t, c, q obtained earlier in Table 9.2. and Var(X) represent V_T, V_C, and V_Q from Table 9.2. For the first integration we need to differentiate the joint utility function (9.20) twice with respect to time only, then substitute the value of t by 8% and V_T by 4.84. The result of the first integration using equation (9.11) is.

$$E(U)_A = \int_{-6.9}^{4.98}\int_{-1.5}^{13.5} 0.45\,(1.3417-0.4663\, e^{0.06216x8})$$

$$+0.45(\,1.3858-0.5312\, e^{0.06393c})$$

$$+0.45(\,0.9788\ln(q+26.25)-2.369)$$

$$-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216x8})(\ 1.3858-0.5312\ e^{0.06393c})-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216x8})(0.9788\ \ln(q+26.25)-2.369)-0.637x0.45x0.45(\ 1.3858-0.5312\ e^{0.06393c})(0.9788\ \ln(q+26.25)-2.369\ )$$

$-0.637x\text{-}0.637x0.45x0.45x0.45(1.3417\text{-}0.4663e^{0.06216x8})(1.3858\text{-}0.5312$
$e^{0.06393c})$ $(0.9788 \ln (q+26.25)\text{-}2.369)$

$+ 1/2(V_T=4.84)\{0.45x(0\text{-}0.4663x0.06216x0.06216\ e^{0.06216x8})$
$-0.637x0.45x0.45x(0\text{-}0.4663x0.06216x0.06216\ e^{0.06216x8})(\ 1.3858\text{-}0.5312$
$e^{0.06393c})\text{-}0.637x0.45x0.45x(0\text{-}0.4663x0.06216x0.06216x\ e^{0.06216x8})(0.9788$
$\ln (q+26.25)\text{-}2.369\ )$
$-0.637x\text{-}0.637x0.45x0.45x0.45x(0\text{-}0.4663x.06216x0.06216$
$e^{0.06216x8})(1.3858\text{-}0.5312\ e^{0.06393c})(0.9788 \ln (q+26.25)\text{-}2.369\ )\}\ f(c)\ f(q)\ dc$
dq **(9.21)**

Note for the first integration t=8% and V_T=4.84 are the only parameters substituted in the equation. The result of the first integration is now considered as a function of cost and quality and again equation (9.11) has to be applied to find the integration for this equation, the second derivative of equation (9.21) has to be found with respect to cost only then substitute the value of c by 6% and V_C by 3.57, which result in.

$E(U)_A = \int_{-6.9}^{4.98}\ 0.45\ (1.3417\text{-}0.4663\ e^{0.06216x8})$
$+0.45(\ 1.3858\text{-}0.5312\ e^{0.06393x6})$
$+0.45(\ 0.9788 \ln (q+26.25)\text{-}2.369)$
$-0.637x0.45x0.45\ \ (1.3417\text{-}0.4663\ \ e^{0.06216x8})(\ \ 1.3858\text{-}0.5312\ \ e^{0.06393c})\text{-}$
$0.637x0.45x0.45\ \ (1.3417\text{-}0.4663\ \ e^{0.06216x8})(0.9788\ \ \ln\ \ (q+26.25)\text{-}2.369)\text{-}$
$0.637x0.45x0.45(\ 1.3858\text{-}0.5312\ e^{0.06393x6})(0.9788 \ln (q+26.25)\text{-}2.369\ )$
$-0.637x\text{-}0.637x0.45x0.45x0.45(1.3417\text{-}0.4663\ \ \ e^{0.06216x8})(1.3858\text{-}0.5312$
$e^{0.06393x6})$ $(0.9788 \ln (q+26.25)\text{-}2.369)$
$+ 1/2(V_T=4.84)\{0.45x(0\text{-}0.4663x0.06216x0.06216\ e^{0.06216x8})$
$-0.637x0.45x0.45x(0\text{-}0.4663x0.06216x0.06216\ \ e^{0.06216x8})(\ \ 1.3858\text{-}0.5312$
$e^{0.06393x6})\text{-}0.637x0.45x0.45x(0\text{-}0.4663x0.06216x0.06216x$
$e^{0.06216x8})(0.9788 \ln (q+26.25)\text{-}2.369\ )$
$-0.637x\text{-}0.637x0.45x0.45x0.45x(0\text{-}0.4663x.06216x0.06216$
$e^{0.06216x8})(1.3858\text{-}0.5312\ e^{0.06393x6})(0.9788 \ln (q+26.25)\text{-}2.369\ )\}$
$+1/2(V_C=3.57)\{0.45(\text{-}\ 0.5312\ x0.06393x0.06393\ e^{0.06393x6})$

$-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216x8})(-0.5312\ x0.06393\ x\ 0.06393\ e^{0.06393x6})-0.637x0.45x0.45(-0.5312x0.06393x0.0639\ e^{0.06393x6})(0.9788\ \ln(q+26.25)-2.369\ )$

$-0.637x-0.637x0.45x0.45x0.45(1.3417-0.4663e^{0.06216x8})(-0.5312\ x0.06393x0.06393\ e^{0.06393x6})\ (0.9788\ \ln(q+26.25)-2.369)$

$+1/2(V_T=4.84)\{-0.637x0.45x0.45x(0-0.4663x0.06216x0.06216\ e^{0.06216x8})(-0.5312x0.06393x0.06393\ e^{0.06393x6})$
$-0.637x-0.637x0.45x0.45x0.45x(0-0.4663x.06216x0.06216\ e^{0.06216x8})(-0.5312x0.06393x0.06393\ e^{0.06393x6})(0.9788\ \ln(q+26.25)-2.369\ )\}\}\ f(q)\ dq$ **(9.22)**

The result of the second integration is now considered as a function of quality q and again equation (9.11) has to be applied for this equation to find the result of the third integration, the second derivative of equaition (9.22) has to be found with respect of quality. For the third integration substitute by q=-1% and V_Q=2.25.

$E(U)_A = 0.45\ (1.3417-0.4663\ e^{0.06216x8})$
$+0.45(\ 1.3858-0.5312\ e^{0.06393x6})$
$+0.45(\ 0.9788\ \ln(-1+26.25)-2.369)$
$-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216x8})(\ 1.3858-0.5312\ e^{0.06393x6})-0.637x0.45x0.45\ (1.3417-0.4663\ e^{0.06216x8})(0.9788\ \ln(-1+26.25)-2.369)-0.637x0.45x0.45(\ 1.3858-0.5312\ e^{0.06393x6})(0.9788\ \ln(-1+26.25)-2.369\ )$
$-0.637x-0.637x0.45x0.45x0.45(1.3417-0.4663\ e^{0.06216x8})(1.3858-0.5312\ e^{0.06393x6})\ (0.9788\ \ln(-1+26.25)-2.369)$
$+\ 1/2(V_T=4.84)\{0.45x(0-0.4663x0.06216x0.06216\ e^{0.06216x8})$
$-0.637x0.45x0.45x(0-0.4663x0.06216x0.06216\ e^{0.06216x8})(\ 1.3858-0.5312\ e^{0.06393x6})-0.637x0.45x0.45x(0-0.4663x0.06216x0.06216x\ e^{0.06216x8})(0.9788\ \ln(-1+26.25)-2.369\ )$
$-0.637x-0.637x0.45x0.45x0.45x(0-0.4663x.06216x0.06216\ e^{0.06216x8})(1.3858-0.5312\ e^{0.06393x6})(0.9788\ \ln(-1+26.25)-2.369\ )\}$

$+1/2(V_C=3.57)\{0.45(-0.5312 x0.06393x0.06393 e^{0.06393x6})$

$-0.637x0.45x0.45 (1.3417-0.4663 e^{0.06216x8})(-0.5312 x0.06393 x 0.06393$
$e^{0.06393x6})-0.637x0.45x0.45(-0.5312x0.06393x0.0639 e^{0.06393x6})(0.9788 \ln (-$
$1+26.25)-2.369)$

$-0.637x-0.637x0.45x0.45x0.45(1.3417-0.4663e^{0.06216x8})(-0.5312$
$x0.06393x0.06393 e^{0.06393x6}) (0.9788 \ln (-1+26.25)-2.369)$

$+1/2(V_T=4.84)\{-0.637x0.45x0.45x(0-0.4663x0.06216x0.06216 e^{0.06216x8})(-$
$0.5312x0.06393x0.06393 e^{0.06393x6})$

$-0.637x-0.637x0.45x0.45x0.45x(0-0.4663x.06216x0.06216 e^{0.06216x8})(-$
$0.5312x0.06393x0.06393 e^{0.06393x6})(0.9788 \ln (-1+26.25)-2.369)\}\}$

$+1/2(V_Q=2.25)\{+0.45(-0.9788 (-1+26.25)^{-2})$

$-0.637x0.45x0.45 (1.3417-0.4663 e^{0.06216x8})(-0.9788 (-1+26.25)^{-2})-$
$0.637x0.45x0.45(1.3858-0.5312 e^{0.06393x6})(-0.9788 (-1+26.25)^{-2})$

$-0.637x-0.637x0.45x0.45x0.45(1.3417-0.4663 e^{0.06216x8})(1.3858-0.5312$
$e^{0.06393x6}) (-0.9788 (-1+26.25)^{-2})$

$+1/2(V_T=4.84)\{-0.637x0.45x0.45x(0-0.4663x0.06216x0.06216x$
$e^{0.06216x8})(-0.9788 (-1+26.25)^{-2})$

$-0.637x-0.637x0.45x0.45x0.45x(0-0.4663x.06216x0.06216$
$e^{0.06216x8})(1.3858-0.5312 e^{0.06393x6})(-0.9788 (-1+26.25)^{-2})\}$

$+1/2(V_C=3.57)\{-0.637x0.45x0.45(-0.5312x0.06393x0.0639e^{0.06393x6})(-$
$0.9788 (-1+26.25)^{-2})$

$-0.637x-0.637x0.45x0.45x0.45(1.3417-0.4663e^{0.06216x8})(-0.5312$
$x0.06393x0.06393 e^{0.06393x6}) (-0.9788 (-1+26.25)^{-2})$

$+1/2(V_T=4.84)\{-0.637x-0.637x0.45x0.45x0.45x(0-$
$0.4663x.06216x0.06216 e^{0.06216x8})(-0.5312x0.06393x0.06393 e^{0.06393x6})(-$
$0.9788 (-1+26.25)^{-2})\}\} \}.$ **(9.23)**

$E(U)_A = 0.7284$

The expected utility of contractors A, B, C, and D could be found using the result of the triple integral in equation (9.23) directly by substituting by the values of t, c, q, V_T, V_C, and V_Q correspond to each contractor from Table 9.2.

Since the equation resulted from the triple integration is very long, a simple computer programme was developed using Matlab language, then used to find the expected utility for contractors A, B, C, and D.

9.9 EXPECTED UTILITY USING COMPUTER PROGRAMME

The joint utility function used for this hypothetical example is the multiplicative function (equation 9.2).

$$\mathbf{u(t,c,q) = k_t u(t) + k_c u(c) + k_q u(q) + k k_t k_c u(t)u(c) + k k_t k_q u(t)u(q) + k k_c k_q u(c)u(q)}$$
$$\mathbf{+ k^2 k_t k_c k_q u(t)u(c)u(q)} \qquad \mathbf{(9.2)}$$

The expected utility E(U) for any contractor is the result of the triple integration of equation (9.19). By substituting the multiplicative equation (9.2) in equation (9.19) we get equation 9.24.

$$\mathbf{E(U) = \int\int\int \{k_t u(t) + k_c u(c) + k_q u(q) + k k_t k_c u(t)u(c) + k k_t k_q u(t)u(q) + k k_c k_q u(c)u(q)}$$
$$\mathbf{+ k^2 k_t k_c k_q u(t)u(c)u(q)\}\ f(t)\ f(c)\ f(q)\ dt\ dc\ dq} \qquad \mathbf{(9.24)}$$

To find the triple integration for the equation (9.24), integrate term by term using the approximate formula (9.11). For the first integration, differentiate the joint utility function twice with respect to time.

$$E(U) = \int \int k_t u(t) + k_c u(c) + k_q u(q)$$
$$+kk_t k_c u(t)u(c) + kk_t k_q u(t)u(q) + kk_c k_q u(c)u(q)$$
$$+k^2 k_t k_c k_q u(t)u(c)u(q) +$$

$$(1/2)(V_T)\{k_t u''(t) +$$
$$+kk_t k_c u''(t)u(c) + kk_t k_q u''(t)u(q)$$
$$+k^2 k_t k_c k_q u''t)u(c)u(q)\}\ f(c)\ f(q)\ dc\ dq \tag{9.25}$$

The result of the first integration is considered as a function of cost and quality and again equation (9.11) has to be applied for finding the integration of equation (9.25). The second derivative has to be found with respect to cost only this time.

$$E(U) = \int k_t u(t) + k_c u(c) + k_q u(q)$$
$$+kk_t k_c u(t)u(c) + kk_t k_q u(t)u(q) + kk_c k_q u(c)u(q)$$
$$+k^2 k_t k_c k_q u(t)u(c)u(q) +$$
$$(1/2)(V_T)\{k_t u''(t) +$$
$$+kk_t k_c u''(t)u(c) + kk_t k_q u''(t)u(q)$$
$$+k^2 k_t k_c k_q u''t)u(c)u(q)\}$$

$$+(1/2)(V_C)\{k_c u''(c) + kk_t k_c u(t)u''(c) + kk_c k_q u''(c)u(q)$$
$$+k^2 k_t k_c k_q u(t)u''(c)u(q) +$$
$$(1/2)(V_T)\{kk_t k_c u''(t)u''(c)$$
$$+k^2 k_t k_c k_q u''t)u''(c)u(q)\}\}\ f(q)\ dq \tag{9.26}$$

The result of the second integration is now considered as a function of quality and again formula (9.11) has to be applied for finding the integration of equation (9.26). The second derivative has to be found with respect to quality only.

$$
\begin{aligned}
E(U) = {} & k_t u(t) + k_c u(c) + k_q u(q) \\
& + k k_t k_c u(t)u(c) + k k_t k_q u(t)u(q) + k k_c k_q u(c)u(q) \\
& + k^2 k_t k_c k_q u(t)u(c)u(q) \\
& + (1/2)(V_T)\{k_t u''(t) + k k_t k_c u''(t)u(c) + k k_t k_q u''(t)u(q) \\
& + k^2 k_t k_c k_q u''t)u(c)u(q)\} \\
& + (1/2)(V_C)\{k_c u''(c) + k k_t k_c u(t)u''(c) + k k_c k_q u''(c)u(q) + k^2 k_t k_c k_q u(t)u''(c)u(q) \\
& + (1/2)(V_T)\{k k_t k_c u''(t)u''(c) + k^2 k_t k_c k_q u''t)u''(c)u(q)\}\} \\
& + (1/2)(V_Q)\{k_q u''(q) + k k_t k_q u(t)u''(q) + k k_c k_q u(c)u''(q) \\
& + k^2 k_t k_c k_q u(t)u(c)u''(q) \\
& + (1/2)(V_T)\{k k_t k_q u''(t)u''(q) + k^2 k_t k_c k_q u''t)u(c)u''(q)\} \\
& + (1/2)(V_C)\{k k_c k_q u''(c)u''(q) + k^2 k_t k_c k_q u(t)u''(c)u''(q) \\
& + (1/2)(V_T)\{k^2 k_t k_c k_q u''(t)u''(c)u''(q)\}\}\}
\end{aligned}
\qquad (9.27)
$$

It is clear that the elements representing equation (9.27) are the independent utility functions u(t), u(c), u(q), the second derivative of the independent utility functions u''(t), u''(c), u''(q), and the scaling constants k, k_t, k_c, and k_q. Equation (9.27) could be considered as a general equation to find the expected utility for any three attributes of multiplicative utility function.

Equation (9.27) is still very long and it is quite difficult to use a hand calculation for finding the expected utility, therefore a small computer programme in a matlab (1992) language appendix 9C was developed and used to find the expected utility of contractors A, B, C, and D. The development of the programme is to facilitate the calculation and it was developed as follows. Equation (9.27) could be rewritten as follows.

$$E(U)=f1+f2+f3+f4+f5+f6 \qquad (9.28)$$

Where

$f1=k_t u(t)+k_c u(c)+k_q u(q)$

$f2=kk_t k_c u(t)u(c)+kk_t k_q u(t)u(q)+kk_c k_q u(c)u(q)$

$f3=k^2 k_t k_c k_q u(t)u(c)u(q)$

$f4=(1/2)(V_T)\{k_t u''(t)+kk_t k_c u''(t)u(c)+kk_t k_q u''(t)u(q)+k^2 k_t k_c k_q u''(t)u(c)u(q)\}$

$f5_1=k_c u''(c)+kk_t k_c u''(c)u(t)+kk_c k_q u''(c)$
$u(q)+k^2 k_t k_c k_q u''(c)u(t)u(q)$

$f5_2=kk_t k_c u''(t)u''(c)+k^2 k_t k_c k_q u''(t)u''(c)u(q)$

$f5=(1/2)(V_C)\{f5_1+(1/2)(V_T)\{f5_2\}\}$

$f6_1=k_q u''(q)+kk_t k_q u''(q)u(t)+kk_c k_q u''(q)u(c)+k^2 k_t k_c k_q$
$u''(q)u(t)u(c)$

$f6_2=kk_t k_q u''(t)u''(q)+k^2 k_t k_c k_q u''(t)u''(q)u(c)$

$f6_3=kk_c k_q u''(c)u''(q)+k^2 k_t k_c k_q u''(c)u''(q)u(t)$

$f6_4=k^2 k_t k_c k_q u''(t)u''(c)u''(q)$

$f6=(1/2)(V_Q)\{f6_1+(1/2)(V_T)\{f6_2\}+(1/2)(V_C)\{f6_3+(1/2)(V_T)\{f6_4\}\}\}$

So all what is required are the scaling constants, the independent utility functions and their second derivatives, the expected means for time, cost and quality and their variances. If this procedure is followed in our case, it is possible to find the expected utility for contractor A as follows:

Expected mean for time $t= 8\%$	Mean cost $c= 6\%$	Mean quality $q= -1\%$
Variance of the time $V_T= 4.84$	Variance of cost $V_C= 3.57$	Variance of quality $V_Q= 2.25$
Time scaling constant $k_t= 0.45$	Cost constant $k_c= 0.45$	Quality constant $k_q= 0.45$

find general scaling constant $k= - 0.637$

$u(t)=1.3417-0.4663\ e^{0.06216t} = 0.575$ $\quad u''(t)= -0.4663 \times 0.06216 \times 0.06216\ e^{0.06216t} = - 0.002962$

$u(c)= 1.3858 - 0.5312\ e^{0.06393c} = 0.60625$ $\quad u''(c)= -0.5312 \times 0.06393 \times 0.06393\ e^{0.06393c} = -0.003186$

$u(q)= 0.9788 \ln(q+26.25)-2.369 = 0.79137$ $\quad u''(q)= -0.9788(q+26.25)^{-2} = -0.0015352$

These are considered as an inputs, then find f1 to f6 and substitute in equation (9.28) to get the expected utility. $EU_A=f1+f2+f3+f4+f5+f6$

Table 9.14 shows the utility values and rank order of the four contractors along side their mean and varianc values for time, cost and quality for the decision maker interviewed in this example. Table 9.15 shows the utility values of the four contractors from the seven decision makers interviewed, while Table 9.16 shows the rank-ordr of these contractors by the same decision makers.

Project success factor	Parameter	means and variance of contractors			
		A	B	C	D
Time	mean	8	3	7	2
	variance	4.84	4	4.41	3.0625
Cost	mean	6	8	2	4
	variance	3.57	2.89	2.56	3.24
Quality	mean	-1	0	-3	-7
	variance	2.25	1.96	2.89	4
Expected utility		0.7281	0.7709	0.7693	0.7489
Rank		4	1	2	3

Table 9.14 . Means, variance of time, cost, quality and expected utilities for contractors A,B,C,and D.

Contractor	Sani	Hussain	Mislati	Jamal	Latif	Oztash	Ali
A	0.7281	0.6162	0.7793	0.7214	0.639	0.6609	0.7006
B	0.7709	0.6274	0.8097	0.7541	0.6896	0.7051	0.7391
C	0.7693	0.7094	0.8009	0.7338	0.6735	0.7013	0.7383
D	0.7489	0.6864	0.7570	0.6476	0.6412	0.6616	0.6995

Table 9.15 . Expected utilities for contractors A,B,C,and D by the seven decision makers.

Contractor	Sani	Hussain	Mislati	Jamal	Latif	Oztash	Ali
A	4	4	3	3	4	4	3
B	1	3	1	1	1	1	1
C	2	1	2	2	2	2	2
D	3	2	4	4	3	3	4

Table 9.16 . Ranks of the four contractors A,B,C,and D by the seven decision makers.

9.10 CONCLUSION

Chapter seven presented the likely impact of the criteria identified in chapter 3 on time, cost and quality in terms of pessimistic, average and optimistic values, the incorporating of multiple ratings permit the uncertainty in contractor data to be evaluated, these data were then converted into expected means and variances via the PERT approach. The identification of the anticipated effect that various CSC have on predominant client objectives in terms of time, cost and quality provide a basis for the development of quantitative techniques for contractor selection.

Chapter 8 presented a quantitative technique to combine the contractor data in terms of the three goals. The study also presented an evaluation strategy that involves the consideration both the client goals as ends and contractor data as the means, the strategy based on the aspiration level, risk analysis for the final selection or rank ordering of the contractors based on the preferences of the client.

This chapter 9 presented an evaluation of contractors using the multiattribute utility theory, which allows to incorporate the decision maker attitude towards risk and tradeoffs. The technique combines tangible and intangible attributes into single scale.

A multiattribute utility decision support system for selecting contractors which is presented in this chapter is expected to be a feasible tool to aid in decision-making regarding contractor prequalification. A system that able to make use of the available data, account for uncertainty, prequalify the contractors in terms of the client goals or project success factors in terms of time, cost and quality, and which type of contractor to be prequalified ultimately depends on decision maker attitude to risk and trade-off.

Multiattribute utility theory presented here generally combines the main advantages of simple scoring techniques and optimization models. Further, in situations in which satisfaction is uncertain, utility functions have the property that expected utility can be used as guide to rational decision making.

The following is a brief steps that could be followed for selecting the contractors.

1- Identify the contractors selection criteria (CSC) (take the criteria from chapters 3 or 5, Tables 3.10 - 3.15)

2- Identify your goals (time, cost , quality...)

3- Investigate the effect of CSC on client goals, then find the expected mean and variance of time, cost and quality due to the effect of each criterion (the values found in chapter 7)

4- Identify the weights of the contractor selection criteria, then combine the effects of all criteria on time, cost and quality (chapter 8)

5- Build your time, cost and quality utility functions using the gambling technique described in this chapter 9.

6- Find the scaling constants for time, cost and quality using the gambling method described in this chapter 9.

7- find the expected utility value for each contractor using equation (9.28), then rank order and select the most suitable contractors.

The evaluation technique proposed in this thesis should help clients in selecting contractors and the contractors themselves to select sub-contractors in offering a means of broadening their analysis of tenderers beyond that of simply relying on tender values. It also alerts contractors to the importance of increasing their ability to satisfy the needs of the clients in terms of their ultimate project goals.

This chapter concluded the main work of this thesis, the next chapter eleven is devoted to test the proposed technique using real data from the construction industry.

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10. TESTING AND VALIDATION

CHAPTER 10

Testing and validation

TRAFFORD PARK DEVELOPMENT CORPORATION PARKWAY/M602 LINK ROAD: CONTRACT 4 REPORT ON SELECT LIST

10.1 INTRODUCTION

The Cerestar section of the Parkway/M602 link road is the final contract to be let for the entire scheme and will complete the route through between the Cerestar and Procter & Gamble factories.

The proposed contract comprises the following items of work:

* Demolition of five buildings presently used by Cerestar as Offices, Laboratories and Canteen.
* Construction of a prestressed concrete overbridge spanning a rail track and the main access to the Cerestar factory.
* Construction of a reinforced earth wall embankment.
* Construction of a normal embankment.
* Construction of a low level circulatory road inside a working factory site, including surface water and foul drainage.

The value of the contract is approximately £3.0 million.

A notice was placed in the "Contract Journal" on 10 June 1993 inviting applications from interested firms to be placed on the selection list of tenderers. A copy of the notice is given in appendix 10A. Applications were required to be lodged with Parkman Consulting Engineers by 18 June 1993.

This assessment report on the select list applications has been prepared by Parkman Consulting Engineers on behalf of Trafford Park Development Corporation.

10.2 APPLICATION RECEIVED

Thirty nine applications were received by the closing date from the following firms, listed in alphabetical order.

1 A E Yates
2 Alfred McAlpine
3 Amec
4 Amey
5 Balfour Beattie
6 Birse
7 Casey
8 Chistiani & Nielson
9 Costain
10 DCT Civil Engineering Ltd
11 Dew Group
12 Eric Wright Civil Engineering
13 Fitzpatrick
14 Galliford North West
15 Greenbooth
16 Harbour & General
17 Henry Boot
18 Hewlett Civil Engineering
19 J N Bentley
20 Kennedy
21 Kier
22 Kinmain
23 Lilley
24 May Gurney
25 Midland Construction Company
26 Miller
27 Morrison Construction Ltd
28 Mowlem
29 Norwest Holst
30 Nuttalls
31 Rawlings Brothers
32 Shephard Hill
33 Sisk
34 Tarmac
35 Thyssen
36 Tilbury Douglas
37 Trafalgar House
38 Tysons
39 Wrekin Construction

10.3 ASSESSMENT PROCEDURE

Assessment of the applications was carried out according to the following procedure. Information supplied by the applicant was scrutinized and points awarded in various categories based on the following marking system:

A Company Organisation

i)	Is company organisation satisfactory?	Yes 1 point
ii)	Is management organisation satisfactory?	Yes 1 point
iii)	Is principal activity of firm Civil Engineering?	Yes 1 point
iv)	Has company been established for a minimum of ten years?	Yes 2 point
v)	Does company have a local head or branch office?	Yes 1 point

B Financial Standing

i)	Have copies of company accounts been submitted?	Yes/no 1 point
ii)	Do accounts seem to be in financial order?	Yes/no 2 point
iii)	If yes, has company sufficient annual turnover to support £3M including contract financial banking?	Yes/no 0-5 point
iv)	Have details of firms banker been supplied?	Yes/no 1 point

C Company Resources

I)	Has company good/adequate technical expertise?	Yes/no	max 2/1 points
ii)	Has company good/adequate site staff and operatives?	Yes/no	max 2/1 points
iii)	Has company a good range of general plant?	Yes/no	1 point

D Relevant Experience - Urban Highways

The company was allotted one of the followings:

- Company has demonstrated good previous relevant experience:	5 points
- Company has adequate or limited previous relevant experience:	3 points
- Company may have experience but has not demonstrated clearly:	1 points
- Company has no experience or is not suitable:	0 points

E **Relevant Experience - Urban Bridgeworks**

The company was allotted one of the followings:

- Company has demonstrated good previous relevant experience: 5 points
- Company has adequate or limited previous relevant experience: 3 points
- Company may have experience but has not demonstrated clearly: 1 points
- Company has no experience or is not suitable: 0 points

The points thus allocated have been added together to give a total score for each applicant.

10.4 ASSESSMENT

Notes on the assessment of one of the contractors are shown in Table 10.1. Assessment of some other applicant is given in tabular form in appendix 10B.

FIRM A E YATES **LOCATION** BOLTON

CATEGORY	POINTS AVAILABLE	REMARKS	POINTS
A Company Organisation	1	Satisfactory	1
Management Organisation	1	Satisfactory	1
Nature of Company	1	Civil Engineering inc drainage	1
Years established	2	Established 1870	2
Location	1	Bolton	1
B Company accounts	1	4 yrs accounts submitted	1
Accounts in order T/O large enough for £3m	2	Yes £150k profit before tax	2
contract(Financial banking)	5	£ 6M turnover	2
Firms banker	1	Royal Bank of Scotland	1
C Technical expertise	2	Adequate tech expertise	1
Site staff and operatives	2	Adequate tech expertise	1
Range of plant	1	Not stated	0
D Urban Highways			
Previous relevant experience			
Good	5		
Adequate/limited	3	Adequate previous experience	3
Not demonstrated	1		
None or not suitable	0		
E Urban Bridgeworks			
Previous relevant experience			
Good	5		
Adequate/limited	3	Limited previous experience	3
Not demonstrated	1		
None or not suitable	0		
	max 30	TOTAL SCORE	20

Table 10.1 Assessment of A E YATES firm

The final marking in descending order in terms of score is as follows:

FIRM	SCORE
Amec	30
Birse	29
Tarmac	29
Alfred McAlpine	28
Galliford North West	28
Tilbury Douglas	28
Kier	28
Morrison Construction Ltd	28
Mowlem	28
Trafalgar House	28
Balfour Beattie	28
Chistiani & Nielson	26
Harbour & General	26
Norwest Holst	26
Nuttalls	26
----------	----------
Henry Boot	25
Costain	25
Dew Group	25
Amey	24
May Gurney	24
Miller	24
Thyssen	24
Lilley	23
Sisk	21
A E Yates	20
Shephard Hill	20
Wrekin Construction	20
Kennedy	19
Casey	17
Greenbooth	17
Tysons	17
J N Bentley	16
DCT Civil Engineering Ltd	15
Midland Construction Company	15
Eric Wright Civil Engineering	15
Hewlett Civil Engineering	10
Rawlings Brothers	9
Kinmain	5
Fitzpatrick	2

10.5 FURTHER CONSIDERATION

Firms gaining 26 points or more were carried forward for further consideration, 15 out of the original 39 received fell into this category.

In drawing up the final recommendation for a select list, the following factors have been taken into consideration:

1. Confidential questionnaires (appendix 10C) were sent to several bodies including the two local authorities involved with the scheme.
2. Performance of the firms in question in relation to previous contracts carried out by them on behalf of the corporation, addressing their approach to programming and contract management issues.
3. Attitude and approach to dealing with third parties.
4. The Health and Safety Policy of the firms were examined.
5. Financial security of firms was determined by scrutinizing the accounts as submitted. In general, the overall value of the contract should not exceed 25% of the the annual turnover of the Company or Group of Companies.
6. The geographical location of the firm's base or major branch office in relation to the Manchester area.

The following firms were recommended without reservation to be placed on the select list, because they were included on the previous select lists and have submitted very competitive tenders in each case:

Birse

Amec Civil Engineering Ltd

Kier Construction have also submitted very competitive tenders on recent Contracts but neither Parkman nor any of the bodies who were asked to comment have had any experience of working with this firm.

Other firms who have been considered and were recommended for placing on the select list in order of preference from the questionnaires are:

Galliford North West - Nuttalls - Norwest Holst - Alfred McAlpin - Tarmac

Despite the fact that six other firms gained 26 points or more from the initial assessment, namely "Morrison Construction, Mowlem, Balfour Beattie, Christiani & Nielson, Tilbury Douglas and Trafalger House", slight reservations were identified during these further consideration which have resulted in their marginal rejection.

These reservations resulted from previous experience of the companies on other schemes under the direction of others or were due to the fact that insufficient information on past experience was available to make an assessment.

One firm which scored well in the initial sift and appeared to adequately satisfy the requirements listed is:

Harbour & General

The firm has no track record in the Manchester area but has performed well for Parkman on marine work in Cumbria. However, their previous experience in urban highways is adequate. They are part of a larger group of Companies who would guarantee their financial viability.

10.6 SELECT LIST

Having considered the wishes of Trafford Park Development Corporation and taking review of the applicants into consideration, Parkman recommended that the select list of the tenders for the Parkway/M602 Link Contract 4 should comprise the following nine firms in order for Trafford Park Development Corporation to make their final selection:

Birse - Kier Construction -Amec Civil Engineering Ltd - Harbour&General

Galliford North West- Nuttalls Norwest Holst - Alfreed McAlpine -Tarmac

Parkman recommended for a scheme of this size a maximum number of eight contractors.

10.7 ASSESSMENT AND SELECTION USING UTILITY THEORY

10.7.1 Contractor selection criteria and the scores

The Tables of appendix 10B shows that the decision maker has used some of contractor selection criteria identified in chapters 3 and 5 and he assigned a numeric scale ranging between zero and different maximum points for each one of these criteria or categories as he called them. For example, Company Organisation in Category A is ranging from 0 to 1 point, so in this case the contractor either scores 0 or 1, Technical expertise in category C ranges from 0 to 2 points so the contractor scores 0 or 1 or 2 and so on for the other criteria.

10.7.2 Equivalent criteria and their weights

As mentioned earlier, the decision maker has used some of the criteria identified in chapters three and five. For example, "years established" in category A appendix 10B is set to be equivalent to "length of time in business" Table 3.15, "Firms banker" in category B is set to be equivalent to "Bank arrangements" in Table 3.11 and so on for other criteria. The weights of these equivalent criteria were taken from Table 8.2 chapter 8. Table 10.2 shows the parameters of each category set by Parkman, the maximum score set for each category, the equivalent criteria in chapter 3 and weights of these criteria used for this case.

Real case parameters		Equivalents	
Category	Points available	Equivalent criteria	Weight
A Company Organisation	1	Experience of technical personnel	0.04625
Management Organisation	1	Project management organization	0.040625
Nature of Company	1	Ability	0.075
Years established	2	Length of time in business	0.085
Location	1	Client/Contractor relationship	0.08625
B Company accounts	1	Financial status	0.0665
Accounts in order T/O large enough for £3m	2	Financial status	0.0665
contract(Financial banking)	5	Financial stability	0.05175
Firms banker	1	Bank arrangements	0.04575
C Technical expertise	2	Personnel	0.07875
Site staff and operatives	2	Personnel	0.07875
Range of plant	1	Plant and equipment	0.03625
D <u>Urban Highways</u>		Experience	0.0725
Previous relevant experience			
Good	5		
Adequate/limited	3		
Not demonstrated	1		
None or not suitable	0		
E <u>Urban Bridgeworks</u>		Experience	0.0725
Previous relevant experience			
Good	5		
Adequate/limited	3		
Not demonstrated	1		
None or not suitable	0		

Table 10.2 Parameters of each category, the equivalent criteria and weights of these criteria used for this case.

10.7.3 Expected mean, variance and standard deviation of time, cost and quality due to the affect of contractor selection criteria

Using the values of expected means and variances found earlier in chapter seven (appendix 7C), the expected mean and variance of time, cost and quality due to the effect of each contractor selection criteria were calculated as follows

1- The scores of each contractor for each criterion were taken from theTables of appendix 10B
2- The expected means, standard deviation and variances corresponding to each score were taken from appendix 7C
3- For those scores between zero and maximum point, an interpolation was used to find their means, and standard deviation.

Table 10.3 shows one of the contractors "**A E Yates**" expected mean, standard deviation and variance values of time, cost and quality.

Criteria		Points scored	Expected mean (E),standard deviation(S) and variance(V)		
			E	S	V
Experience of technical personnel	Time Cost Quality	1	100 100 100	1.83 1.67 1.50	3.36 2.78 2.25
Project management organization	Time Cost Quality	1	100 100 100	2.33 1.67 1.5	5.44 2.78 2.25
Ability	Time Cost Quality	1	100 100 100	1.67 1.33 1.5	2.78 1.78 2.25
Length of time in business	Time Cost Quality	2	100 100 100	1.00 1.33 1.33	1 1.78 1.78
Client/contractor relationship	Time Cost Quality	1	100 100 100	1.67 1.50 1.00	2.78 2.25 2
Financial status	Time Cost Quality	1	100 100 100	2.17 1.5 1.33	4.69 2.25 1.78
Financial status	Time Cost Quality	2	100 100 100	2.17 1.5 1.33	4.69 2.25 1.78
Financial stability	Time Cost Quality	2	104.8 104.8 95.80	2.27 2.332 2.17	5.153 5.438 4.69
Bank arrangements	Time Cost Quality	1	100 100 100	1.67 1.67 1.00	2.78 2.78 1.00
Personnel	Time Cost Quality	1	104.5 103.5 95.5	2 1.75 1.585	4 3.063 2.512
Personnel	Time Cost Quality	1	104.5 103.5 95.5	2 1.75 1.585	4 3.063 2.512
Plant and equipment	Time Cost Quality	0	109 106 97	2.5 2.33 1.5	6.25 5.44 2.25
Experience	Time Cost Quality	3	104 104 97.2	2.468 2.134 1.9	6.091 4.554 3.61
Experience	Time Cost Quality	3	104 104 97.2	2.468 2.134 1.9	6.091 4.554 3.61

Table 10.3 Expected mean, standard deviation and variance of **A E Yates**

To find the aggregate means and standard deviation, the equations (8.7 to 8.15) used in chapter eight were used again here, note that the sum of weights of criteria in Table 10.2 is equal to 0.902375. In order to make this sum equal to 1, each one of the list of the criteria was multiplied by 1.1082 and used in equations 8.7 to 8.15. Table 10.4 shows the means, standard deviation and variance of the contractor selection criteria alongside the weights of **A E Yates firm**, while Table 10.5 shows the aggregate expected mean, standard deviation and variance of time, cost and quality.

Criteria		Weight	Expected mean (E), standard deviation(S) and variance(V)		
			E	S	V
Experience of technical personnel	Time Cost Quality	0.0511	100 100 100	1.83 1.67 1.50	3.36 2.78 2.25
Project management organization	Time Cost Quality	0.0450	100 100 100	2.33 1.67 1.5	5.44 2.78 2.25
Ability	Time Cost Quality	0.083	100 100 100	1.67 1.33 1.5	2.78 1.78 2.25
Length of time in business	Time Cost Quality	0.094	100 100 100	1.00 1.33 1.33	1 1.78 1.78
Client/contractor relationship	Time Cost Quality	0.0955	100 100 100	1.67 1.50 1.00	2.78 2.25 2
Financial status	Time Cost Quality	0.0736	100 100 100	2.17 1.5 1.33	4.69 2.25 1.78
Financial status	Time Cost Quality	0.0736	100 100 100	2.17 1.5 1.33	4 69 2.25 1.78
Financial stability	Time Cost Quality	0.0573	104.8 104.8 95.80	2.27 2.332 2.17	5.153 5.438 4.69
Bank arrangements	Time Cost Quality	0.0507	100 100 100	1.67 1.67 1.00	2.78 2.78 1.00
Personnel	Time Cost Quality	0.0872	104.5 103.5 95.5	2 1.75 1.585	4 3.063 2.512
Personnel	Time Cost Quality	0.0872	104.5 103.5 95.5	2 1.75 1.585	4 3.063 2.512
Plant and equipment	Time Cost Quality	0.04017	109 106 97	2.5 2.33 1.5	6 25 5.44 2.25
Experience	Time Cost Quality	0.0803	104 104 97.2	2.468 2.134 1.9	6.091 4.554 3.61
Experience	Time Cost Quality	0.0803	104 104 97.2	2.468 2.134 1.9	6.091 4.554 3.61

Table 10.4 Expected mean, standard deviations, variances and weights of **A E Yates**

Aggregate Expected mean=sum of weights times individual means		Aggregate variance= sum of(wight x standard deviation)^2	Aggregate standard deviation = sqrt of aggregate variance
Time	102.522	0.30486	0.55214
Cost	102.227	0.22874	0.47827
Quality	98.826	0.18085	0.42527

Table 10.5 Aggregate expected mean, standard deviation and variance of time, cost and quality of **A E Yates** firm

Using similar procedure, the aggregate expected mean, and variance of time, cost and quality for all contractors were calculated. Table 10.6 shows the aggregate mean, aggregate standard deviation and aggregate variance in terms of time, cost and quality for all contractors.

Firm		Aggregate values		
		AE	AV	AS
A E Yates	Time Cost Quality	102.52 102.23 98.83	0.304 0.228 0.180	0.55 0.47 0.42
Alfred McAlpine	Time Cost Quality	101.31 101.41 99.66	0.257 0.228 0.178	0.51 0.47 0.42
Amec	Time Cost Quality	100.44 100.44 100.44	0.253 0.181 0.155	0.50 0.43 0.39
Amey	Time Cost Quality	103.34 102.57 98.12	0.338 0.246 0.208	0.58 0.49 0.45
Balfour Beattie	Time Cost Quality	102.42 101.81 99.29	0.300 0.200 0.171	0 54 0.44 0.41
Birse	Time Cost Quality	100.88 100.75 100.08	0.26 0.184 0.160	0.51 0.43 0.4
Casey	Time Cost Quality	104.09 103.46 97.37	0.375 0.288 0.224	0 61 0.54 0.47
Christian & Nielson	Time Cost Quality	102.06 101.96 99.15	0.268 0.236 0.183	0 52 0.48 0.43
Costain	Time Cost Quality	102.57 102.36 98.98	0.331 0.288 0.219	0.57 0.54 0.47

DCT Civil Engineering Ltd	Time Cost Quality	104.38 103.66 96.97	0.345 0.226 0.195	0.58 0.47 0.44
Dew Group	Time Cost Quality	102.68 102.14 98.84	0.305 0.213 0.179	0.55 0.46 0.42
Eric Wright Civil Eng.	Time Cost Quality	104.37 103.66 96.98	0.345 0.226 0.195	0.58 0.47 0.44
Fitzpatrick	Time Cost Quality	108.35 107.43 94.31	0.513 0.402 0.28	0.71 0.63 0.53
Galliford North West	Time Cost Quality	100.99 100.91 99.93	0.264 0.189 0.161	0 51 0.43 0.4
Greenbooth	Time Cost Quality	104.01 103.32 97.39	0.335 0.234 0.192	0.57 0.48 0.44
Harbour & General	Time Cost Quality	101.81 101.84 99.57	0.283 0.243 0.189	0.53 0 49 0.43
Henry Boot	Time Cost Quality	101.97 101.63 99.33	0.284 0.204 0.174	0.53 0.45 0.42
Hewlett Civil Eng.	Time Cost Quality	104.87 104.59 96.68	0.373 0.331 0.242	0.61 0.57 0.49
J N Beentley	Time Cost Quality	105.18 104.45 96.68	0.352 0.272 0.219	0.59 0.52 0.46
Kennedy	Time Cost Quality	103.75 103.13 97.91	0.336 0.237 0.197	0.58 0.48 0.44
Kier	Time Cost Quality	100.77 100.77 100.20	0.267 0.193 0.164	0.52 0.44 0.41
Kinmain	Time Cost Quality	108.24 107.31 94.09	0.533 0.407 0.29	0.73 0.64 0.54
Lilley	Time Cost Quality	102.7 102.23 98.51	0.29 0.208 0.175	0 54 0.46 0.42
May Gurney	Time Cost Quality	102.19 102.21 98.92	0.284 0.248 0.194	0.53 0.49 0.44
Midland Construction Comp.	Time Cost Quality	103.99 103.76 97.35	0.327 0.279 0.212	0.57 0.53 0.46
Miller	Time Cost Quality	102.69 102.16 98.76	0.296 0.205 0.171	0.54 0.45 0.41
Morrison Construction Ltd.	Time Cost Quality	101.38 101.15 99.79	0.273 0.188 0.16	0.52 0.43 0.4
Mowlem	Time Cost Quality	101.25 100.99 99.95	0.265 0.191 0.163	0.51 0.44 0.41
Norwest Holst	Time Cost Quality	101.84 101.53 99.18	0.277 0.194 0.168	0.52 0 44 0.41
Nuttall	Time Cost Quality	102.19 101.70 99.31	0.286 0.197 0.168	0 53 0.44 0.41
Rawlings Brothers	Time Cost	106.95 105.95	0.498 0.364	0.71 0.60

	Quality	95.15	0.264	0.51
Shephard	Time Cost Quality	103.55 103.2 97.77	0.315 0.246 0.202	0.56 0.49 0.45
Sisk	Time Cost Quality	102.93 102.56 98.25	0.354 0.257 0.217	0.59 0.51 0.46
Tarmac	Time Cost Quality	100.99 100.84 100.18	0.268 0.186 0.158	0.52 0.43 0.39
Thyssen	Time Cost Quality	102.36 102.31 99.06	0.294 0.251 0.195	0.54 0.50 0.44
Tilbury Douglas	Time Cost Quality	100.77 100.77 100.2	0.266 0.193 0.164	0.51 0.43 0.4
Trafalgar House	Time Cost Quality	101.19 100.98 99.92	0.263 0.19 0.16	0.51 0.43 0.40
Tysons	Time Cost Quality	103.81 103.65 97.55	0.337 0.289 0.226	0.58 0.54 0.47
Wrekin Construction	Time Cost Quality	104.01 103.48 97.63	0.32 0.264 0.209	0.56 0.51 0.46

Table 10.6 Aggregate (mean, variance and standard deviation) for all contractors

10.7.4 Utility values and rank order of contractors using utility theory

Having calculated the aggregate mean and variance values of time, cost and quality for all contractors, the computer programme developed in appendix 9C was used to find the expected utility value of each contractor in terms of the three attributes (t,c,q). Due to the difficulty of finding the decision maker who made the earlier assessment of these contractors for this case, the utility function (9.17) of Mr Sani detailed in chapter 9, was used to find the expected utility values of all contractors. Table 10.7 shows the utility values and rank orders of all contractors listed in alphabetical order, while Table 10.8 shows the contractors listed in ranking order.

	Firm	Utility value	Rank order
1	A E Yates	0.8388	18
2	Alfred McAlpine	0.8663	9
3	Amec	0.8899	1
4	Amey	0.8196	23
5	Balfour Beattie	0.8489	15
6	Birse	0.8800	3
7	Casey	0.7932	29
8	Chistiani & Nielson	0.8491	14
9	Costain	0.8385	19
10	DCT Civil Engineering Ltd	0.7833	31
11	Dew Group	0.8385	19
12	Eric Wright Civil Engineering	0.7833	31
13	Fitzpatrick	0.6406	36
14	Galliford North West	0.8763	5
15	Greenbooth	0.7961	27
16	Harbour & General	0.8568	10
17	Henry Boot	0.8551	12
18	Hewlett Civil Engineering	0.7647	32
19	J N Bentley	0.7607	33
20	Kennedy	0.8068	24
21	Kier	0.8821	2
22	Kinmain	0.6410	35
23	Lilley	0.8338	21
24	May Gurney	0.8429	16
25	Midland Construction Company	0.7904	30
26	Miller	0.8372	20
27	Morrison Construction Ltd	0.8694	8
28	Mowlem	0.8737	7
29	Norwest Holst	0.8557	11
30	Nuttalls	0.8521	13
31	Rawlings Brothers	0.6971	34
32	Shephard Hill	0.8066	25
33	Sisk	0.8251	22
34	Tarmac	0.8794	4
35	Thyssen	0.8418	17
36	Tilbury Douglas	0.8821	2
37	Trafalgar House	0.8739	6
38	Tysons	0.7960	28
39	Wrekin Construction	0.7969	26

Table 10.7 Utility values and rank order of all contractors listed in alphabetical order

Firm		Utility value	Rank order
1	Amec	0.8899	1
2	Kier	0.8821	2
3	Tilbury Douglas	0.8821	2
4	Birse	0.8800	3
5	Tarmac	0.8794	4
6	Galliford North West	0.8763	5
7	Trafalgar House	0.8739	6
8	Mowlem	0.8737	7
9	Morrison Construction Ltd	0.8694	8
10	Alfred McAlpine	0.8663	9
11	Harbour & General	0.8568	10
12	Norwest Holst	0.8557	11
13	Henry Boot	0.8551	12
14	Nuttalls	0.8521	13
15	Chistiani & Nielson	0.8491	14
16	Balfour Beattie	0.8489	15
17	May Gurney	0.8429	16
18	Thyssen	0.8418	17
19	A E Yates	0.8388	18
20	Dew Group	0.8385	19
21	Costain	0.8385	19
22	Miller	0.8372	20
23	Lilley	0.8338	21
24	Sisk	0.8251	22
25	Amey	0.8196	23
26	Kennedy	0.8068	24
27	Shephard Hill	0.8066	25
28	Wrekin Construction	0.7969	26
29	Greenbooth	0.7961	27
30	Tysons	0.7960	28
31	Casey	0.7932	29
32	Midland Construction Company	0.7904	30
33	DCT Civil Engineering Ltd	0.7833	31
34	Eric Wright Civil Engineering	0.7833	31
35	Hewlett Civil Engineering	0.7647	32
36	J N Bentley	0.7607	33
37	Rawlings Brothers	0.6971	34
38	Kinmain	0.6410	35
39	Fitzpatrick	0.6406	36

Table 10.8 List of contractors listed in order

10.8 COMPARISON OF RANK ORDERS BETWEEN CLASSICAL AND UTILITY SYSTEMS

Table 10.9 shows the ranking order of contractors by both systems. Below are some of the differences in ranking order of the contractors between the two systems.

1- The classical system has categorised the list of 39 contractors to 17 groups only, for example, 8 contractors have ranked 3; 4 contractors ranked 4 and so on, while the utility theory system categorised the whole list up to 36 groups, this indicates that the utility theory technique could give more detailed results and shows the differences between contractors capabilities.

2- Both systems agreed in ranking only four contractors, the first one, Amec and the last three, and this could be explained easily. The first contractor is the only one who scored the maximum points in all criteria, this means he dominates the others, and logically this has to be the ranked first in both systems. The other three had scored the lowest points and regarded as the weakest contractors by both system and therefore ranked last in the list.

3- The rank orders of contractors for the rest of the list were different between the two systems.

4- Both systems agreed on the list of the first 15 contractors except for the contractors "Balfour Beattie" and "Henry Boot", the classical system includes the first one and excludes the second, while the utility system excludes the first and includes the second as he ranked 12.

5- The differences between the two systems for this specific list are as follows

5.1 - In the classical system, the 15 contractors were ranked 1,2,3 and 4 only i.e. one contractor was ranked first, two contractors are ranked second, eight are ranked third and four contractors are ranked fourth.

5.2 - In utility system, the 15 contractors were ranked from 1 to 15, except for two contractors were both ranked second.

The utility system has considered the uncertainty in the contractors data, the decision maker attitude toward risk and the selection were based on client goals in terms of time, cost and quality. These factors makes the system more convincing and the proposed tool for selecting contractor more suitable.

10.9 SELECT LIST

The scores of the referees from the questionnaire shown in appendix 10C were not recorded, therefore no further analysis could be done, but the same principle used to rank order the contractor could be applied to find a short list from 15 to 5 or 6.

Firm	Traditional or Scoring system		Utility theory system	
	Score	Rank order	Utility value	Rank order
Amec	30	1	0.8899	1
Birse	29	2	0.8800	3
Tarmac	29	2	0.8794	4
Alfred McAlpine	28	3	0.8663	9
Galliford North West	28	3	0.8763	5
Tilbury Douglas	28	3	0.8821	2
Kier	28	3	0.8821	2
Morrison Construction Ltd	28	3	0.8694	8
Mowlem	28	3	0.8737	7
Trafalgar House	28	3	0.8739	6
Balfour Beattie	28	3	0.8489	15
Chistiani & Nielson	26	4	0.8491	14
Harbour & General	26	4	0.8568	10
Norwest Holst	26	4	0.8557	11
Nuttalls	26	4	0.8521	13
--	------	------	-------	-----
Henry Boot	25	5	0.8551	12
Costain	25	5	0.8385	19
Dew Group	25	5	0.8385	19
Amey	24	6	0.8196	23
May Gurney	24	6	0.8429	16
Miller	24	6	0.8372	20
Thyssen	24	6	0.8418	17
Lilley	23	7	0.8338	21
Sisk	21	8	0.8251	22
A E Yates	20	9	0.8388	18
Shephard Hill	20	9	0.8066	25
Wrekin Construction	20	9	0.7969	26
Kennedy	19	10	0.8068	24
Casey	17	11	0.7932	29
Greenbooth	17	11	0.7961	27
Tysons	17	11	0.7960	28
J N Bentley	16	12	0.7607	33
DCT Civil Engineering Ltd	15	13	0.7833	31
Midland Construction Company	15	13	0.7904	30
Eric Wright Civil Engineering	15	13	0.7833	31
Hewlett Civil Engineering	19	14	0.7647	32
Rawlings Brothers	9	15	0.6971	34
Kinmain	5	16	0.6410	35
Fitzpatrick	2	17	0.6406	36

Table 10.9 Rank order of the contractors by both systems

11. SUMMARY, CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

CHAPTER 11

Summary, conclusions and recommendations for future research

11.1 INTRODUCTION

Despite the increasing use of alternative forms of project delivery systems in the last two decades, the performance of the construction industry has declined as many projects end up with sub-standard work, delays and cost over-runs.

Literature and past research suggests that one of the reasons for this poor performance is due to the insufficiency and inappropriateness of the awarded contractor. In order to ensure a successful completion of a project, a comprehensive and careful assessment of contractors data in a prequalification stage is required. Appointing an appropriate contractor to carry out the construction work, therefore, becomes one of the most important tasks to ensure the success of a project.

The main aim of this research is to offer a rational method for selecting contractors during the prequalification stage in particular.

11.2 SUMMARY

In the preceding chapters the author has described investigations on the procedures and techniques of contractor selection in construction. The methodologies used for the investigations included literature review, interviews, questionnaire survey, hypothetical project, and real case study.

The literature review, interviews with professionals and the questionnaire survey have provided valuable knowledge and insight on the issues of contractor selection. These assisted the author in developing the multiplicative utility model for contractor selection. The model provided a systematic multiattribute decision analysis technique.

The technique was based on utility theory and permits tangible and intangible multicriteria modelling. A real case study was used to validate the applicability of the model, to examine the use of client's objectives in terms of time, cost, and quality as a means of assessing the contractor capability, and to investigate the effect of contractor selection criteria on time, cost and quality. The development of the model and the validation were described in Chapters 9 and 10.

Chapter 2 examines the current methods used in tendering and bid evaluation for UK construction contracts. A series of interviews with client representatives in the North West of England was conducted. It was found that both public and private clients use methods with similar characteristics and generally select the contractor tendering the lowest bid.

Chapter 3 was concerned with identifying the criteria for prequalification and bid evaluation and the means by which different emphases can be accommodated to suit the requirements of clients and projects. The information, assessment and evaluation strategies currently used by procurers for screening contractors are considered. The results reported extensive literature review and interviews with a sample of construction professionals having extensive experience in prequalification and bid evaluation processes

Chapter 4 was devoted to outlining the variety of models proposed by the researchers for modelling prequalification. At the end, it presented the principles of utility theory, its advantages as a decision tool for selecting contractors, literature review was conducted.

Chapter 5 has covered a wide range of professionals involved in prequalification in the construction industry and also substantiated the findings of the literature survey and the interviews conducted in chapters 2 and 3. In this respect, a questionnaire survey was prepared and sent to the public and private clients. The format, structure, contractor selection criteria and measures used in the questionnaire were based upon the findings of chapters 2 and 3.

Chapter 6 described the basics of utility theory technique. The theoretical basis of the technique was provided together with a hypothetical case study of an additive model in order to illustrate the technique, and for which real interviews with a number of construction professionals were conducted to generate the utility functions needed. In this case, the contractor selection criteria identified in chapter 3 were used as a means of assessing the contractors in the hypothetical case.

Chapter 7 described a Delphi study investigating the perceived relationship between contractor selection criteria (CSC) currently in use and project success factors (PSF) in terms of time, cost and quality involving a sample of experienced construction personnel. A consensus of the likely impact of each criterion on time, cost and quality was established in terms of pessimistic, average and optimistic values which were then converted into expected means and variances via the PERT approach. The ten most and ten least important CSC were identified and examined for differences and similarities between PSF.

Chapter 8 presented a quantitative technique to combine the contractor data in terms of the three goals, time, cost and quality. The study also presented an evaluation strategy that involves the consideration of both the client goals as ends and contractor data as the means, the strategy based on the aspiration level, risk analysis for the final selection or rank ordering of the contractors based on the preferences of the client.

Chapter 9 presented a decision analysis technique for the evaluation of contractors using multiplicative utility model. Time, cost and quality were the three attributes used in this model. In order to apply the utility theory in identifying and ranking the suitable contractors a detailed hypothetical case was offered and real interviews with a sample of professionals were conducted to investigate the preferential and utility independence and to build the utility functions of time, cost and quality. At the end of the chapter a computer programme was developed to assist in solving the expected utility formulae.

Chapter 10 was devoted to testing the decision technique, real case study was used for the validation.

11.3 CONCLUSIONS

Two basic types of tendering procedures were identified in chapter (2). One is where bids are invited for a contract from a standing list of potential bidders who wish to bid for contract projects of that type -termed *standing list tendering*, another is where bids are invited from a set of potential bidders who wish to bid for that specific contract - termed *project tendering*. All the clients concerned use methods with similar characteristics and generally select the contractor tendering the lowest bid.

A model was proposed in which the five elements of *project package*, *invitation*, *prequalification*, *short list* and *bid evaluation* are common to both standing list and project tendering procedures. It is suggested that these elements occur to some extent in all types of procurement arrangements.

The model proposed may serve as a systematic approach to tendering and bid evaluation for novice owner organisations. Also, the proposal that this model may apply beyond the purely traditional procurement arrangements offers a much needed breakthrough in the conceptual understanding of the relationship between, and separation of, contractor selection and the general construction procurement process. With the continued proliferation of new, novel and increasingly complex approaches to construction procurement, such an understanding is of vital importance both for practitioners and students of the subject. Also, as with all good descriptive models, it is possible that the insights afforded by the model may provide inspiration for the development of further such systems perhaps in more coherent and systematic manner than hitherto.

The findings of chapter three indicate the most common criteria considered by procurers during the prequalification and bid processes pertaining to financial soundness, technical ability, management capability, health and safety performance and reputation of contractors.

There is constancy between the practitioners interviwed both in the selection of the lowest bid and the using in general approach to tendering, and in the common criteria being used. There is however sufficient corroboration with the general literature on the subject to indicate that the model proposed in chapter 3 for collecting different types of criteria may well be appropriate in the general field.

As outlined in chapter four, there is currently no decision model which maximise the usage of available data for prequalification decision making. They do not account for imprecision and/or uncertainty associated with data submitted by the contractor. Consequently, each decision model has some limitations in arriving at a solution. Varying types of data were presented; quantitative, qualitative but artificially quantified and qualitative. This is the result of the restricted capabilities and flexibility that each modelling technique has adequately to model each aspect of the problem domain.

The Financial model was found to be inaccurate about the contractor's performance capabilities and capacity. In terms of ease of implementation, some models, such as fuzzy set model and statistical models seem to be too sophisticated to be operated by the decision makers

Out of the 300 questionnaire distributed to public and private clients discussed in chapter 5, 156 useful replies were received, a response rate of 52%. For the three types of contracts covered in this survey, 85% to 100% of the respondents used either standing or project list to solicit tenders (Q5). For the Invitation, Prequalification, short list and bid evaluation elements, almost 100% of the respondents for the three types of contracts agreed to the offered definition (Q6).

For traditional contracts, term and design and building contracts, over 90% of the respondents used the major five elements (Q7) in their tendering systems.

For term contracts, 100% of the respondents used the major steps to prequalify the contractors (Q8). For traditional contracts, 80% to 100% of the private clients and 90% to 100% of the public clients used these major steps. For design and build 70% to 100% used these steps to prequalify the contractor but only 50% of the respondents categorised the applicants.

For traditional contracts, 90% to 100% of the respondents of public and private clients used the major steps for evaluation of bids (Q9) except a pre-award meeting. In term contracts, 100% of the respondents used all the steps. For design and building contracts, 100% of the respondents answered yes to all the steps for evaluation of bids.

The result of this survey showed that the clients that were using all types of contracts covered in this study used the same methods of soliciting tenders, used the five major elements in their tendering system, and they used the major steps to prequalify contractors and evaluation of bids.

For the three types of contracts covered in this survey, all types of criteria for contractor selection considered in the questionnaire survey of chapter 5 (Q10.1 to Q14.4) were used by the clients with some variance. The only exceptions were the experience modification rate (EMR) (Q13.2) and occupational safety and housing administration incidence rate (OSHA) (Q13.3) which were it is not used by traditional and design and build contracts' users, about 25% of term contract users indicated they were using the (EMR) while 33% of the respondents used (OSHA) incidence rate.

Chapter six proposed that more than one attribute should be considered in contractor selection. Multiattribute utility theory provides one such approach and is especially useful as it allows the treatment of both quantitative and qualitative criteria. An additive model was proposed for its simplicity. The utility model uses utility curves to represent the relationship between a specific capability of a contractor and the value of that capability in risky situations. The individual importance of each contractor attribute is specified using a weighting which also incorporates the risk of the decision maker.

A case study was described to illustrate the data requirements, mechanics, and solution nature of the theory and in which real interviews with four leading professionals were conducted for building the utility functions. A method of building utility functions using a gambling technique was described using a real interview. Precise assessment of the relative weights was shown to have a crucial bearing on the solution suggested by the analysis technique.

Multiattribute utility analysis was found to be one of the most promising technique for prequalification and bid evaluation decisions where attributes are of different characteristics. It is believed that application of a multiattribute utility theory approach in complex and risky situations will aid an owner in making good decisions.

In order to invite suitable bidders it is necessary to clarify and develop appropriate pre-determined contractor selection criteria (CSC), improve and organise the assessment of information relating to these, and develop methods for evaluating them against various project success factors (PSF). Following a Delphic round and further interviews with additionally experienced construction personnel conducted in chapter 7. The results of the research indicated "past failures, financial status, financial stability, credit ratings, experience, ability, management personnel, management knowledge" were considered to be the most dominant CSC affecting all three PSF with safety CSC (safety, experience modification rate, occupational housing association, management safety accountability) and the length of time in business being considered to have the least effect overall. It was also found that some CSC, such as "past performance, bank arrangements, project management organization, plant and equipment", were considered to affect only one or two PSF.

The results presented provided insight into how time, cost, and quality are differently affected by contractors' capabilities in terms of different CSC. The benefits of this study is a documented identification of the effect that various CSC have on project objectives, and also to provide a clients with a direct quantitative technique for contractor selection in terms of their own goals either for prequalification. The opinion of the validators confirmed that the expected mean values received were sufficiently representative to become default values for any future systems development.

This research was based on the premise that selection should concentrate on determining contractor potential for achieving project goals. The main benefit of chapter eight is that it provided a means of using the PERT methodology to incorporate uncertainty and/or imprecision associated with the assessment of contractors data, this all, in terms of the ultimate project goals of time, cost, and quality. The chapter presented a quantitative technique to combine the contractor data in terms of these goals. The study also presented in brief an evaluation strategy that involves the consideration of both the client goals as ends and the contractor data as the means, the strategy based on the aspiration level, risk analysis for the final selection or rank ordering of the contractors based on the preferences of the client.

A multiattribute utility decision support system which was presented in chapter nine is the main contribution of this thesis. The technique is expected to be a feasible tool to aid in decision-making regarding contractor prequalification. A system that was able to make use of the available data, account for uncertainty, prequalify the contractors in terms of the client goals or project success factors such as time, cost and quality, and which type of contractor to be prequalified ultimately depends on decision maker attitude to risk and trade-off.

Multiattribute utility theory presented here generally combines the main advantages of simple scoring techniques and optimization models. Further, in situations in which satisfaction is uncertain, utility functions have the property that, expected utility can be used as guide to rational decision-making.

The evaluation technique proposed should help clients in selecting contractors and the contractors themselves for selecting sub-contractors in offering a means of broadening their analysis of tenderers beyond that of simply relying on tender values. It also alerts contractors to the importance of increasing their ability to satisfy the needs of the clients in terms of their ultimate project goals.

The research on which this thesis is based, rests on the premise that there is a possible common set of contractor selection criteria and these criteria have an impact on the project success factors. If these criteria are identified, their levels of importance determined, and the relationship between these criteria and project success factors is investigated, the development of an objective quantitative selection framework could be facilitated. The results presented in this research proved that there is a common set of contractor selection criteria and these criteria have an impact on the project success factors, a quantitative framework is provided on which construction clients may then apply more objective contractor selection methods as a means of identifying the most suitable contractor for a project. The alternative approach could avoid duplication of effort (with a commensurate reduction in individual clients' resource costs).

11.4 RECOMMENDATIONS

11.4.1 Further work

1- The model proposed in chapter two may serve as a systematic approach to tendering and bid evaluation for novice owner organisations. Also, the proposal that this model may apply beyond the purely traditional procurement arrangements offers a much needed breakthrough in the conceptual understanding of the relationship between, and separation of, contractor selection and the general construction procurement process. With the continued proliferation of new, novel and increasingly complex approaches to construction procurement, such an understanding is of vital importance both for practitioners and students of the subject. Also, as with all good descriptive models, it is possible that the insights afforded by the model may provide inspiration for the development of further such systems perhaps in more coherent and systematic manner than hitherto.

2- The author recommends that a separate study for each type of procurement system should now be made to conduct a larger and more focused survey covering a wider range of clients. In this respect, I recommend using the common set of criteria identified from this study as a basis for comparison in terms of identity of contractor selection criteria used by different clients in the construction industry.

3- For the previous recommendation, it would be helpful if a matrix including type of project against size of the project, was established, then the relevant criteria, its weights could be known. The matrix may take the following form.

		Type of building			
		H	E	C	L
Size of building	S	HS	ES	CS	LS
	M	HM	EM	CM	LM
	L	HL	EL	CL	LL
	VL	HVL	EVL	CVL	LVL

Where

H = Health buildings (hospitals, medical centres, ...)
E = Educational buildings (schools, nurseries, colleges,...)
C = Commercial buildings(shopping centres, malls,..)
L = Living buildings (houses, flats, bungalows,..)
S = Small (0.25 million to 0.5 million)
M = Medium (0.5 million to 1 million)
L = Large (1 million to 5 million)
VL = Very large (more than 5 million)

4- The two methodologies for evaluation of strategy proposed in chapter eight i.e (Lexicographical ordering with aspiration level and Risk analysis technique) needs deep investigation and they could provide a promising practical tool for selecting contractors.

5- It is very helpful if the system proposed in this thesis is computerized, in this respect I recommend dividing the system into different modules as follows:

a) Contractor selection criteria module
b) Weights of the contractor selection criteria module
c) Module for investigating the effect of contractor selection criteria on the ultimate client goals, then finding the expected means and variances
d) Module for building the utility functions for the ultimate client goals.
e) Module for the scaling constants of the client goals.
f) Module for linking the above modules and calculating the expected utility of contractors.

11.4.2 General industry recommendations

1- It is recommended to study the possibility of establishing an independent firm(s) that can monitor the overall performance of the companies, i.e like Dun & Bradstreet which is dealing only with the financial status and financial history of the companies. It is beneficial to establish the same type of organization that can assess the technical, managerial, past failures, and reputation of the contractors.

2- The procurers of the public sector are not fully aware of all the options available of the current procurement practice. I suggest for procurers to share experiences and data so that good estimates of likely costs and benefits of using any system can be made.

3- The results presented in this research proved that there is a common set of contractor selection criteria, therefore it is recommended to use these set of criteria to avoid duplication of effort and to save the costs of developing the criteria. Once this has been realised, there is a real prospect of developing a prescriptive, or even normative Code, for selection criteria to provide a consistent, logical, objective and therefore a comparable and communicable basis for useful information exchange between procurers of construction work for more accurate, reliable and efficient decision making.

4- According to this research the contractor selection criteria were found to have an impact on the project success factors, therefor clients should use these factors as ends for the contractor selection.

5- A quantitative framework is provided on which construction clients could apply more objective contractor selection methods as a means of identifying the most suitable contractor for a project. The alternative approach make use of the available data and account for uncertainty.

6- The construction industry should consider implementing the decision support technique developed in this research. The technique prequalify the contractors in terms of the predominant project success factors time, cost and quality. The utility method used in the technique is the best for measuring the decision maker attitude towards risk and tradeoffs.

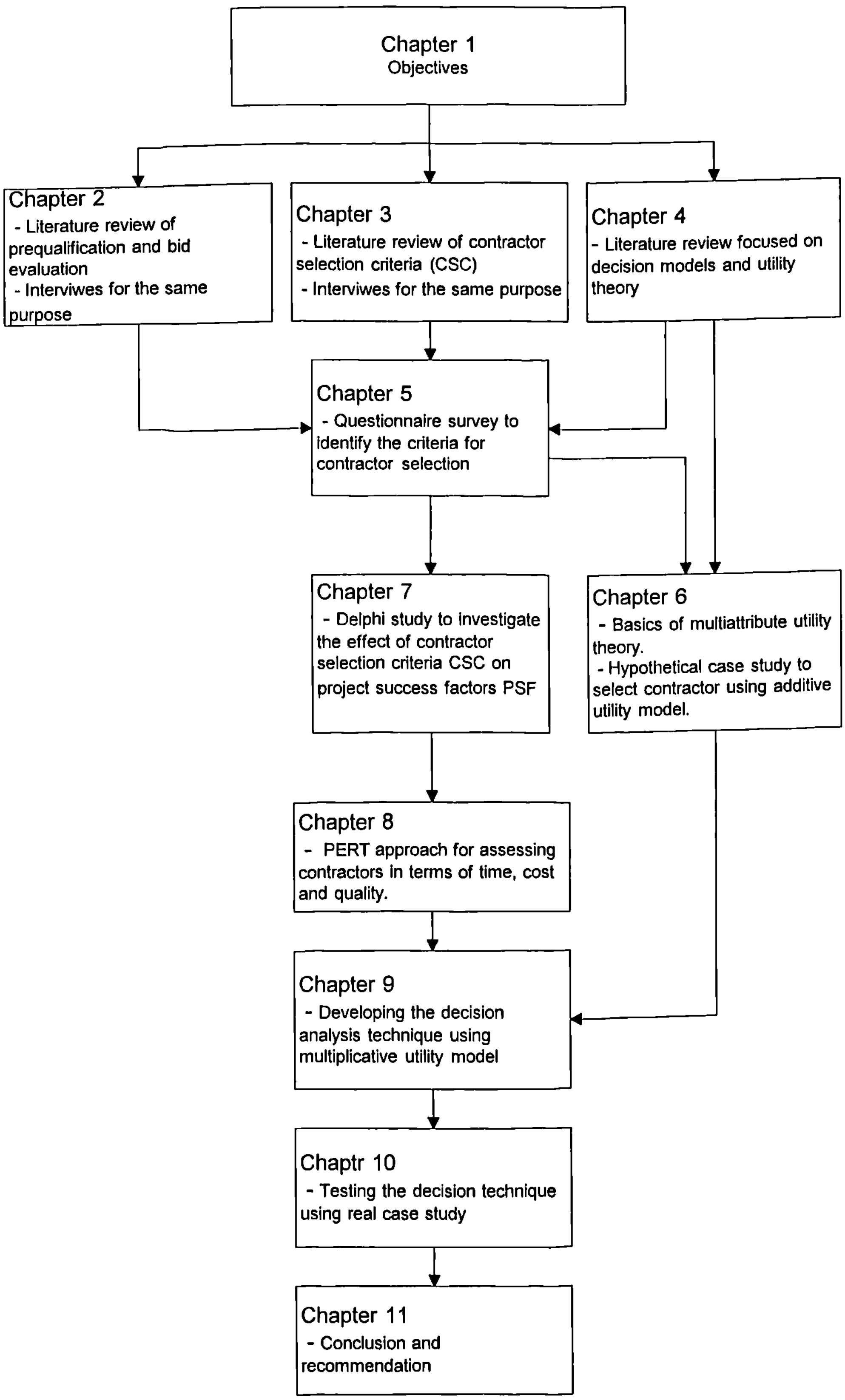
11.4.3 Limitations

1- The Delphi study conducted in chapter seven to investigate the effect of contractor selection criteria was limited to the ultimate client goals and eight practitioners. It is recommended that a wider survey will be very helpful to identify the expected time, cost and quality due to different contractors performance, it is also possible to include the operational client goals (see chapter seven for details)

2- The research in this thesis is limited to the ultimate client goals, it is recommended to investigate the possibility of including some other goals and some other utility models.

12 APPENDICES

APPENDIX 1. Thesis layout diagram



APPENDIX 2A. List of questions discussed during the preliminary interviews for tendering procedures.

Q1- Please give details of the firm, your position in its activities, contractor selection and involvement in bid evaluation.?

Q2- What is the objective of the client from the prequalification process?

Q3- What are the methods do you use to solicit tenders during the prequalification process?

Q4- What are the steps do you follow to prequaify the contractors?

Q5- What are the steps do you follow to evaluate tenders?

Q6- What is the current method or methods being used for bids evaluation?

Q7- What type of problems if any, you have experienced during project execution period, in which the contractor is considered not capable of carrying out the job within the contract conditions?

Q8- Do you think the methods used currently for prequalification and bids analysis are capable of identifying the most suitable and favourite contractor?

Q9- Do you have any other comments related to the prequalification process and bids evaluation ?

APPENDIX 2B. Standing list of approved contractors

The clients request the interested contractors to fill and return an application form, which include the following information in brief.

Section 1- Categories of work for different schemes.
Section 2- Company details
Section 3- Scope of work offered
Section 4- Technical resources and references
Section 5- Particulars of existing insurances
Section 6- Taxation details
Section 7- Financial information
Section 8- Sub-contracting
Section 9- Race relations
Section 10- Plant and equipment
Section 11- Health and safety
Section 12- Declaration

APPENDIX 3. List of questions discussed during the preliminary interviews for contractor selection criteria

Q1 The first question will be about the position of the interviewee, the firm and its activities, contractor selection, and involvement in bid evaluation.

Q2 What are the criteria that are currently considered by the firm during the prequalification process?

Q3 What criteria are used in bid analysis and evaluation?

Q4 Which of the criteria considered of more important than others ?

Q5 What is the current method or methods being used for prequalification?

Q6 What type of problems if any, have you experienced during the project execution period caused by the contractor not being capable of carrying out the job within the contract conditions?

Q7 Do you think the methods used currently for bid analysis are capable of identifying the most suitable and favourite contractor?

Q8 What other criteria do you think should be included in the prequalification process, and what other methods might be considered better for bid analysis?

Q9 Do you have any other comments related to the prequalification and bid evaluation criteria ?

APPENDIX 4. list of Articles addressing Methodological and implementation of utility technique, taken from Corner and Kirkwood (1990)

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APPENIX 5. Questionnaire for identifying contractor selection criteria and tendering procedure

In my previous research, I interviewed several people dealing with tendering procedures, prequalification, contractor selecting and bid evaluation, as a result of which twenty criteria, their measures and some common characteristics in tendering procedures were identified. In order to support this preliminary work, this simple questionnaire has been prepared.

I would be grateful if you could spare a few minutes of your valuable time to complete the enclosed questionnaire and return it as soon as possible. All the information you provide will be treated **in the strictest confidence** and used for statistical analysis.

A. QUESTIONS RELATED TO THE FIRM

Q1. What is the type of your firm ?

* Private (---)
* Public (---)

Q2. What is your qualification ?

* Quantity surveyor (---)
* Architect (---)
* Building engineer (---)
* Others please specify --

Q3. What is the function you perform?

* Prequalification (---)
* Bid evaluation (---)
* Others please specify --

Q4. What is the approximate number, value and types of contracts that you have been involved in over the last three years ?

	Number	amount(£ million)
* Traditional contract	(-------)	----------------------
* Term contracts	(-------)	-----------------------
* Design and build	(-------)	-----------------------
* Target cost contract	(-------)	-----------------------
* Other pleas specify	(-------)	-----------------------

B. QUESTIONS RELATED TO TENDERING PROCEDURES

In the following questions, please answer according to the type of contract you are mostly involved in (i.e type of contract with larger number in Q4).

Q5. Which of the following methods do you use to solicit tenders?

a) **Standing list tendering system.** Where bids are invited for a contract from a standing list of potential bidders who wish to bid for contract projects of that type (-----)

b) **Project list tendering system.** Where bids are invited from a set of potential bidders who wish to bid for that specific contract. (-----)

c) Others (please describe) ---

Q6. The following is a definition of the five major elements in your tendering system. If you do not agree please offer alternative definition.

a) **Project package.** This consists of

* specifications, drawings, bills of quantities, contract conditions. (Y/N/DN)
* specifications, drawings, contract conditions. (Y/N/DN)
* priced schedule of rates, specification, contract conditions. (Y/N/DN)
* client states his requirements, contractors prepares design and cost proposals, detailed design is developed after both parties reached an agreement regarding specification and price. (Y/N/DN)
* (Y/N/DN)

----

b) **Invitations.** This is the process where contractors are invited for entry to the **prequalified standing list** of contractors, **project list** or for receiving the tender documents for bidding. (Y/N/DN)

* (Y/N/DN)

----

c) **Prequalification.** This is the process of selecting or screening and classifying of contractors by project client's or their representative according to a given set of requirements or criteria. (Y/N/DN)

* (Y/N/DN)

----

d) **Short list.** This is the process where the number of applicants for prequalification is so great that the number of contractors have to be reduced to a short list and/or its a group of around 4 to 8 prequalified contractors that are invited and then receive the full project package. (Y/N/DN)

* (Y/N/DN)

----

e) **Bid evaluation**. This is the process of selecting a contractor from a number of tenderers, given that the client has received the bids or tenders from these tenderers for a specified project. (Y/N/DN)
*

Q7. Are all the five elements in Q6 are present in your tendering system ?

	Yes	No.	Don't No
a) Project package	(-----)	(-----)	(-----)
b) Invitations	(-----)	(-----)	(-----)
c) Prequalification	(-----)	(-----)	(-----)
d) Short list	(-----)	(-----)	(-----)
e) Bid evaluation	(-----)	(-----)	(-----)

Q8. Do you use the following major steps to prequalify the contractors?

a) **Development** of prequalification criteria. (Y/N/DN)
b) **Collection** of data through application forms. (Y/N/DN)
c) **Evaluation** of data against the criteria. (Y/N/DN)
d) Collection of **supplementary** data if necessary, by contacting the referees. (Y/N/DN)
e) **Acceptance/rejection** of application. (Y/N/DN)
f) **Categorisation** of applicants. (Y/N/DN)
g) Others (Y/N/DN)

Q9. Do you use the following major steps for evaluation of bids?

a) **Tenders** returned. (Y/N/DN)
b) Bid **assessment.** (Y/N/DN)
c) Award **decision.** (Y/N/DN)
d) Pre-award **meeting.** (Y/N/DN)
e) **Award.** (Y/N/DN)
f) Others (Y/N/DN)

-- --
-- --

C. QUESTIONS RELATED TO TYPE OF CRITERIA FOR CONTRACTOR SELECTION

In the following questions, please answer according to the type of contract you are mostly involved in (i.e type of contract with larger number in Q4)

Q10. Financial soundness. Please tick (/) if you use the following criteria and/or their measures or (x) if you do not use for contractor selection.

10.1 Financial stability (----)
- a) Current and fixed assets (----)
- b) Liquidity (----)
- c) Annual turnover (----)

10.2 Credit rating (----)
- a) Subcontractors (----)
- b) Suppliers (----)

10.3 Bank arrangements and bonding (----)
- a) Short term borrowing (----)
- b) Long term borrowing (----)
- c) Bonds (----)

10.4 Financial status (----)
- a) Balance sheet (----)
- b) Income statement (----)

10.5 Others --

* ------------------------------ * ---------------------- * --------------------------

Q11. Technical ability. Please tick (/) if you use the following criteria and/or their measures or (x) if you do not use for contractor selection.

11.1 Experience (----)
- a) Experience over the last five years in construction. (----)
- b) Current and completed contracts. (----)
- c) Past experience on client's major projects. (----)
- d) Experience and capability of technical personnel. (----)
- e) Complexity of work executed (----)
- f) Level of technology. (----)
- g) Types of projects executed in the past five years. (----)
- h) Performed work of the same general type and scale and ability to absorb subsequent changes. (----)

11.2 Plant and Equipment (----)
- a) Availability of owned construction equipment. (----)
- b) dequate plant and equipment to do the work properly and expeditiously. (----)
- c) Small tools and construction equipment. (----)
- d) The testing equipment as quality assurance. (----)

11.3 Personnel (----)
- a) Availability of first level supervisors and number presently employed. (----)
- b) Availability of skilled crafts. (----)

c) Expertise in design. (----)
d) Skills including professional, and technical expertise, that are available to the company, e.g. qualifications and relevant experience. (----)
e) Craftsmen availability (training or skill level of craftsmen). (----)
f) Supervision. (----)

11.4 Ability (----)
a) Ability to handle the offered type and size of work. (----)
b) Ability to perform on site. (----)
c) Ability to control and organise contracts and efficiently integrate labour resources. (----)
d) Ability to meet target dates. (----)

11.5 Others ---

* ------------------- * ------------------------------ * ----------------------

Q12. Management Capability. Please tick (/) if you use the following criteria and/or their measures or (x) if you do not use for contractor selection.

12.1 Past Performance and quality (----)
a) Past performance (----)
b) Quality-control programme and quality of past projects (----)
c) Quality certificate (----)
d) Quality level,including confidence in design, and flexibility in accommodating design inputs by the client (----)
e) Quality of workmanship. (----)

12.2 Project Management Organization (----)
a) Experience in completion of project on schedule. (----)
b) Planning, and Programming (----)
c) Site organisation. (----)
d) Engineering coordination. (----)
e) Present workload and capability to support the current projects. (----)
f) Capability to manage subcontractors. (----)
g) Drawing control procedure. (----)
h) Capability to perform material control. (----)
i) Methods of procurement adopted. (----)
j) Certainty, including the reliability of the original price, reliability of the estimated construction time, and knowledge of exactly how much the client has to pay at each period during the construction phase. (----)
k) Field organization, work rules, work policies. (----)

12.3 Experience of technical personnel (----)
a) Present workload and capability of contractor key site management personnel. (----)
b) Availability of first-line supervisors. (----)

c) Staffing levels in the company including management, professional/technical, administrative/clerical. (----)
d) Executive involvement- leadership. (----)

12.4 Management knowledge. (----)
a) Scheduling and cost control system and how it is utilized. (----)
b) Material control, personnel, accounting, subcontracts, purchasing. (----)
c) Level of research and development. (----)
d) Risk avoidance and responsibility, including client involvement and design liability. (----)
e) Productivity improvement programme. (----)
f) Time performance. (----)
g) Predicted outturn costs. (----)

12.5 Others ---

* ----------------------- * ------------------------- * ----------------

Q13. Health and Safety. Please tick (/) if you use the following criteria and/or their measures or (x) if you do not use for contractor selection.

13.1 Safety (----)
a) Experience in handling dangerous substances. (----)
b) Experience in noise controlling. (----)
c) Accident Book. (----)
d) Complied in all respects with health and safety regulations. (----)
e) Health and Safety Information chart for employees. (----)
f) Safety record. (----)
g) Company safety policy. (----)

13.2 Experience Modification Rating (EMR) (----)
a) Financially rewarding or penalizing employers according to their accident claims. (----)

13.3 OSHA Incidence rate (----)
a) OSHA is the Occupational Safety and Housing Adminstration which is the average numbers of injures and illness. (----)

13.4 Management safety accountability (----)
a) Who in the organization receives and reviews accident reports, and what is the frequency of distribution of these reports. (----)
b) Frequency of safety meetings for field supervisors. (----)
c) Compilation of accident records by foremen and superintendents and the frequency of reporting. (----)
d) Frequency of project safety inspection and the degree to which they involve project mangers and field superintendents. (----)
e) Use of an accident cost system measuring individual foremen and superintendents as well as project managers (----)

Q14. Reputation. Please tick (/) if you use the following criteria and/or their measures or (x) if you do not use for contractor selection.

14.1 Past failures (----)
- a) Past and present experience regarding legal suits or claims. (----)
- b) Reasons for recent debarment (if any). (----)
- c) Reasons for failed contract(if any). (----)
- d) Previous failures to perform contracts properly or fail to complete them on time. (----)
- e) Financial penalties previously levied in respect of failures to perform to the terms of a contract. (----)
- f) Contracts the firm has had terminated or employment determined under the terms of contract. (----)
- g) Contracts not renewed due to failure to perform in accordance with the terms of contract. (----)

14.2 Length of time in business. (----)
- a) Amount of projects executed in the past five years. (----)
- b) Capacity of work. (----)
- c) Company's stability. (----)
- d) Permanent place of business. (----)
- e) Depth of organization. (----)

14.3 Past client/contractor relationship (----)
- a) Proximity of contractor's home office to project. (----)
- b) Responsibility and consideration for the client staff and general public. (----)
- c) The performance of contractors over a number of previous invitations. (----)
- d) Responsibility and consideration for the adjoining owners affected by the work. (----)
- e) Experience of working with the client, i.e., understanding of the client's procedures in meetings and for payments. (----)
- f) Local knowledge. (----)
- g) Responsible attitude towards the work. (----)

14.4 Other relationships (----)
- a) Relationships with subcontractors. (----)
- b) Maximum percentage of subletting. (----)
- c) Relationship with employees. (----)
- d) Relations with Statutory Undertakers. (----)
- e) Working relations between members of the referee staff and the staff of the firm including head Office staff. (----)
- f) Race relations. (----)
- g) Standard of Sub-contractors work. (----)

14.5 Others --

Q15. What are the criteria considered by your firm in evaluating bids submitted by tenderers?

a) Lowest bid price (----)
b) Average bid prices (----)
c) Lowest net present value (----)
f) Others please specify ---

D. QUESTION RELATED TO PROJECT PERFORMANCE

You could consult your colleagues if you find difficulty in answering the following question.

Q16. To what extent you are satisfied generally with the performance of your completed projects in terms of time, cost and quality?

	Not satisfied	Moderately satisfied	Satisfied
Time	(------)	(-------)	(-------)
Cost	(------)	(-------)	(-------)
Quality	(------)	(-------)	(-------)

Please comment

Would you like a summary of results? if yes write your name and address

Name .... Address..........................

....

Thank you for your kind assistance

Please return to:

Zedan Hatush
Department of surveying
University of Salford
M5 4WT

APPENDIX 6. Interview with Mr Oztash for building utility function for the {plant and equipment} attribute

Mr Oztash, First of all let me tell you that I am working as a Contract Administrator, the client I am working with is planning to develop and invest the money of the firm, so he is going to build a multistorey building in a city centre.

Description of the example, and objectives of the client in brief.

Type of building. The building is a three story building of 4,000 square meter. The first floor is to be used as a shopping area, second and third floors to be rented as an offices.

Tendering procedure. Following the normal project tendering system we ended up with five bidders (A,B,C,D,E) that submitted their offers. We examine the offers in detail and we found the lowest one is the bidder E with an offer of 4.2 million pound.

Contract award and argument. According the normal procedure we should award the contract to bidder E, but we decided to investigate the other characteristics and capabilities of each bidder rather than to depend on judgment and decision on the bid price only for awarding the contract.

We ask ourselves what type of information do we have to collect about the contractors; to what level of detail we go for these details. In order to answer these questions we decide to set out the objectives we are intended to achieve from this building.

Objectives. We set a list of global and project objectives, we examine our available resources, and we also examine the resources required. Having defined the objectives and the other parameter we decided to make an interviews with the construction professional in order to identify the relevant type of criteria, and their scaling factors that should be considered in assessment the capabilities of the five bidders.

Criteria and scaling factors. The result of interviews revealed that we should look at six main criteria for the assessment of each bidder. Each one of these six criteria is then traced by four criteria in which they are also considered as the criteria of a second level.

The main six criteria was (Bid amount, Financial soundness, Technical ability, Management capability, Health and safety, and finally the Reputation). Each one of these has four criteria, so in total we have to look to 24 criteria in order to make a proper judgment for selecting the most suitable contractor for our contract. During the interviews the criteria has been ranked in order of importance and then scaled from 0 to 1.

Scores. Information about the contractors covering the criteria identified was carried out by internal team. Due to the subjective nature of the criteria identified, each one of the criteria is judged on a point scale system in which a score from 1 to 20 is assigned for each bidder in these attributes.

Summary. I will summarize to you the information we got so far.
- Five bidders (A,B,C,D,E)
- Five offers and bidder E is the lowest

- Global and project objectives
- 24 Criteria
- Score system from 1 to 20 for each criterion
- Scaling constant from 0 to 1 for each criterion

Contractor selection problem

Having all these mixture of parameters in hand, the selection of the best contractor for our project becomes more complicated, because we have to see what method we should use to solve such kind of decision making problems that involves multi-parameters.

We decided to use a multiattribute utility theory, this technique is able to consider different kinds of attributes, it is basically based on tradeoffs and a decision maker preferences for the consequences he is expecting form any decision he takes.

In this respect and to apply the utility theory successfully we need your help by construction a utility function for your preferences of the expected outcomes for each one of the criteria for the different options at hand.

Do not wary I will make every thing easy for you. First of all let us keep near to us Table 1. that shows the list of the criteria and their scaling factors, it also shows the score of each bidder in these criteria and we look at the same time to Figure 1. that shows how you use the gambling procedure.

The best thing to do is to start by taking any attribute and we see how we can build a utility function for it, let us take attribute number {10}

Utility function for the attribute {10} - Plant and equipment

Let us start together by taking attribute number 10 (plant and equipment) which is a sub of the technical ability criterion, remember the weight assigned for this attribute is 4.5% refer to the Table 1. Let us see why we include this attribute or criterion, what each of the bidders has scored then we continue in building the utility function of your preferences.

This criterion is included to verify that the various equipments required for the execution is available at any time during the construction process. The measurement of this criterion can be traced by the availability of construction equipment at any time they needed, adequate plant and equipment to do the work properly and expeditionary, small tools and, the testing equipment.

To make it easy for you we will extract from Table 1. the criterion under investigation and the scores of the five bidders in a separate Table 2.

In order to build a utility function for this attribute we have to know some principals of the utility theory, then a conversion between us in a form of questions and answers will get us to the point we are seeking.

Set of criteria	Weights %	Bidder A	B	C	D	E
{1} Advance payment(Million £)	2.75	0.1	0.3	0.3	0.15	0.1
{2} Capital bid (m £)	41.25	3.9	3.5	3.5	4	3.6
{3} Routine maintenance(m£)	5.5	0.3	0.25	0.3	0.25	0.1
{4} Major repairs (m£)	5.5	0.4	0.35	0.2	0.4	0.4
{5} Financial stability (points)	4.5	12	11	13	10	10
{6} Credit rating (points)	3	14	15	14	9	11
{7} Bank arrangements (points)	2.25	15	13	15	10	13
{8} Financial status (points)	5.25	17	17	16	11	14
{9} Experience (points)	2	11	15	9	16	6
{10} Plant and equipment (pnts)	4.5	13	14	10	18	16
{11} Personnel (points)	3	9	14	14	15	6
{12} Ability (points)	0.5	11	11	15	13	6
{13} Past performance (points)	4	15	10	16	10	10
{14} Management organization(pts)	2	10	17	13	10	11
{15} Experience of technical personnel(points)	2	12	16	11	9	14
{16} Management Knowledge (pnts)	2	15	15	14	19	15
{17} Safety (points)	1	9	17	16	10	17
{18} EMR (points)	1.5	15	8	17	6	20
{19} OSHA (points)	1.5	8	13	9	10	16
{20} Management safety accountability (points)	1	7	11	12	8	11
{21} Past failures (points)	1.5	15	16	11	10	11
{22} Length of time in business	0.5	14	15	14	11	6
{23} Cleint/contractors relationship (points)	2	10	13	14	10	10
{24} Other relationships	1	9	12	17	9	13

Table 1. Set of criteria, their relative weights and the scores of the bidders

Table 2 shows the weight of the criterion and the score of five bidders. This Table is taken from Table 1.

Contractor	A	B	C	D	E
{10} Plant and equipment score wight =4.5%	13	14	10	18	16

Table 2. Scores of the five bidders in criteria {10}

The principal of the utility theory states that we should assign 1 for the best outcome and 0 for the worst outcome, therefore we will start together building the utility function for any score between 10 and 18, let us say 13 points.

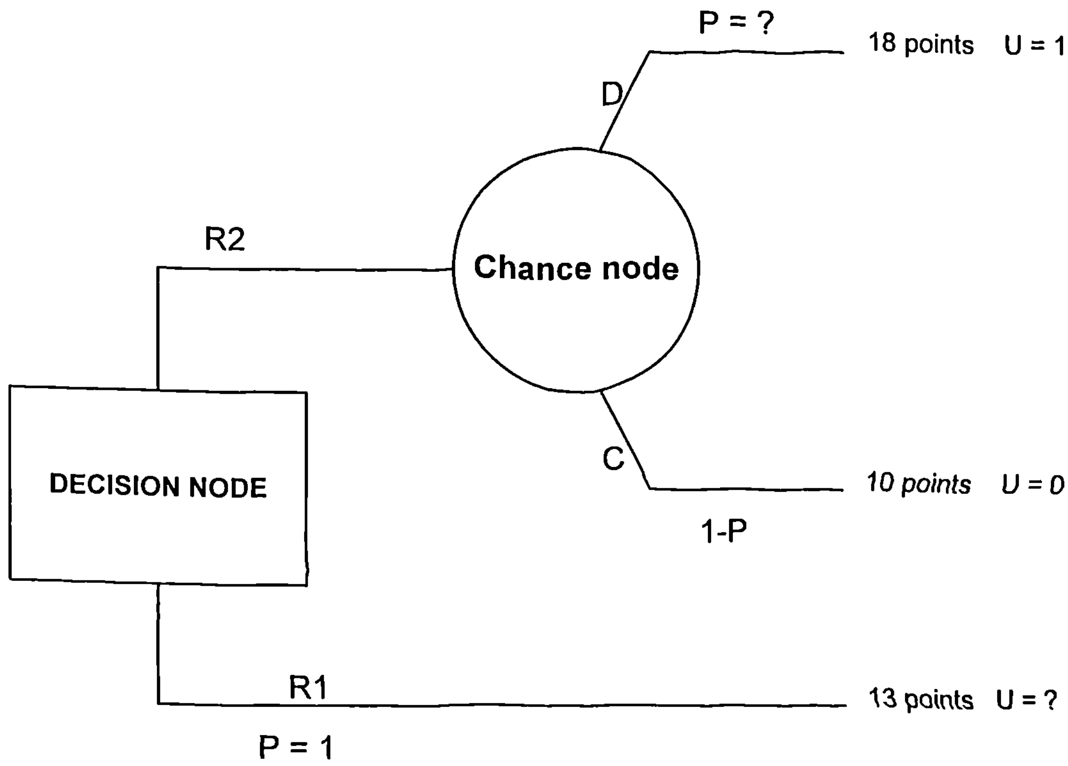


Fig 1. Pair of lotteries for {plant and equipment} attribute

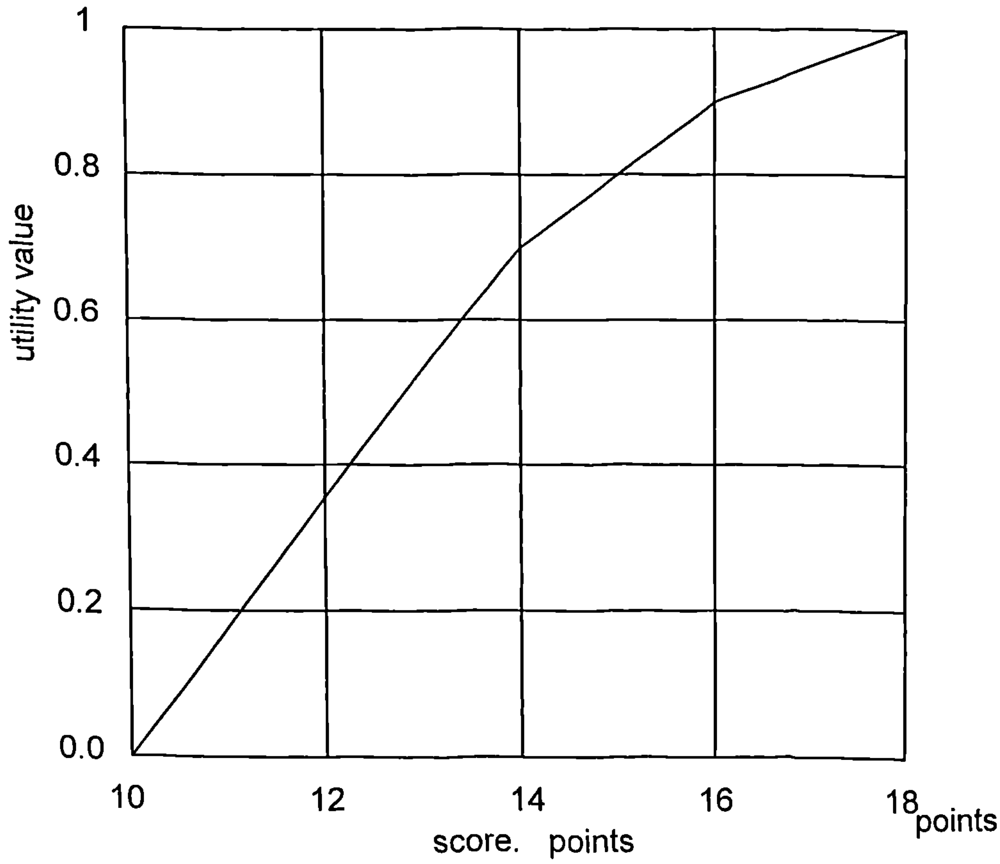


Fig 2. Utility curve for {plant and equipment} attribute

Utility value for 13 points score. It is better if you refer to the scores in Table 2. and to the Figure 1. to assist you in answering the following questions.

Questionnaire

Q1. Since you have been told about the principal of utility theory, do you think which of the contractors has to receive 1 and which has to receive 0 ?

Ans. Bidder D of 18 points score will be assigned a utility value u=1
Bidder C of 10 points score will be assigned a utility value u=0

Q2. You are offered two routes, refer to the Figure 1 please.
The first route is R1 will give you an outcome score of 13 points for sure i.e with a probability p=1.

The second route R2 is a gamble route, in this route either you receive the best outcome of 18 points which has a utility u=1 with a probability p which is so far unknown or you will get the worst outcome of 10 points which has a utility u=0 with a probability of (1-p). Which route you will go for?

Ans. It is difficult choice because I dont no what is the probability of getting the best outcome and the probability of getting the worst outcome from the route R2. so that I can compare between the two routs based on these probabilities.

Q3. Let us assume that the probability P = 0.3 is the chance of getting the best outcome and a probability of (1 - 0.3 = 0.7) of getting the worst outcome from the route R2, which route you prefer in this case R1 or R2 ?

Ans. Since P= 0.3, it seems to me that the chance of getting the best outcome from route R2 is very small, so in this case I will not gamble and I prefer to choose route R1 of 13 points ceratin outcome.

Q4. Now let us assume that the probability P = 0.9 is the chance of getting the best outcome and a probability (1 - 0.9 = 0.1) of getting the worst outcome from route R2, which route you prefer in this case R1 or R2 ?

Ans. Since p = 0.9, in this case there is a high chance to get the best outcome of 18 points, so I will go for gambling and choose route R2.

Q5. Now let us take the probability P = 0.45 is the chance of getting the best outcome and a probability (1 - 0.45 = 0.55) of getting the worst outcome from route R2, which route you prefer in this case R1 or R2 ?

Ans. I am an aversion man, but putting P= 0.45 makes the thing difficult to choose for me, but I believe I will go for ceratin outcome I mean the route R1.

Q6. Can you make your some trial and error in your mind and tell me what is the value of the probability (P) you assign for the best outcome that makes you indifferent between the two routs R1 and R2?

Ans. I would guess that a probability (P = 0.5) will makes me indifferent between the two routs R1 and R2.

Q7. It is great, do you now according to the utility theory by choosing the probability that makes you indifferent between the two routes you have assigned a utility value for the certain outcome of 13 points ?

Ans. How can you explain to me please?

In fact this what I am looking for, i.e I want to know the probability that makes you indifferent between the lotteries R1 and R2. In this case I can tell you the utility value of your certain outcome.

It is known from the principals of probabilities that the expected value of any random variables in the space will equal the sum of probability of each variable times its score.

In this case the expected utility for the route R2 which includes two variables or two outcomes (the best outcome with u = 1 and the worst outcome with u = 0) will be:

$$0.5 \times 1 + (1 - 0.5) \times 0 = 0.5$$

So the utility value of route R2= 0.5

Since you are indifference between the two routes at a probability P = 0.5, therefore according to the utility theory the two routes will have the same utility values.

In this case utility value of R1 which represent the certain outcome or the 13 points score will be equal the utility of R2 which is equal 0.5

From this we achieve an excellent result by finding the U (13 points) = 0.5

Utility value for 16 points score. Now let start again from the beginning and in this case we will choose another score instead of 13 points. let us take a 16 point score but bear in mind that we can choose any score between 10 and 18, even if it is not recorded for one of our bidders. The idea is to build a utility function for this attribute that shows your preferences of the outcomes irrespective of what the score we take as long as it lies between 10 and 18.

Again we will apply the principal of the utility theory that we should assign 1 for the best outcome and 0 for the worst outcome, therefore we will start together building the utility function.

Questionnaire

Q1. Do you think which of the contractors has to receive 1 and which has to receive 0?

Ans. Bidder D of 18 points score will be assigned a utility value u=1
Bidder C of 10 points score will be assigned a utility value u=0

Q2. You are offered two routes, refer to the Figure 1. please.
The first route is R1 will give you an outcome score of 16 points for sure i.e with a probability p=1.
The second route R2 is a gamble route, in this route either you receive the best outcome of 18 points which has a utility u=1 with a probability p which is unknown so far or you will get the worst outcome of 10 points which has a utility u=0 with a probability (1-p). Which route you will go for?

Ans. Again it is difficult choice because I don no what is the probability of getting the best outcome and the probability of getting the worst outcome from the route R2. so that I can compare between the two routs based on these probabilities.

Q3. Let us assume that the probability P = 0.5 is the chance of getting the best outcome and a probability (1 - 0.5 = 0.5) of getting the worst outcome from the route R2, which route you prefer in this case R1 or R2 ?

Ans. 16 points is very close to 18 points and it is sure outcome, and you are offering me 50% probability only, no I will not gamble and I prefer to choose route R1 of 16 points ceratin outcome.

Q4. let us assume that the probability P = 0.6 is the chance of getting the best outcome and a probability (1 - 0.6 = 0.4) of getting the worst outcome from route R2, which route you prefer in this case R1 or R2 ?

Ans. Again I am not satisfied that the value of P= 0.6, because in this case the chance of getting the worst outcome will be 40% as I understood, so I will not gamble, and I will stick with the route R1 of 16 points ceratin outcome.

Q5. If you are offered a value of P= 0.75, which route do you ready to gamble and go for?

Ans. I feel P = 0.75 is still small, so still I would not gamble, and I will go for route R1 of the 16 points.

Q6. Can you tell me what is the value of the probability (P) you assign for the best outcome that makes you indifferent between the two routs R1 and R2?

Ans. I would feel confident that a probability (P = 0.9) will makes me indifferent between the two routs.

Q7. Do you now that by choosing the probability that makes you indifferent between the routes you have assigned a utility value for the certain outcome of 16 points as you have did for the 13 points?

Ans. I would guess that I understand the idea, but can you clearer this for me again ?

In fact the probability that makes indifferent between the lotteries R1 and R2, will tell us the utility value of your certain outcome, 16 point score this time.

Following the principals of probabilities as before the expected utility for the route R2 which includes two variables or two outcomes (the best outcome $u = 1$ and the worst outcome $u = 0$) will be:

$0.9 \times 1 + (1 - 0.9) \times 0 = 0.9$ So the utility value of route R2= 0.9

Since you are indifference between the two routes at a probability $P = 0.9$, therefore the two routes will have the same utility values.

In this case utility of R1 which represent the certain outcome or the 16 points score will be equal the utility of R2 which is equal *0.9*

From this we found the utility of 16 points $u = 0.9$

Now the idea I would guess is clear to you, so can we take another score, but quickly in this case since you are now familiar with the idea and the principal of the utility theory.

Utility value for 15 points score. Let us take any score between 10 and 18, say 15 points, note this score is not belong to any of the five bidders.

Questionnaire

Q. Always referring to the Figure 1, what probability that makes you indifferent between the two routes R1 with a score of 15 points for sure or R2 to enter a gamble that either you get a chance of getting the best outcome with an 18 points score of a utility value u=1 or a chance of getting worst outcome with a score of 10 points of a utility value u=0.

Ans. I would say $P = 0.8$ is quite enough to make me indifferent between the two routes.

As we did before, that mean the expected utility value of the gamble route R2 will be:

$0.8 \times 1 + (1 - 0.8) \times 0 = 0.8$

Since P= 0.8 makes you indifferent between the routes, so the utility value of route R1, or u(15 point score)= 0.8

Questionnaire

Q. What probability that makes you indifferent between the two routs for a certain outcome score of 11 points only in this case.

Ans. It is very easy, I would say P=0.2

That mean the utility value of 11 points u(11 points)=0.2.

Let us Tabulate the scores we tested so far and the utility values we are assigned for them, it will be very beneficial.

Score Tested (points)	13	16	15	11
Utility value	0.5	0.9	0.8	0.2

Now we are able to build your utility curve for this attribute i.e attribute {10}. If we plot the score points that are examined i.e (13, 16, 15, 11) in your preferences against its corresponding utility value that are shown in the Table above. We will end up with a curve which is known a utility curve of your preferences as shown in the Figure 2. The more points you examine the more the exact the curve will represent your preferences.

After the curve was built it is very easy to find a utility value for any bidder that scores between 10 and 18. If we go back to our case we will be easily extract the utility value for bidders A,B,C,D,E for this attribute.

If you have taken the scores of the fives bidders in finding the utility values you will straight end up with Table 3. If you have taken any scores between the best and worst, then you have to build the best fit curve first, then form the curve you will find the utility values of the scores of the five bidders to end up with Table 3 again.

Contractor	A	B	C	D	E
Plant and equipment score (points)	13	14	10	18	16
Utility values	0.5	0.7	0	1	0.9

Table 3. Utility values of the five bidders in attribute {10}

Utility function for the attribute {18} - Experience modification rating

Let us take another criterion say number {18} (experience modification rating EMR) which is a sub of the health and safety criterion, remember the weight assigned for this attribute is 1.5% or 0.015 see Table 1. First of all let us see why we include this attribute or criterion that makes you think deeply of your preferences, we will show you what each of the bidders has scored in this attribute then we continue in building the utility function of your preferences as we did before.

This criterion is included as a measure of the safety performance of the company, which provides an objective indicator of a contractor's performance to the average accident claim performance in his mix of work classification. EMR, has been developed by the insurance industry as an equitable means for financially rewarding or penalizing employers according to their accident claims over the last 3- years. It, therefore discriminates between contractors with varying safety performance.

The following is the scores of the five bidders for this attribute, these scores are taken from Table 1.

Contractor	A	B	C	D	E
Experience modification rating EMR	15	8	17	6	20

We will again use the same principals of probability and utility theory as we did before.

Following the principals of utility theory we should assign 1 for the best outcome and 0 for the worst outcome, therefore we will start together building the utility function, and we will start by a score 13 points.

Utility value for the score 13 points. It is better again if you refer to scores in the Table above. and to Figure 3 this time, to assist you in answering the following question which are exactly similar to those we did before, the idea of repeating the same question just I want to be sure that you are fully aware of the our problem.

<u>Questionnaire</u>

Q1. Do you think which of the contractors has to receive 1 and which has to receive 0 ?

Ans. Bidder E of 20 points score will be assigned a utility value u=1
Bidder D of 6 points score will be assigned a utility value u=0

Q2. You are offered two routes see Fig 3.
The first route is R1 will give you an outcome score of say 13 points for sure i.e with a probability p=1.
The second route R2 is a gamble in this route either you receive the best outcome of 20 points which has a utility u=1 with a probability p which is so far unknown for this route or you will get the worst outcome of 6 points which has a utility u=0 with a probability (1-p). Which route you will go for?

Ans. It is difficult because as I said before the value of P for the best and worst outcome is not known, so that I can compare between the two routs.

Q3. Let us assume that the probability P = 0.3 is the chance of getting the best outcome and a probability (1 - 0.3 = 0.7) of getting the worst outcome from the route R2, which route you prefer in this case R1 or R2 ?

Ans. In this case I will not gamble and I prefer to choose route R1 of 13 points ceratin outcome.

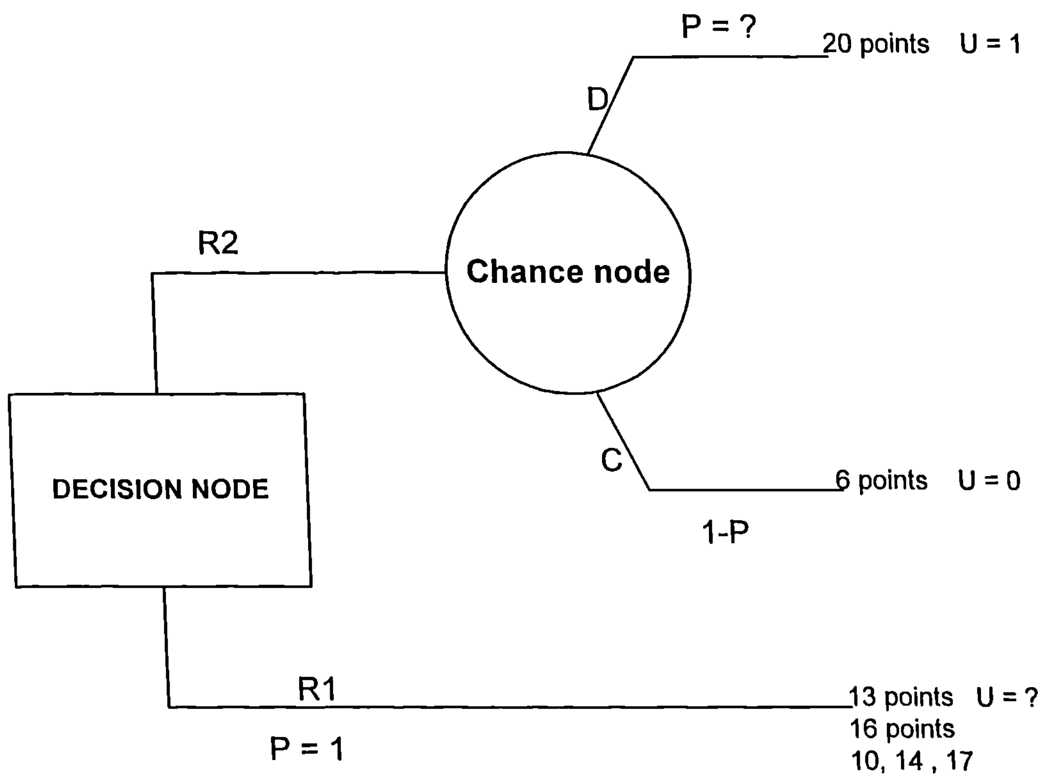


Fig 3. Pair of lotteries for attribute {18} Expereince modification rating

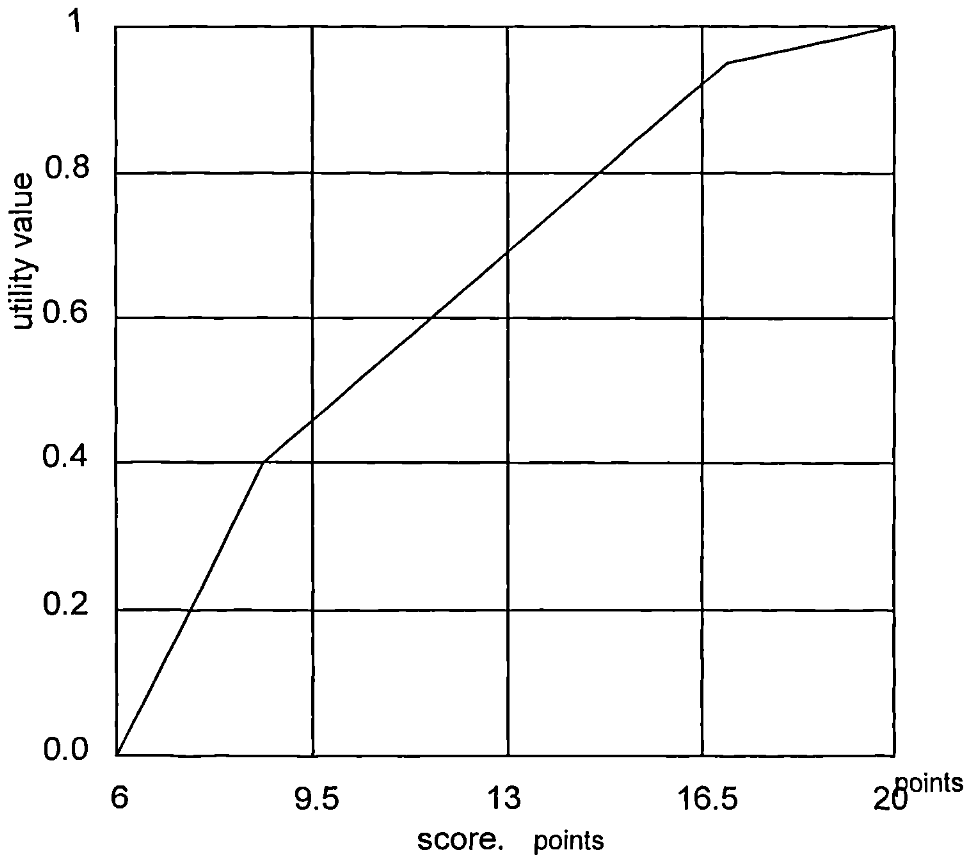


Fig 4. Utility curve for attribute {18} espereince modification rating

Q4.	Now let us assume that the probability P = 0.9 is the chance of getting the best outcome and a probability (1 - 0.9 = 0.1) of getting the worst outcome from route R2, which route you prefer in this case R1 or R2 ?	

Q4. Now let us assume that the probability P = 0.9 is the chance of getting the best outcome and a probability (1 - 0.9 = 0.1) of getting the worst outcome from route R2, which route you prefer in this case R1 or R2 ?

Ans. Since p = 0.9, in this case there is a high chance to get the best outcome of 20 points, so I will go for gambling and choose route R2.

Q5. Now let us assume that the probability P = 0.45 is the chance of getting the best outcome and a probability (1 - 0.45 = 0.55) of getting the worst outcome from route R2, which route you prefer in this case R1 or R2 ?

Ans. Well again it is really difficult to say, but I would guess I will go for certain outcome of the 13 points.

Q6. Can you make some trial and error in your mind and tell me what is the value of the probability (P) you assign for the best outcome that makes you indifferent between the two routs R1 and R2?

Ans. I would guess that a probability (P = 0.70) will makes me indifferent between the two routs.

Therefore utility value for the u(score 13) is = 0.70

Utility value for the score 16 points. Now let start again from the beginning and in this case we will choose another score instead of 13 points. let us take a 16 point score but bear in mind that we can choose any score between 6 and 20 as I said before, even if it is not recorded for one of our bidders.

Questionnaire

Q. I guess now you understand the principals of tradeoffs, can you tell me straightaway what is the value of the probability (P) you assign for the best outcome that makes you indifferent between the two routs R1 and R2 ?. you can look to Fig 3. if you want.

Ans. I would guess that a probability (P = 0.9) will makes me indifferent between the two routs.

So the utility value of route R2 or u(16)= 0.9

Now the idea I would guess is clear to you, so can we take another score, but quickly in this case since you are now familiar with the principal.

Questionnaire

Q.	What P for the score 10 ?	Ans.	P = 0.5
Q.	What P for the score 14 ?	Ans.	P = 0.75
Q.	What P for the score 17 ?	Ans.	P = 0.95

Now we can build your utility function or your utility curve for the attribute number {18}. Again we will plot the score points that are examined in your preferences against its corresponding to get the utility curve for the attribute {18}, the utility curve of this attribute is shown in Fig 4.

If we go back to our case we will be easily find the utility value for bidders A,B,C,D,E for this attribute, then we will end up with Table 4. which shows the utility value of each bidder for this particular attribute.

Contractor	A	B	C	D	E
Plant and equipment score (points)	15	8	17	6	20
Utility values	0.85	0.4	0.95	0	1

Table 4. Utility values for the five bidders in attribute {18}

Really you have done a great job for me, now after this long discussion and tradeoffs I believe that you are aware as we did to identify the best bidder after you notice how they are varying in their scores for different attributes. I am sure now I can leave you alone and you are still be able to build any utility function for any attribute by your own as long as you know the scores of the bidders and the relative weight of the attribute.

Building utility function of the other attributes. After we build together the utility values of the scores for the attribute number {10} and {18}, I would be grateful Mr Oztash if you could help me in filling the utility values for the rest of the attributes.

I will leave with you

1- Table 5. which include the set of criteria and their relative weights, it also include the score of the five bidders in these criteria.
2- Table 6. which is a blank Table for filling the utility values of the five bidders.

3- Figure 5 that shows how you use the gambling procedure.

In case you want to know more about each criterion for assigning the utility values, I attached a list that briefs the purpose of inclusion of each one of these criteria.

Hopefully receiving your answers as soon as possible

Thank you very much

Set of criteria and their	Weights %	Bidder A	B	C	D	E
{1} Advance payment(Million £)	2.75	0.1	0.3	0.3	0.15	0.1
{2} Capital bid (m £)	41.25	3.9	3.5	3.5	4	3.6
{3} Routine maintenance(m£)	5.5	0.3	0.25	0.3	0.25	0.1
{4} Major repairs (m£)	5.5	0.4	0.35	0.2	0.4	0.4
{5} Financial stability (points)	4.5	12	11	13	10	10
{6} Credit rating (points)	3	14	15	14	9	11
{7} Bank arrangements (points)	2.25	15	13	15	10	13
{8} Financial status (points)	5.25	17	17	16	11	14
{9} Experience (points)	2	11	15	9	16	6
{10} Plant and equipment (pnts)	4.5	13	14	10	18	16
{11} Personnel (points)	3	9	14	14	15	6
{12} Ability (points)	0.5	11	11	15	13	6
{13} Past performance (points)	4	15	10	16	10	10
{14} Management organization(pts)	2	10	17	13	10	11
{15} Experience of technical personnel(points)	2	12	16	11	9	14
{16} Management Knowledge (pnts)	2	15	15	14	19	15
{17} Safety (points)	1	9	17	16	10	17
{18} EMR (points)	1.5	15	8	17	6	20
{19} OSHA (points)	1.5	8	13	9	10	16
{20} Management safety accountability (points)	1	7	11	12	8	11
{21} Past failures (points)	1.5	15	16	11	10	11
{22} Length of time in business	0.5	14	15	14	11	6
{23} Cleint/contractors relationship (points)	2	10	13	14	10	10
{24} Other relationships	1	9	12	17	9	13

Table 5. Set of criteria, their relative weights and the scores of the bidders

Contractor	A	B	C	D	E
{1} Advance payment(Million £)					
{2} Capital bid (m £)					
{3} Routine maintenance(m£)					
{4} Major repairs (m£)					
{5} Financial stability (points)					
{6} Credit rating (points)					
{7} Bank arrangements (points)					
{8} Financial status (points)					
{9} Experience (points)					
{10} Plant and equipment (pnts)					
{11} Personnel (points)					
{12} Ability (points)					
{13} Past performance (points)					
{14} Management organization(pts)					
{15} Experience of technical personnel (points					
{16} Management Knowledge (pnts)					
{17} Safety (points)					
{18} EMR (points)					
{19} OSHA (points)					
{20} Management safety accountability (points)					
{21} Past failures (points)					
{22} Length of time in business					
{23} Client/contractors relationship (points)					
{24} Other relationships					

Table 6 Utility values to be filled

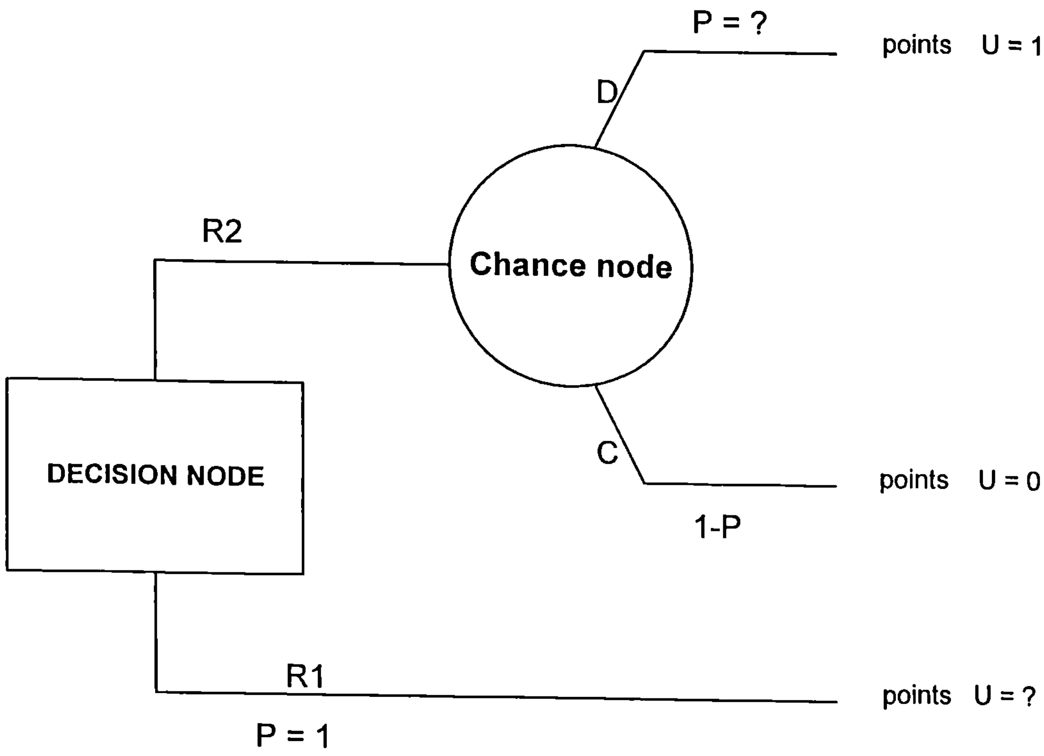
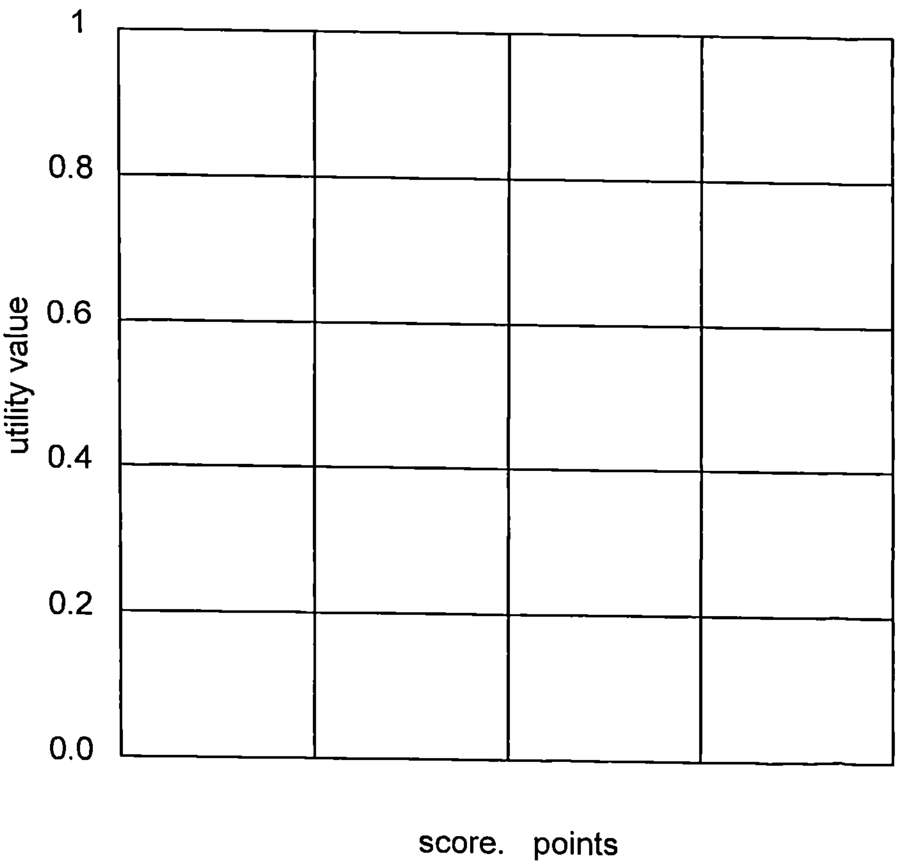


Fig 5 Pair of lotteries for attribute { }......................................



List of the set of the criteria and the purpose of their inclusion

{1} **Advance payment cost.** The bidders were asked to submit their separate amount for the advance payment, this amount is usually requested by the bidders for the purpose of mobilization and preparation of the site. The difference in the advance payments submitted by the bidders will give a client an indication of the capacity of each bidder and their capability of starting the project with or without the assistance of an advance payment.

{2} **Capital cost of bid.** This is the price that the bidder submits to perform the work, which is basically based on bill of quantities and the bidders were submitted their total sums accordingly without taking into account the time value of money. It was considered that the size of this project and the time span of its duration (28 weeks) did not justify the inclusion in the analysis of interest rate and escalation factors. However, this might not be the case in projects of larger duration.

{3} **Routine maintenance cost.** It is possible in many cases that, some differences may arise in operating and maintenance (O&M) routine costs of the equipments proposed by each of the bidders even for a fixed level of performance required. For this reason bidders were requested to submit their proposals for routine maintenance cost as a separate figure in the total bid amount, in order for the client to make an appropriate decision to chose among the alternatives such as the choice between heating systems (electrical, natural gas) or enclosure systems.

{4} **Major repairs cost.** The repairing costs are related to the costs of repairs of the major parts of the building that the client has to do from time to time in order to prevent excessive deterioration of the building, therefore bidders were asked to submit their bids for repairing the elements of the building that are expected to be deteriorated due to different causes.

Since an annual maintenance and repair cost are increasing as the life expectancy of the structure increase, therefore these two criteria are included for the evaluation purposes.

Remember that in these four criteria the lowest value is the best outcome therefore should be given a utility value 1

{5} **Financial stability.** By this criterion it is intended to follow-up the financial history of the company. That is why it is considered not only the period of time since the legal formation of the company will give an indication of the financial stability but also the trend of its volume of business, results of trend analysis along a wide range of period. This is done to find out if the company is following an ascendant, stable or descendent trend in its volume of business, its previous current and fixed assets, its liquidity, its annual turnover are all means of measure of the financial stability of the firm.

{6} **Credit ratings.** The management abilities and activities of the general contractor are a major variable in the fortunes of subcontractors, suppliers, banks and thus are major variables in the whole realm of construction management. This criterion is included to investigate the management abilities of the mains towards their subs and suppliers.

This criterion can be identified and measured through the credits from these parties which have an experience in dealing with the general contractor. Many parameters can be looked at in the evaluation of this criterion, such as the assessment of honesty, trustworthy and fair dealing, financial stability for this type of job, payment to his subs, schedule to coordinate work of all trades.

{7} **Bank arrangements and bonding.** The reason for the inclusion of this criterion is to verify if the companies have the financial strength to perform the job. This criterion is very related to the capacity of the company to obtain bid and performance bonds, which generally are conditions for a bid to be accepted; but also refers to the capacity of the company to finance its operations between payments and its ability to guarantee a source of fund in case of cash difficulties between the payments. Its borrowing wither is it for short term borrowing or long term borrowing indicate its financial management and its use of fund for the investment.

{8} **Financial status.** This is an important criterion as it depicts the financial status of the firm, financial status will consists mainly of two main statements; balance sheet statement and income statement.

These statements provide the raw material for the financial ratios which are the principal tool of financial analysis. The financial ratios provide the basis for the financial well-being of the firm, such as the liquidity of the firm which is referred to the ability of the to meet obligation and to convert assets into cash. Financial ratios also indicates wither the firm's finance management generating sufficient profits from the firm's asset. These parameters can measured by means of liquidity ratios, efficiency ratios, leverage ratios and profitability ratios.

The normal procedure by the finance personnel to assess the financial capacity of the firm is by looking to the firm own figures and make a comparison over a period of time within a firm itself to check if there is any trend of improvements.

The other comparison is made with the average of the industry and how the firm performed financially with the other firms.

{9} **Experience**. The inclusion of this criteria is to ensure that the bidders has experience in similar type of projects, specially this project is to be of high quality standard. This criterion is measured by means of the, experience over the last five years in construction, past experience on client's major projects, experience and capability of technical field personnel, complexity of work executed, level of technology, types of projects executed in the past five years, performed work of the same general type and scale and ability to absorb subsequent changes.

{10} **Plant and equipment**. This criterion is included to verify that the various equipments required for the execution is available at any time during the construction process. The measurement of this criterion can be traced by the availability of owned construction equipment at any time, adequate plant and equipment to do the work properly and expeditionary, small tools and, the testing equipment.

{11} **Personnel**. The personnel represent the main parameter in the success of any project as they will implement the planned programm for the project management and construction, for this reason this criterion is considered essential and included in the evaluation of bidders. This criterion can be measured by the availability of first level supervisors and number presently employed, availability of skilled crafts , expertise in design, skills including professional, and technical expertise, that are available to the company, e.g. qualifications and relevant experience, craftsmen availability.

{12} **Ability**. This is included to be sure that the bidders can handle such kind of jobs with a high efficiency performance. This can measured by the ability to handle the offered type and size of work, ability to perform on site, ability to control and organise contracts and efficiently integrate labour resources, ability to meet target dates. All these parameters can be extracted form the previous measures such the credit ratings form the subs and suppliers, contacting referees, visiting their sites.

For the assessment of technical ability of the firms, usually the client's wants to be sure that the firm has an adequate own different type of resources along the period of the project.

{13} **Past performance and quality**. This criterion was included to account for the previous performance of the company in projects of similar size and technical characteristics. In the evaluation it was considered which percentage of the works previously performed by the company were completed within budget and schedule, the quality of work achieved in the last projects, the success of quality programmes of the company. Only the performance of the last five years in these issues was considered for the evaluation.

{14} **Project Management Organization**. The purpose of the inclusion of this criterion is to determine the existence of procedure and systems that would ensure a proper development of the work. Adequate programs in aspects such as quality assurance, quality control, safety control, procurement procedures, and value engineering certainly are a good indication of good management capability, these are means of evaluating the capability of the bidder in terms of the project management organization.

{15} **Experience of technical personnel**. This criterion is included to cover the capabilities and experience of the "key" personnel considered for the job (foremen, construction superintendents, engineers), these personnel are the key of the project success. For this the experience, curricula vitae, personnel attitude, honesty and any other relevant information about the academic preparation and working experience of the key personnel must be analyzed carefully. It is also understood that the personnel evaluated will be those in charge of the job; otherwise the inclusion of this criterion would be meaningless.

{16} **Management Knowledge**. This criterion can be measured by investigating the contractors scheduling and cost control system and how it is utilized, material control, personnel, accounting, subcontracts, purchasing, level of research and development, risk avoidance and responsibility, including client involvement and design liability, productivity improvement programme, time performance, predicted outturn costs.

{17} **Safety**. This criterion is included to be sure that the bidder has compiled with the health and safety regulation, it is also included to assess the capability of bidder to work in a dangerous areas. This criterion can be measured by experience in handling dangerous substances, experience in noise controlling, accident Book, health and Safety Information chart for employees, safety record, weekly testing programme for the equipment, and company safety policy.

{18} **Experience modification rating (EMR)**. This is included as a measure of the safety performance of the company, which provides an objective indicator of a contractor's performance to the average accident claim performance in his mix of work classification. EMR, has been developed by the insurance industry as an equitable means for financially rewarding or penalizing employers according to their accident claims over the last 3- years. It, therefore discriminates between contractors with varying safety performance.

{19} **Occupational safety OSHA**. OSHA is the Occupational Safety and Housing Adminstration incidence rate which gives the average numbers of injures and illness per 100 man-year for a construction firm. bidders can compile this rate from the accidents rate, this rate can be used to compare different project managers or supervisors. Since there is no third party involved in assessing this rate, therefore the client didn't put high weight for this criterion.

{20} Management safety accountability. This is the criterion which describe the level of management in the firm. This can be recognized by checking who in the organization receives and reviews accident reports, and what is the frequency of distribution of these reports, frequency of safety meetings for field supervisors, compilation of accident records by foremen and superintendents and the frequency of reporting, frequency of project safety inspection and the degree to which they involve project mangers and field superintendents, use of an accident cost system measuring individual foremen and superintendents as well as project managers.

{21} Past failures. The following is used to measure this criterion; past and present experience regarding legal suits or claims; reasons for recent debarment (if any), reasons for failed contract(if any); previous failures to perform contracts properly or fail to complete them on time; financial penalties previously levied in respect of failures to perform to the terms of a contract; contracts the firm has had terminated or employment determined under the terms of contract; contracts not renewed due to failure to perform in accordance with the terms of contract.

{22} Length of time in business. This is included to check the ability of the contractor to compete and get a chance to increase his volume of work form the time of establishment. The following could be considered as the indication of this criterion: amount of projects executed in the past five years; capacity of work, company's stability; permanent place of business; depth of organization; number and size of contracts signed every year.

{23} Past client/contractor relationship. This can be measured by the following: proximity of contractor's home office to project; responsibility and consideration for the client staff and general public; the performance of contractors over a number of previous invitations; responsibility and consideration for the adjoining client affected by the work; experience of working with the client, i.e., understanding of the client's procedures in meetings and for payments in other words public clients are quite different in this respect to private clients; local knowledge; responsible attitude towards the work. These are all means of which the reputation of the contractor can be judged.

{24} Other relationships. The management abilities and activities of the general contractor are a major variable in the fortunes of subcontractors, and the suppliers, and thus are major variables in the whole realm of construction management. The inclusion of this criterion is basically to investigate the responsibilities of the main contractors towards his subs and suppliers, as these two parties sometimes can cause a delay or failures to the project plan. Many parameters in this respect could be used to judge the management ability of the bidder, this might be put in a form of questionnaire passed to the subcontractors and suppliers, these questions may include.

1. Does the general contractor push his subs to do their work?
2. Is he honest, trustworthy and fair dealing?
3. Does he "shop" bids?
4. Does he have enough financial stability for this type of job?
5. Does he pay his subs on time?
6. Does he set up a schedule to coordinate work of all trades?
7. Does he pays his suppliers on time?
8. Does he a honest firm to deal with in trading ?

In addition to that the client has to investigate the bidders relation with employees, relations with Statutory Undertakers, working relations between members of the referee staff and the staff of the firm including head Office staff, race relations, standard of Sub-contractors work.

Thank you Mr Oztash for filling the utility Table 6, this will certainly will help us in selecting the best bidder.

Table 6. shows the utility values assigned by Mr Oztash

Contractor	A	B	C	D	E
{1}. Advance payment	1	0	0	0.8	1
{2}. Capital bid	0.55	1	1	0	0.85
{3}. Routine maintenance	0	0.85	0	0.85	1
{4}. Major repairs	0	0.8	1	0	0
{5}. Financial stability	0.9	0.85	1	0	0
{6}. Credit rating	0.95	1	0.95	0	0.70
{7}. Bank arrangements	1	0.85	1	0	0.85
{8}. Financial status accounts	1	1	0.95	0	0.55
{9}. Experience	0.85	0.95	0.6	1	0
{10}. Plant and equipment	0.5	0.7	0	1	0.9
{11}. Personnel	0.7	0.95	0.95	1	0
{12}. Ability	0.85	0.85	1	0.95	0
{13}. Past performance	0.95	0	1	0	0
{14}. Management organization	0	1	0.85	0	0.7
{15}. Experience of technical personnel	0.80	1	0.70	0	0.90
{16}. Management Knowledge	0.5	0.5	0	1	0.5
{17}. Safety	0	1	0.95	0.5	1
{18}. EMR	0.85	0.4	0.95	0	1
{19}. OSHA	0	0.7	0.5	0.6	1
{20}. Management safety accountability	0	0.90	1	0.5	0.90
{21}. Past failures	0.90	1	0.50	0	0.5
{22}. Length of time in business	0.95	1	0.95	0.75	0
{23}. Client/contractors relationship	0	0.90	1	0	0
{24}. Other relationships	0	0.70	1	0	0.75

Table 6 Utility values for the five bidders as assigned by Mr Oztash

APPENDIX 7A Questionnaire investigating the effect of contractors criteria on project success factors (time, cost, quality)

Q1 What effect does financial stability (financial history)of the contractor have on the following project objectives (time, cost, quality), simply give three percentages for each stability case

	Financially unstable contractor			Financially stable contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q2 What effect does credit ratings (from subcontractors and suppliers) of the contractor have on the following project objectives, simply give three percentages for each credit case

	Low credited contractor			High credited contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q3 What effect does Bank arrangements and bonding of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient Bank arrangements			Sufficient Bank arrangements		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q4 What effect does financial status (ratio analysis) of the contractor have on the following project objectives, simply give three percentages for each case

	poor financial status			excellent financial status		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q5 What effect does experience (last three to five years) of the contractor have on the following project objectives, simply give three percentages for each case

	Inadequate experience			Adequate experience		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q6 What effect does plant and equipment (availability at any time) of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient			Sufficient		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q7 What effect does personnel (availability and experience) of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient			Sufficient		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q8 What effect does ability of the contractor have on the following project objectives, simply give three percentages for each case

	poor ability			excellent ability		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q9 What effect does past performance and quality of the contractor have on the following project objectives, simply give three percentages for each case

	poor performance			excellent performance		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q10 What effect does project management organization of the contractor have on the following project objectives, simply give three percentages for each case

	Ineffective			Effective		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q11 What effect does management personnel (key personnel) of the contractor have on the following project objectives, simply give three percentages for each case

	Inadequate			Adequate		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q12 What effect does management knowledge (scheduling, cost control, material control, risk avoidance,..) of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q13 What effect does safety performance of the contractor have on the following project objectives, simply give three percentages for each case

	Poor safety performance			Excellent safety performance		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q14 What effect does experience modification rate (accident claims) of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q15 What effect does occupational hosing rate (number of injures and illness)of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q16 What effect does management safety accountability of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q17 What effect does past failures(claims, debarment, failed contract, financial penalties) , of the contractor have on the following project objectives, simply give three percentages for each case

	poor record			excellent record		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q18 What effect does length of time in business of the contractor have on the following project objectives, simply give three percentages for each case

	Newly established			Well established		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q19 What effect does owner/contractor relationship (responsibility and consideration for the client staff and general public,..)have on the following project objectives, simply give three percentages for each case

	Poor relation			Excellent relation		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

Q20 What effect does other relationships (subcontractors, suppliers,..) of the contractor have on the following project objectives, simply give three percentages for each case

	Poor relation			Excellent relation		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time						
Cost						
Quality						

APPENDIX 7B The effect of contractors selection criteria on project success factors (time, cost, quality)

Q1 What effect does financial stability (financial history)of the contractor have on the following project objectives (time, cost, quality), simply give three percentages for each stability case

	Financially unstable contractor			Financially stable contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	118	107	102	105	100	95
Cost	118	108	100	105	100	97
Quality	87	93	100	95	100	108

Q2 What effect does credit ratings (from subcontractors and suppliers) of the contractor have on the following project objectives, simply give three percentages for each credit case

	Low credited contractor			High credited contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	118	107	100	105	100	92
Cost	122	109	103	104	100	94
Quality	88	95	100	95	100	105

Q3 What effect does Bank arrangements and bonding of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient Bank arrangements			Sufficient Bank arrangements		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	120	111	102	103	100	93
Cost	115	108	102	104	100	94
Quality	90	95	99	98	100	104

Q4 What effect does financial status (ratio analysis) of the contractor have on the following project objectives, simply give three percentages for each case

	poor financial status			excellent financial status		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	126	111	104	106	100	93
Cost	120	110	104	103	100	94
Quality	83	90	95	96	100	104

Q5 What effect does experience (last three to five years) of the contractor have on the following project objectives, simply give three percentages for each case

	Inadequate experience			Adequate experience		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	119	110	100	105	100	93
Cost	119	109	102	105	100	95
Quality	85	93	100	96	100	105

Q6 What effect does plant and equipment (availability at any time) of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient			Sufficient		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	118	108	103	105	100	95
Cost	114	106	100	103	100	96
Quality	91	97	100	99	100	103

Q7 What effect does personnel (availability and experience) of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient personnel			Sufficient personnel		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	116	108	103	104	100	93
Cost	113	106	102	105	100	95
Quality	85	92	95	96	100	105

Q8 What effect does ability of the contractor have on the following project objectives, simply give three percentages for each case

	poor ability			excellent ability		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	120	111	100	105	100	95
Cost	118	108	100	104	100	96
Quality	83	92	100	95	100	104

Q9 What effect does past performance and quality of the contractor have on the following project objectives, simply give three percentages for each case

	poor performance			excellent performance		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	121	108	102	104	100	91
Cost	114	107	101	105	100	95
Quality	83	93	99	98	100	108

Q10 What effect does project management organization of the contractor have on the following project objectives, simply give three percentages for each case

	Ineffective			Effective		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	121	109	103	107	100	93
Cost	114	107	102	105	100	95
Quality	85	92	98	96	100	105

Q11 What effect does management personnel (key personnel) of the contractor have on the following project objectives, simply give three percentages for each case

	Inadequate			Adequate		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	124	111	104	105	100	93
Cost	115	108	102	105	100	95
Quality	84	92	97	98	100	108

Q12 What effect does management knowledge (scheduling, cost control, material control, risk avoidance,..) of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	121	110	105	105	100	95
Cost	114	105	100	105	100	95
Quality	84	93	98	98	100	106

Q13 What effect does safety performance of the contractor have on the following project objectives, simply give three percentages for each case

	Poor safety performance			Excellent safety performance		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	107	102	100	102	100	97
Cost	105	102	100	101	100	97
Quality	100	100	101	100	100	101

Q14 What effect does experience modification rate (accident claims) of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	106	102	100	101	100	98
Cost	106	102	100	101	. 100	98
Quality	98	99	100	99	100	101

Q15 What effect does occupational hosing rate (number of injures and illness)of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	107	103	100	101	100	97
Cost	104	102	100	101	100	97
Quality	100	100	100	100	100	100

Q16 What effect does management safety accountability of the contractor have on the following project objectives, simply give three percentages for each case

	Poor			Excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	102	102	100	100	100	100
Cost	102	102	100	100	100	100
Quality	98	100	100	99	100	100

Q17 What effect does past failures(claims, debarment, failed contract, financial penalties) , of the contractor have on the following project objectives, simply give three percentages for each case

	poor record			excellent record		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	119	113	107	105	100	92
Cost	126	113	108	105	100	95
Quality	82	89	95	96	100	106

Q18 What effect does length of time in business of the contractor have on the following project objectives, simply give three percentages for each case

	Newly established			Well established		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	107	100	99	103	100	97
Cost	105	101	100	105	100	97
Quality	92	96	100	96	100	104

Q19 What effect does owner/contractor relationship (responsibility and consideration for the client staff and general public,..)have on the following project objectives, simply give three percentages for each case

	Poor relation			Excellent relation		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	110	105	100	104	100	94
Cost	116	107	100	105	100	96
Quality	89	96	100	98	100	104

Q20 What effect does other relationships (subcontractors, suppliers,..) of the contractor have on the following project objectives, simply give three percentages for each case

	Poor relation			Excellent relation		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	116	110	103	103	100	93
Cost	114	108	101	105	100	97
Quality	88	93	98	97	100	104

APPENDIX 7C Expected mean, standard deviation and variance values of time, cost, and quality for desirable and undesirable contractors.

Contractor Selection Criteria	Project Suceess Factors	undesirable contractor			desirable contractor		
		E	S	V	E	S	V
financial stability	time cost quality	108 108 93	2.67 3 2.17	7.11 9 4.7	100 100 100	1.67 1.33 2.17	2.78 1.78 4.69
credit rating	Time cost quality	107 110 95	3 3.17 2	9 10 4	100 100 100	2.17 1.67 1.67	4.69 2.78 2.78
bank arrangements	time cost quality	111 108 95	3 2.17 1.5	9 4.7 2.25	100 100 100	1.67 1.67 1.00	2.78 2.78 1
financial status	time cost quality	112 111 90	3.67 2.67 2	13.44 7.11 4	100 100 100	2.17 1.5 1.33	4.69 2.25 1.78
experience	time cost quality	110 110 93	3.17 2.83 2.5	10 8 6.25	100 100 100	2.00 1.67 1.50	4 2.78 2.25
plant and equipment	time cost quality	109 106 97	2.5 2.33 1.5	6.25 5.44 2.25	100 100 100	1.67 1.17 0.67	2.78 1.36 .44
technical personnel	time cost quality	109 107 91	2.17 1.83 1.67	4.69 3.36 2.78	100 100 100	1.83 1.67 1.50	3.36 2.78 2.25
ability	time cost quality	111 108 92	3.33 3 2.83	11.11 9 8	100 100 100	1.67 1.33 1.50	2.78 1.78 2.25
past performance	time cost quality	109 107 92	3.17 2.17 2.67	10 4.69 7.11	100 100 100	2.17 1.67 1.67	4.69 2.78 2.78
project management organization	time cost quality	110 107 92	3 2 2.17	9 4 4.69	100 100 100	2.33 1.67 1.50	5.44 2.78 2.25

APPENDIX 7C Continued

Contractor Selection Criteria	Project Sucess Factors	undesirable contractor			desirable contractor		
		E	S	V	E	S	V
management personnel	time cost quality	112 108 92	3.33 2.17 2.17	11.11 4.69 4.69	100 100 100	2.00 1.67 1.67	4 2.78 2.78
management knowledge	Time cost quality	111 106 92	2.67 2.33 2.33	7.11 5.44 4.44	100 100 100	1.67 1.67 1.33	2.78 2.78 1.78
safety performance	time cost quality	103 102 100	1.17 0.83 0.17	1.36 .69 .03	100 100 100	0.83 0.67 0.17	.69 .44 .03
experience modification rate	time cost quality	102 102 99	1.00 1.00 0.33	1 1 .11	100 100 100	0.50 0.50 0.33	.25 .25 .11
occupational housing rate	time cost quality	103 102 100	1.17 0.67 0.00	1.36 .44 0	100 100 100	0.67 0.67 0.00	.44 .44 0
management safety accountability	time cost quality	102 102 100	0.33 0.33 0.33	.11 .11 .11	100 100 100	0.00 0.00 0.22	0 0 .05
past failures	time cost quality	113 114 89	2.00 3.00 2.17	4 9 4.69	100 100 100	2.17 1.67 1.67	4.69 2.78 2.78
length of time in business	time cost quality	101 102 96	1.33 0.83 1.33	1.78 .69 1.78	100 100 100	1.00 1.33 1.33	1 1.78 1.78
cliant/ contractor relationship	time cost quality	105 107 96	1.67 2.67 1.83	2.78 7.11 3.36	100 100 100	1.67 1.50 1.00	2.78 2.25 2
other relations	time cost quality	110 108 93	2.17 2.17 1.67	4.69 4.69 2.78	100 100 100	1.67 1.33 1.17	2.78 1.78 1.36

Note. For time and cost the lower the better, but for quality the higher the better

Appendix 8A: Questionnaire investigating the effect of contractor selection criteria on project success factors (time, cost, and quality)

Q1 What effect does financial stability (financial history)of the contractor have on the following project objectives (time, cost, quality), simply give three percentages for each stability case

	Financilly unstable contractor			Financially stable contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	120	105	100	110	100	100
Cost	120	110	100	105	100	95
Quality	85	90	100	95	100	110

Q2 What effect does credit ratings (from subcontractors and suppliers) of the contractor have on the following project objectives, simply give three percentages for each credit case

	Low credited contractor			High credited contractor		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	120	105	100	105	100	90
Cost	125	110	110	105	100	95
Quality	85	95	100	95	100	105

Q3 What effect does Bank arrangements and bonding of the contractor have on the following project objectives, simply give three percentages for each case

	Insufficient			Sufficient		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	120	110	100	105	100	95
Cost	120	110	105	105	100	95
Quality	90	95	100	100	100	105

Q4 What effect does financial status (ratio analysis) of the contractor have on the following project objectives, simply give three percentages for each case

	poor			excellent		
	pessimistic	average	optimistic	pessimistic	average	optimistic
	P	A	O	P	A	O
Time	125	115	105	105	100	95
Cost	125	110	105	105	100	95
Quality	85	90	95	95	100	105

APPENDIX 8B: Questionnaire on the importance of contractor selection criteria

Q1. The criteria shown in the Table below deal with the selection of contractors for standing or project list. What is the importance of each of these main criteria on successful selection of a contractor? simply give weight from 0 to 100 for each criterion.

Example

Financial soundness F	Technical ability T	Management capability M	Health and safety S	Reputation R
21	25	18	7	29

note: the total weight of the criteria must be equal 100
i.e (F+T+M+S+R) must equal 100
(21+25+18+7+29)=100 o.k.

Please fill your scores in the following Table

Financial soundness F	Technical ability T	Management capability M	Health and safety S	Reputation R
21	20	14	10	35

Q2. Each of the previous main criteria is broken down to subcriteria. What is the importance of each of the subcriteria on identifying its main criterion and on successful selection of a contractor? simply give weight from 0 to 100 for each subcriteria.

Example

Financial soundness F			
Financial stability F1	Credit ratings F2	Bank arrangements F3	Financial status F4
20	20	25	35

note: The total weight of the subcriteria must also be equal 100
i.e (F1+F2+F3+F4) must equal 100
(20+20+25+35) = 100 o.k.

Please fill the following Tables in a similar way

Financial soundness F			
Financial stability F1	Credit ratings F2	Bank arrangements F3	Financial status F4
20	20	20	40

APPENDIX 9A. Verifying preferential independence.

ANALYST. I would now like to investigate how you feel about various Y=(t,c) values when we hold fixed a particular value of Y'=(q). For example, in Table 1 of this questionnaire there is a list of 10 paired comparisons between (t,c) evaluations; each element of the pair describes levels on the (t,c) attributes alone. For Table 1 it is assumed that, throughout, the (q) evaluation are all the same at an undesirable level of-15% below the required standard. We have identified that the maximum limit of undesirable levels of time, and cost are 17% and 15% respectively, and it is -15% for quality, while the desired levels are -5% for time and cost and 5% for quality. Is this clear?

ASSESSOR. But you are asking me for a lot of work.

ANALYST. Well, I have a devious purpose in mind and it will not take as much as time as you think to find out what I want. Now on the Table 2. the identical set of 10 paired comparisons are repeated but now the fixed, common level on the (q) is changed and lowered from -15% to -11%. Are you with me?

ASSESSOR. All the way.

ANALYST. On Table 3 and Table 4, we have the same 10 paired comparisons but now the common value of the quality (q) is changed to a relatively less undesirable level -7% and -3% respectively.

ASSESSOR. You said this would not take long.

ANALYST. On Table 5, 6, 7 and 8, we have the same 10 paired comparisons but now the common value of the quality (q) is changed to a desirable levels +2%, +3%, +4%, and +5% respectively.

ASSESSOR. But this is too much for me.

ANALYST. Well now, here comes the punchline. Suppose that you painstakingly respond to all 10 paired comparisons on Table 1 where q is fixed at -15%. Now when you go to Table 2. would your responses change to these same 10 paired comparisons?

ASSESSOR. Let's see. In Table 2 all paired comparisons are the same as in Table 1 except q=-15% is replaced by q=-11%. What difference should that make?

ANALYST. Well, you tell me. If we consider this first comparison does it make any difference if q values are all fixed at -15% or -11%? There could be some interaction concerning how you view the paired comparison depending on the common value of the q values.

ASSESSOR. I suppose that might be the case in some other situation but in the first comparison I prefer the left alternative to the right no matter what the q values are....as long as they are the same.

ANALYST. Okay. Would you now feel the same if you consider the comparison between Table 1 and Table 3.

ASSESSOR. Yes. And the Table 1 and Tables 4,5,6, and so on. Is there some trick here?

ANALYST. No, not at all. I am just checking to see if the q values have any influence on your responses to the paired comparisons. So I gather that you are telling me that your responses on Table 1 would carry over to Tables 2.

ASSESSOR. That's right.

ANALYST. And to Tables 3, 4, 5, 6, 7 and 8 where q values are held fixed at -7%, -3%, +2%, +3%, +4% and +5%.

ASSESSOR. Yes.

ANALYST. Well, on the basis of this information I pronounce that for you the attribute set Y=(t,c) is preferentially independent of the attribute Y'=q.

ASSESSOR. That's nice to know.

ANALYST. That's all that I wanted to find out.

ASSESSOR. Aren't you going to ask me to fill Tables 1 to 8.

ANALYST. No. That's too much work. There are less painful ways of getting that information.

Table 1		Table 2	
q=-15%		q=-11%	
(t,c)	(t,c)	(t,c)	(t,c)
(0,3)	(2,5)	(0,3)	(2,5)
(-1,0)	(2,5)	(-1,0)	(2,5)
(2,7)	(3,9)	(2,7)	(3,9)
(-3,-1)	(-1,0)	(-3,-1)	(-1,0)
(12,6)	(12,9)	(12,6)	(12,9)
(4,9)	(7,10)	(4,9)	(7,10)
(3,8)	(4,9)	(3,8)	(4,9)
(0,-5)	(1,2)	(0,-5)	(1,2)
(2,4)	(3,4)	(2,4)	(3,4)
(8,9)	(8,12)	(8,9)	(8,12)

Table 3		Table 4	
q=-7%		q=-3%	
(t,c)	(t,c)	(t,c)	(t,c)
(0,3)	(2,5)	(0,3)	(2,5)
(-1,0)	(2,5)	(-1,0)	(2,5)
(2,7)	(3,9)	(2,7)	(3,9)
(-3,-1)	(-1,0)	(-3,-1)	(-1,0)
(12,6)	(12,9)	(12,6)	(12,9)
(4,9)	(7,10)	(4,9)	(7,10)
(3,8)	(4,9)	(3,8)	(4,9)
(0,-5)	(1,2)	(0,-5)	(1,2)
(2,4)	(3,4)	(2,4)	(3,4)
(8,9)	(8,12)	(8,9)	(8,12)

Table 5		Table 6	
q = + 2%		q = + 3%	
(t,c)	(t,c)	(t,c)	(t,c)
(0,3)	(2,5)	(0,3)	(2,5)
(-1,0)	(2,5)	(-1,0)	(2,5)
(2,7)	(3,9)	(2,7)	(3,9)
(-3,-1)	(-1,0)	(-3,-1)	(-1,0)
(12,6)	(12,9)	(12,6)	(12,9)
(4,9)	(7,10)	(4,9)	(7,10)
(3,8)	(4,9)	(3,8)	(4,9)
(0,-5)	(1,2)	(0,-5)	(1,2)
(2,4)	(3,4)	(2,4)	(3,4)
(8,9)	(8,12)	(8,9)	(8,12)

Table 7		Table 8	
q = +4%		q = +5%	
(t,c)	(t,c)	(t,c)	(t,c)
(0,3)	(2,5)	(0,3)	(2,5)
(-1,0)	(2,5)	(-1,0)	(2,5)
(2,7)	(3,9)	(2,7)	(3,9)
(-3,-1)	(-1,0)	(-3,-1)	(-1,0)
(12,6)	(12,9)	(12,6)	(12,9)
(4,9)	(7,10)	(4,9)	(7,10)
(3,8)	(4,9)	(3,8)	(4,9)
(0,-5)	(1,2)	(0,-5)	(1,2)
(2,4)	(3,4)	(2,4)	(3,4)
(8,9)	(8,12)	(8,9)	(8,12)

Using the same procedure, it is possible to check whether time and quality are preferentially independent of cost, in this case let Y'=c and let Y=(t,q). Tables 9 to 16 shows this process.

Table 9		Table 10	
c=15%		c=11%	
(t,q)	(t,q)	(t,q)	(t,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Table 11		Table 12	
c=7%		c=3%	
(t,q)	(t,q)	(t,q)	(t,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Table 13		Table 14	
c = - 1%		c = - 3%	
(t,q)	(t,q)	(t,q)	(t,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Table 15		Table 16	
c=-4%		c = -5%	
(t,q)	(t,q)	(t,q)	(t,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

It is also possible to investigate whether cost and quality are preferentially independent of time in this case Y'=t and Y= (c,q). Tables 17 to 24 shows this process.

Table 17		Table 18	
t = 17%		t = 11%	
(c,q)	(c,q)	(c,q)	(c,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Table 19		Table 20	
t= 7%		t = 3%	
(c,q)	(c,q)	(c,q)	(c,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Table 21		Table 22	
t = -2%		t = -3%	
(c,q)	(c,q)	(c,q)	(c,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Table 23		Table 24	
t= -4%		t = -5%	
(c,q)	(c,q)	(c,q)	(c,q)
(0,-3)	(2,-5)	(0,-3)	(2,-5)
(-1,0)	(2,-5)	(-1,0)	(2,-5)
(2,-7)	(3,-9)	(2,-7)	(3,-9)
(-3,+1)	(-1,0)	(-3,+1)	(-1,0)
(12,-6)	(12,-9)	(12,-6)	(12,-9)
(4,-9)	(7,-10)	(4,-9)	(7,-10)
(3,-8)	(4,-9)	(3,-8)	(4,-9)
(0,+5)	(1,-2)	(0,+5)	(1,-2)
(2,-4)	(3,-4)	(2,-4)	(3,-4)
(8,-9)	(8,-12)	(8,-9)	(8,-12)

Appendix 9B Verifying utility independence.

ANALYST. I would now like to investigate how you feel about various Y=[<(t,c),(t,c)> , <(t,c),(t,c)>],i.e comparison of two 50-50 lotteries or various Y=[<(t,c),(t,c)> , (t,c)] i.e comparison between a 50-50 lottery and a single certain consequence when we hold fixed a particular value of Y'=(q) (Note the symbol <(t,c),(t,c)> indicate a lottery of 50-50 probability that either one of the consequences might result) For example, on the following Table 25 of this questionnaire there is a list of 10 paired comparisons between (t,c) evaluations either between two lotteries or between lottery and single consequence; each element of the pair describes levels on the (t,c) attributes alone. For Table 25 it is assumed that, throughout, the (q) evaluation are all the same at -15%. Is this clear?

ASSESSOR. But this is too much.

ANALYST. It will not take as much as time as you think. Now on the Table 26. the identical set of 10 paired comparisons are repeated but now the fixed, common level on the q attribute is changed from -15% to -11%. Are you with me?

ANALYST. On Table 27 and Table 28, we have the same 10 paired comparisons but now the common value of the quality (q) is changed to +2% and +5% respectively.

ASSESSOR. You said this would not take long.

ANALYST. Well now, here comes the punchline. Suppose that you painstakingly respond to all 10 paired comparisons on Table 25 where q is fixed at -15%. Now when you go to Table 26. would your responses change to these same 10 paired comparisons?

ASSESSOR. In Table 26 all paired comparisons are the same as in Table 25 except q=-15% is replaced by q=-11%. What difference that make?

ANALYST. If we consider this first comparison does it make any difference if q values are all fixed at -15% or -11%?

ASSESSOR. I prefer the left alternative to the right no matter what the q values are....as long as they are the same.

ANALYST. Okay. Would you now feel the same if you consider the comparison between Table 25 and Table 27.

ASSESSOR. Yes. And the Table 25 and Table 28 and so on.

ANALYST. I am just checking to see if the q values have any influence on your responses to the paired comparisons. So I gather that you are telling me that your responses on Table 25 would carry over to Tables 26.

ASSESSOR. That's right.

ANALYST. And to Tables 27 and 28, where q values are held fixed at +2% and +5%.

ASSESSOR. Yes.

ANALYST. Well, on the basis of this information, for you the attribute set Y=(t,c) is utility independent of the attribute Y'=q.

ASSESSOR. That's nice to know.

ANALYST. That's all that I wanted to find out.

Table 25. q=-15%

<(t,c),(t,c)>	<(t,c),(t,c)> or (t,c)
<(2,4),(3,6)>	<(3,5),(4,7)>
<(5,4),(8,2)>	<(5,4),(8,3)>
<(3,7),(5,10)>	(12,13)
<(1,4),(3,6)>	(7,8)
<(0,3),(4,1)>	<(4,4),(3,6)>
<(2,3),(1,5)>	(6,5)
<(10,4),(2,7)>	<(9,7),(3,9)>
<(4,7),(5,9)>	<(6,7),(8,8)>
<(2,4),(3,9)>	<(5,5),(3,12)>
<(6,7),(8,4)>	(10,10)

Table 26. q=-11%

<(t,c),(t,c)>	<(t,c),(t,c)> or (t,c)
<(2,4),(3,6)>	<(3,5),(4,7)>
<(5,4),(8,2)>	<(5,4),(8,3)>
<(3,7),(5,10)>	(12,13)
<(1,4),(3,6)>	(7,8)
<(0,3),(4,1)>	<(4,4),(3,6)>
<(2,3),(1,5)>	(6,5)
<(10,4),(2,7)>	<(9,7),(3,9)>
<(4,7),(5,9)>	<(6,7),(8,8)>
<(2,4),(3,9)>	<(5,5),(3,12)>
<(6,7),(8,4)>	(10,10)

Table 27. q=+2%

<(t,c),(t,c)>	<(t,c),(t,c)> or (t,c)
<(2,4),(3,6)>	<(3,5),(4,7)>
<(5,4),(8,2)>	<(5,4),(8,3)>
<(3,7),(5,10)>	(12,13)
<(1,4),(3,6)>	(7,8)
<(0,3),(4,1)>	<(4,4),(3,6)>
<(2,3),(1,5)>	(6,5)
<(10,4),(2,7)>	<(9,7),(3,9)>
<(4,7),(5,9)>	<(6,7),(8,8)>
<(2,4),(3,9)>	<(5,5),(3,12)>
<(6,7),(8,4)>	(10,10)

Table 28. q=+5%

<(t,c),(t,c)>	<(t,c),(t,c)> or (t,c)
<(2,4),(3,6)>	<(3,5),(4,7)>
<(5,4),(8,2)>	<(5,4),(8,3)>
<(3,7),(5,10)>	(12,13)
<(1,4),(3,6)>	(7,8)
<(0,3),(4,1)>	<(4,4),(3,6)>
<(2,3),(1,5)>	(6,5)
<(10,4),(2,7)>	<(9,7),(3,9)>
<(4,7),(5,9)>	<(6,7),(8,8)>
<(2,4),(3,9)>	<(5,5),(3,12)>
<(6,7),(8,4)>	(10,10)

Using the same procedure, it is possible to check whether time and quality are utility independent of cost, in this case let Y'=c and let Y=(t,q). Tables 29 to 32 shows this process.

Table 29. c=15%

<(t,q),(t,q)>	<(t,q),(t,q)> or (t,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

Table 30. c=11%

<(t,q),(t,q)>	<(t,q),(t,q)> or (t,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

Table 31. c=-2%

<(t,q),(t,q)>	<(t,q),(t,q)> or (t,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

Table 32. c=-5%

<(t,q),(t,q)>	<(t,q),(t,q)> or (t,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

It is also possible to investigate whether cost and quality are utility independent of time, in this case Y'=t and Y= (c,q).

Table 33. t=15%

<(c,q),(c,q)>	<(c,q),(c,q)> or (c,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

Table 34. t=11%

<(c,q),(c,q)>	<(c,q),(c,q)> or (c,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

Table 35. t=-2%

<(c,q),(c,q)>	<(c,q),(c,q)> or (c,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

Table 36. t=-5%

<(c,q),(c,q)>	<(c,q),(c,q)> or (c,q)
<(2,-4),(3,-6)>	<(3,-5),(4,-7)>
<(5,-4),(8,-2)>	<(5,-4),(8,-3)>
<(3,-7),(5,-10)>	(12,-13)
<(1,-4),(3,-6)>	(7,-8)
<(0,-3),(4,-1)>	<(4,-4),(3,-6)>
<(2,-3),(1,-5)>	(6,-5)
<(10,-4),(2,-7)>	<(9,-7),(3,-9)>
<(4,-7),(5,-9)>	<(6,-7),(8,-8)>
<(2,-4),(3,-9)>	<(5,-5),(3,-12)>
<(6,-7),(8,-4)>	(10,-10)

It is very important to note that if Y is utility independent of Y' this does not imply that Y' is utility independent of Y. In some of the results like result 2 the multiplicative case it is necessary to investigate whether only one of the attributes is utility independent of its set complement. for example whither time is utility independent of cost and quality, in this case the same procedures were followed by letting Y'=(c,q) and Y=t. Let us take one of the attributes Y=t and check whether it is utility independent of Y'=(c,q).

Partition X into Y and Y' where Y' represent the cost and quality and Y is the time. To check whether Y is utility independent of Y' we might proceed along the lines of the following interview between the analyst and the assessor.

ANALYST. I would like to investigate how you feel about various Y=[<t,t> , <t,t>],i.e comparison of two 50-50 lotteries of different levels of time or various Y=[<t,t> , (t)] i.e comparison between a 50-50 lottery and a single certain consequence when we hold fixed a particular value of Y'=(c,q). For example, on the following Table 37 of this questionnaire there is a list of 10 paired comparisons between (t,t) evaluations either between two lotteries or between lottery and single consequence; each element of the pair describes levels on the (t,t) attributes alone. For Table 37 it is assumed that, throughout, the (c,q) evaluation are all the same at 15% and -15%. Is this clear?

ANALYST. Now on the Table 38. the identical set of 10 paired comparisons are repeated but now the fixed, common level on the c and q attributes is changed from 15% and -15% to 8% and -6%. Are you with me?

ASSESSOR. All the way.

ANALYST. On Table 39 and Table 40, we have the same 10 paired comparisons but now the common value of the cost and quality c,q are changed to -2% and +1% in Table 39 and changed to -5% and +5% in Table 40.

ASSESSOR. But you are asking me for a lot of work.

ANALYST. Suppose that you painstakingly respond to all 10 paired comparisons on Table 37 where c,q is fixed at 15% and -15%. Now when you go to Table 38. would your responses change to these same 10 paired comparisons?

ASSESSOR. Let's see. In Table 38 all paired comparisons are the same as in Table 37 except c=15% and q=-15% is replaced by c=8% and q=-6%. What difference should that make?

ANALYST. Well, you tell me. If we consider this first comparison does it make any difference if c,q values are all fixed at 15 and -15% or at 8 and -6%?.

ASSESSOR. I prefer the left alternative to the right no matter what the c,q values are....as long as they are the same.

ANALYST. Okay. Would you now feel the same if you consider the comparison between Table 37 and Table 39.

ASSESSOR. Yes. And the Table 37 and Table 40.

ANALYST. So I gather that you are telling me that your responses on Table 37 would carry over to Tables 38.

ASSESSOR. That's right.

ANALYST. And to Tables 39 and 40, where c,q values are held fixed at -2% and +1% in Table 39 and is held fixed at -5% and +5% in Table 40.

ASSESSOR. Yes.

ANALYST. Well, on the basis of this information I pronounce that for you the attribute set Y=t is utility independent of the attribute Y'=(c,q).

Table 37. c=15% q=-15%

<t,t>	<t,t> or (t)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,-5>	(-5)

Table 38. c=8% q=-6%

<t,t>	<t,t> or (t)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,-5>	(-5)

Table 39. c=-2% q=+1%

<t,t>	<t,t> or (t)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,-5>	(-5)

Table 40. c=-5% q=+5%

<t,t>	<t,t> or (t)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,-5>	(-5)

Using the same procedure it is also possible to investigate whether cost is utility independent of time and quality, in this case let Y'=(t,q) and Y=c.

Table 41. t=17% q= -15%

<c,c>	<c,c> or (c)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,4>	(0)

Table 42. t=9% q= -5%

<c,c>	<c,c> or (c)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,4>	(0)

Table 43. t= -2% q=+1%

<c,c>	<c,c> or (c)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,4>	(0)

Table 44. t=-5% q=+5%

<c,c>	<c,c> or (c)
<3,6>	<4,7>
<5,8>	<6,12>
<3,7>	<12,13>
<1,8>	(6)
<-1,4>	<-2,10>
<-4,5>	(4)
<2,7>	<3,9>
<5,9>	<8,8>
<-4,3>	<3,3>
<-5,4>	(0)

Also it is possible to investigate whither quality is utility independent of time and cost, in this case let Y'=(t,c) and Y=q.

Table 45. t=17% c=15%

<q,q>	<q,q> or (q)
<-3,-6>	<-4,-7>
<-5,-8>	<-6,-12>
<-3,-7>	<-12,-13>
<-1,-8>	(-6)
<+1,-4>	<+2,-10>
<+4,-5>	(-4)
<-2,-7>	<-3,-9>
<-5,-9>	<-8,-8>
<+4,-3>	<-3,-3>
<+5,+5>	(+5)

Table 46. t=8% c=5%

<q,q>	<q,q> or (q)
<-3,-6>	<-4,-7>
<-5,-8>	<-6,-12>
<-3,-7>	<-12,-13>
<-1,-8>	(-6)
<+1,-4>	<+2,-10>
<+4,-5>	(-4)
<-2,-7>	<-3,-9>
<-5,-9>	<-8,-8>
<+4,-3>	<-3,-3>
<+5,+5>	(+5)

Table 47. t=-2% c=-2%

<q,q>	<q,q> or (q)
<-3,-6>	<-4,-7>
<-5,-8>	<-6,-12>
<-3,-7>	<-12,-13>
<-1,-8>	(-6)
<+1,-4>	<+2,-10>
<+4,-5>	(-4)
<-2,-7>	<-3,-9>
<-5,-9>	<-8,-8>
<+4,-3>	<-3,-3>
<+5,+5>	(+5)

Table 48. t=-5% c=-5%

<q,q>	<q,q> or (q)
<-3,-6>	<-4,-7>
<-5,-8>	<-6,-12>
<-3,-7>	<-12,-13>
<-1,-8>	(-6)
<+1,-4>	<+2,-10>
<+4,-5>	(-4)
<-2,-7>	<-3,-9>
<-5,-9>	<-8,-8>
<+4,-3>	<-3,-3>
<+5,+5>	(+5)

APPENDIX 9C. Matlab language computer programme used for calculating the expected utilities of contractors A, B, C and D.

function [EU] = utility (n)

% The following programme calculates the expected utility of any (n) number of contractors

% function [EU] = utility (4)

% t, c, and q values in the matrices used in this programme represents the means of the data for time cost, and quality for the four contractors A, B, C, and D respectively

% V_T, V_C, and V_Q was changed to VT, VC, and VQ in the matrices and it represents the variances of time, cost, and quality for the four contractors A, B, C, and D respectively.

% The symbols of the utility function of time, cost and quality and its second derivative was changed for simplicity (for example u(t) is changed to ut u"(t) = ut2, u(c) = uc and u"(c)=uc2 and so on.

% k_t, k_c, k_q are that scaling constants and was changed to kt, kc, and kq respectively in this programme and k is general constant.

```
EU = [ ] ;

kt = 0.45 ;          kc = 0.45 ;          kq = 0.45 ;

% to find k use the general formula
```

% $k = (- B \pm \sqrt{B^2 - 4 A C}) / 2A$

```
% it was found that

A = kt * kc * kq ;     B = kt * kc + kt * kq + kc * kq ;     C = kt + kc + kq - 1 ;

% so

k = ( - B + sqrt(B^2 - 4 * A * C))/ (2 * A) ;

% From Table 9.2

t = [8 3 7 2] ;   c = [6 8 2 4] ;   q = [-1 0 -3 -7] ;

VT=[4.84 4 4.41 3.062]; VC=[3.57 2.89 2.56 3.24]; VQ=[2.25 1.44 2.89 4];
```

```
for i = 1 : n

ut = 1.3417 - 0.4663 * exp( 0.06216 * (t(i))) ;
ut2= -0.4663 * 0.06216 * 0.06216 * exp( 0.06216 * (t(i))) ;

uc = 1.3858 - 0.5312 * exp(0.06393 * (c(i))) ;
uc2= -0.5312 * 0.06393 * 0.06393 * exp(0.06393 * (c(i))) ;

uq = 0.9788 * ln(q(i)+26.25)-2.369  ;
uq2= -0.9788 * (q(i)+26.25)^-2 ;

% find f1 to f6

f1=kt * ut+kc * uc + kq * uq ;

f2= k* kt * kc* ut * uc + k * kt * kq * ut * uq + k * kc * kq * uc * uq  ;

f3 = k^2 * kt * kc * kq * ut * uc * uq ;

f4 = (1/2) * (VT(i)) *(kt * ut2 + k * kt * kc * ut2 * uc + k * kt * kq * ut2  * uq + k^2 *...
kt * kc * kq * ut2 * uc * uq) ;

f51= kc* uc2 + k * kt *kc *uc2 * ut + k * kc * kq * uc2 * uq + k^2 *  kt  * kc * kq *uc2...
* ut * uq ;

f52= k * kt * kc * ut2 * uc2 + k^2 * kt * kc * kq * ut2 * uc2 * uq ;

f5 = (1/2) * (VC(i)) * ( f51 + (1/2) * (VT(i)) * f52) ;

f61= kq * uq2 + k * kt * kq * uq2 * ut + k * kc * kq * uq2 * uc + k^2 * kt * kc * kq *...
uq2 * ut * uc  ;

f62= k * kt * kq * ut2 * uq2 + k^2 * kt * kc * kq * ut2 * uq2 * uc ;

f63= k * kc * kq * uc2 * uq2 + k^2 * kt * kc * kq * uc2 * uq2 * ut ;

f64= k^2 * kt * kc * kq * ut2 * uc2 * uq2 ;

f6 = (1/2) * (VQ(i)) * (f61 + (1/2) * (VT(i)) * f62 + (1/2) * (VC(i)) * ( f63 + (1/2)*...
(VT(i)) * f64)) ;

% Then the expected utility

eu = f1 + f2 + f3 + f4 + f5 + f6 ;

EU = [ EU ; eu ] ;


end
```

APPENDIX 10A. Copy of select list notice

PARKWAY/M602 LINK-CONTRACT 4
TRAFORD PARK, MANCHESTER

Applications are invited from suitably experienced contractors for inclusion on a select list of tenderers for the above scheme, to be carried out on behalf of Trafford Park Development Corporation.

The scheme comprise the construction of an elevated section of highway supported by reinforced earth walls and by normal embankment. Between these two elevated sections is a concrete bridge of approximately 20 meters span over a private works entrance and railway track. The works also include demolition of four buildings and provision of a low level road parallel to this elevated section. Work is scheduled to start in October 93.

Contractors wishing to be considered should apply in writing, not later than 18 june 1993 to Parkman Consulting Engineers, 25-27 Winders Way, Salford University Business Park, Salford, Manchester M6 6AR.

The applications should include details of work undertaken of a similar nature; proof of their current financial standing and a statement of the technical qualifications of the management and design/supervisory staff who would be responsible for executing the work.

APPENDIX 10B. Notes on assessment of some applicants

<u>FIRM</u> BIRSE <u>LOCATION</u> CHEADLE

CATEGORY	POINTS AVAILABLE	REMARKS	POINTS
A Company Organisation	1	Satisfactory	1
Management Organisation	1	Not given	-
Nature of Company	1	Building & Civil Engineering	1
Years established	2	23 years	2
Location	1	Stockport	1
B Company accounts	1	Satisfactory 1991,92	1
Accounts in order T/O large enough for £3m	2	Yes	2
contract(Financial banking)	5	Yes, £350M	5
Firms banker	1	Midland Bank	1
C Technical expertise	2	Good	2
Site staff and operatives	2	Good	2
Range of plant	1	Birse Plant Hire is a subsidiary	1
D <u>Urban Highways</u>			
Previous relevant experience			
Good	5	Good	5
Adequate/limited	3		
Not demonstrated	1		
None or not suitable	0		
E <u>Urban Bridgeworks</u>			
Previous relevant experience			
Good	5	Good	5
Adequate/limited	3		
Not demonstrated	1		
None or not suitable	0		
	max 30	TOTAL SCORE	29

FIRM CASEY **LOCATION** ROCHDALE

CATEGORY	POINTS AVAILABLE	REMARKS	POINTS
A Company Organisation	1	Satisfactory	1
Management Organisation	1		-
Nature of Company	1		-
Years established	2	1976	2
Location	1	Rochdale	1
B Company accounts	1	Yes	1
Accounts in order T/O large enough for £3m	2	Satisfactory	2
contract(Financial banking)	5		
Firms banker	1	Turnover £2.5M	1
		Natwest	1
C Technical expertise	2	Adequate	1
Site staff and operatives	2	None given	-
Range of plant	1	Own substantial plant	1
D Urban Highways			
Previous relevant experience			
Good	5		
Adequate/limited	3	Limited	3
Not demonstrated	1		
None or not suitable	0		
E Urban Bridgeworks			
Previous relevant experience			
Good	5		
Adequate/limited	3	Limited	3
Not demonstrated	1		
None or not suitable	0		
	max 30	TOTAL SCORE	17

APPENDIX 10C. Copy of questionnaire sent to various bodies

Parkman Manchester are presently carrying out Prequalification assessment of Contractors who have replied to an advertisement in the Contract Journal. A "long" short list has been prepared and we would ask you to comment as appropriate on the following questions for each contractor under consideration.

Contractor's Name..

	Good	Moderate	Poor	Other
1 Staff - Site relationship with RE staff 2 Ability to complete on time 3 Ability to complete within budget 4 Approach to Health and safety 5 Attitude towards claims 6 Speed/response to dealing with claims 7 Attitude to contract Management 8 Approach to dealing with 3rd parties (adjoining landowners etc.)				

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